The impact of emphasis on consonant sequences in Najdi Arabic:

An acoustic investigation

Khalid Alsubaie

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Abstract

This thesis acoustically investigates the impact of emphasis on the degree of gestural overlap in consonant sequences in Najdi Arabic. It has been reported that the identity of the articulators influences the degree of gestural overlap in consonant sequences. Lingual/lingual sequences, such as /gt/, tend to exhibit lower degree of gestural overlap than labial/lingual sequences, such as /bt/, because the former involve two *interdependent* articulators (tongue tip and tongue dorsum), while the latter involve two *independent* articulators (lips and tongue tip). The emphatic coronals /tˤ/, /sˤ/ and /ðˤ/ are considered in this thesis. They differ from their plain counterparts /t/, /s/ and /ð/ in that they are produced with a secondary articulation involving a movement of the tongue back. This thesis aims to examine whether the secondary articulation of emphatic coronals will influence the degree of gestural overlap. The state of the glottis has also been reported to influence the degree of gestural overlap. When both consonants in a sequence share the same state of the glottis, they exhibit greater degree of gestural overlap than when they differ in the state of the glottis. The emphatic coronals /tˤ/ and /sˤ/ are reported to be produced with a less open glottis than /t/ and /s/. Another aim is to examine whether the less open glottis of the emphatic coronals will influence the degree of gestural overlap. A third aim is to find out whether the two types of vowel insertion (intrusive and epenthetic vowels) occur in Najdi Arabic; the thesis also aims to examine whether emphasis impact will be observed in intrusive, epenthetic vowels or in both.

The hold phase, frication, inter-consonantal interval (ICI), Voice Onset Time, sequence durations and ICI voicing proportion were examined. The sequence position in the word, the order of place of articulation, the identity of the articulators, the speech rate and gender were all considered.

The results reveal that there is an impact of emphasis on the degree of gestural overlap in consonant sequences in Najdi Arabic. Two features of emphasis reflect this impact. First, the secondary articulation of emphatic coronals influences the degree of gestural overlap. Lingual/lingual sequences in an emphatic context are found to exhibit lower degree of gestural overlap than those in the plain counterpart. This has been attributed to motor constraints. Second, the state of the glottis of the emphatic coronal /tˤ/ influences the degree of gestural overlap, but that of the emphatic /sˤ/ does not. The state of the glottis of /sˤ/ was found to be the same as that of the plain /s/; the ICI voicing proportion was similar between sequences including /sˤ/ and sequences including /s/. The state of the glottis of /tˤ/ was found to be different from that of the plain /t/; the ICI voicing proportion was higher in sequences including /tˤ/ than in sequences including /t/. Accordingly, sequences including /tˤ/ exhibit greater degree of gestural overlap than sequences including /t/; this has been attributed to the role of the state of the glottis which is less open in /tˤ/ than in /t/.

The results also reveal that the two types of vowel insertion occur in Najdi Arabic. These types vary as a function of the word position and the place order. Intrusive vowels occur in CC# (in front-back place order), in C#C and in #CC word positions. Epenthetic vowels occur in CC# (in back-front) and at the word boundary in CC#CC positions. Emphasis impact was observed in intrusive vowels, but not in epenthetic vowels. Intrusive vowels were variable in duration and voicing, depending on surrounding consonants, unlike epenthetic vowels that were longer in duration and mostly voiced regardless of surrounding consonants.

The findings contribute to our understanding of timing relations in consonant sequences and of emphasis, and to the study of phonetics of Arabic, particularly Najdi Arabic. The findings reveal that not only the primary articulation affects gestural overlap, but also the secondary articulation has an impact on gestural overlap. The findings reveal that not only the state of the glottis of voiced consonants can affect gestural overlap, but also the less open glottis of the emphatic /tˤ/ can influence gestural overlap too. The findings also reveal that the two types of vowel insertion exist in Najdi Arabic, and emphasis impact is observed in intrusive vowels. Future work, using instruments such as Magnetic resonance imaging, has been suggested to have a clearer view of emphasis impact on gestural overlap.

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Abbreviations

BF	Back-Front
CA	Classical Arabic
C1	1st Consonant
C2	2nd Consonant
EMA	Electromagnetic Articulography
EMMA	Electromagnetic Mid-sagittal Articulometry
EPG	Electropalatography
ES	Emphasis Spread
FB	Front-Back
F1	1st Vowel Formant
F2	2nd Vowel Formant
F3	3rd Vowel Formant
HP	Hold Phase
ICI	Inter-Consonantal Interval
MA	Moroccan Arabic
MSA	Modern Standard Arabic
MSAL	Modern South Arabian Languages
NA	Najdi Arabic
SA	Standard Arabic
SSP	Sonority Sequencing Principle
TLA	Tripolitanian Libyan Arabic
V	Vowel
VOT	Voice Onset Time

1 Introduction

1.1 Aim and goals of the thesis

This study investigates the impact of emphasis on the degree of gestural overlap in Najdi Arabic. It provides an acoustic examination of consonant sequences[1] that include at least one of the emphatic consonants /tˤ/, /sˤ/ or /ðˤ/ in Najdi Arabic, as spoken in Saudi Arabia. The articulation of these emphatic consonants differs from that of their plain counterparts, /t/, /s/ and /ð/, in that they involve a secondary articulation at the back of the oral tract. It has been reported that the place of articulation of consonants involved in the sequence influences the degree of gestural overlap (e.g., Kühnert et al, 2006 for French; Shitaw, 2014 for Tripolitanian Libyan Arabic; Zeroual et al, 2014 for Moroccan Arabic; Alsubaie, 2014 for Najdi Arabic). Sequences that involve only the tongue (coronal and dorsal), such as /gt/, tend to exhibit a lower degree of gestural overlap than sequences that involve the lips and tongue (coronal and labial), such as /tb/, as the former involve two *interdependent* articulators (the tongue tip and the tongue dorsum) and the latter involve two *independent* articulators (the tongue tip and the lips). Emphatic consonants, produced with a secondary constriction in the posterior vocal tract, are considered in this study. This secondary constriction adds more complexity to the production of the emphatic coronal (by adding a posterior gesture), compared to the plain counterpart, when occurring with another lingual consonant such as a dorsal in a sequence. Previous studies on timing relations did not examine the impact of emphasis on the gestural overlap. This study aims to identify whether the secondary articulation in emphatic coronals affects the degree of gestural overlap in consonant sequences that involve these sounds.

In addition, it has been reported that laryngeal specification plays a role in the degree of gestural overlap of consonant sequences (e.g., Shitaw, 2014 for Tripolitanian Libyan Arabic; Alsubaie, 2014 for Najdi Arabic). In particular, voiced/voiced consonant sequences were found to exhibit a greater degree of gestural overlap (as they share the same state of the glottis) than voiced/voiceless[2] sequences (as they differ in the state of the glottis). It has also been reported that emphatic consonants differ from their plain counterparts in the state of the glottis (e.g., Zeroual, 1999). The emphatic coronals, /tˤ/ and /sˤ/, were found to be produced with a less open glottis than the plain coronals, /t/ and /s/ respectively (Watson and Heselwood, 2016 for

[1] *Sequence* is used as a general term throughout the thesis to refer to any sequence of two or more consonants, whether the consonants are occurring word-initially (#CC), word-finally (CC#) or at the word boundary (C#C, CC#CC). The term *cluster* will be restricted to word-initial clusters (#CC) or word-final clusters (CC#).

[2] The slash (/) indicates that it could be both orders while the dash (-) indicates a single order. Voiced/voiceless sequences could be voiced-voiceless or voiceless-voiced. These symbols are used consistently throughout the thesis.

San'ani Arabic; Heselwood et al, 2022 for Modern South Arabian Languages). Thus, the emphatic coronals, /tˤ/ and /sˤ/, were found to pattern with the voiced consonants in the state of the glottis, compared to their plain voiceless counterparts (e.g., Watson and Bellem, 2011, Heselwood, 2020). This will be referred to as the state of glottis effect throughout the thesis. Previous studies on timing relations examining the role of the state of the glottis on gestural overlap did not include emphatic consonants (e.g., Bombian and Hoole, 2013 for German; Shitaw, 2013 for Tripolitanian Libyan Arabic; Alsubaie, 2014 for Najdi Arabic). This study aims to find out whether the less open glottis associated with emphatic consonants affects the degree of gestural overlap in consonant sequences. In brief, this study aims to fill a gap in the literature by examining the impact of emphasis on the degree of gestural overlap; and in particular, this study will investigate the impact of the secondary articulation of emphasis and the role of the less open glottis of emphatic coronals on the degree of gestural overlap in consonant sequences.

A further aim of the current thesis is to find out whether the impact of emphasis, if any, will be observed in intrusive vowels[3], epenthetic vowels or in both. It has been reported that there are two types of inserted vowels. The first type is an intrusive vowel which appears as a result of retiming of existing consonantal gestures, and is not an independent phonological unit; it does not form a syllable nucleus (Hall, 2006). The second type is an epenthetic vowel which appears to repair illicit syllable structures, has its own articulatory gesture, hence is an independent phonological unit that forms a syllable nucleus (Hall, 2006). It has also been reported that intrusive vowels are likely to be optional, variable in duration and may disappear at fast speech rate, unlike epenthetic vowels that are independent in the sense that they are not influenced by the place of articulation of surrounding sounds, and their presence is not dependent on speech rate (Hall, 2006). These inserted vowels were examined in several languages following the diagnostics set by Hall (2006). Plug et al (2019), for instance, examined the variability of these inserted vowels using their duration and voicing assimilation as diagnostics in Tripolitanian Libyan Arabic. It has also been found that intrusive vowels can be transparent to phonological processes while epenthetic vowels cannot. Ghummed (2015) and Plug et al (2019) found that voicing assimilation was blocked by epenthetic vowels but not by intrusive vowels in Tripolitanian Libyan Arabic. The current thesis will examine the variability of these inserted vowels in Najdi Arabic using their duration and voicing proportion as diagnostics, and this thesis will also examine whether emphasis impact, if any, will be observed in intrusive vowels, epenthetic vowels or in both, an aim that has not been investigated in

[3] It should be noted that intrusive vowels can be voiceless (or partially voiceless) when ocurring adjacent to voiceless consonant(s). I will refer to them as vowels throughout the thesis, following Hall (2006).

previous studies. This will be tested using the inter-consonantal intervals (ICIs: Non-lexical vocoidal segments that occur between two consonants). One of the aims of this thesis is to find out whether these ICIs exhibit the characteristics of intrusive vowels, epenthetic vowels or both. Then, it will be tested whether emphasis impact, if any, can be observed in ICIs that exhibit the characteristics of intrusive vowels or in ICIs that exhibit the characteristics of epenthetic vowels.

There are three primary goals of this research. The first goal is to contribute to our understanding of timing relations in consonant sequences occurring word-initially, finally or across a word boundary. This study will add more to our understanding of timing relations in sequences that include an emphatic consonant; i.e., it will enhance the body of research on timing relations by investigating the role of the secondary articulation and the less open glottis of emphatic coronals in the gestural overlap in consonant sequences. Secondly, this research will contribute to the study of emphasis in Arabic varieties. Most studies investigating emphasis were restricted to two main aims: examining how emphatic sounds are articulated as occurring in singletons (e.g., Al-Tamimi and Heselwood 2011), or examining emphasis spread (e.g., Almuhaimeed, 2021). This study will add more to our understanding of emphasis by examining emphatic consonants within sequences and their effect on gestural overlap, an aim that has not been considered in previous studies. Thirdly, this thesis will contribute to the study of phonetics of Arabic, particularly Najdi Arabic (NA). The findings of this thesis will provide a more comprehensive view of gestural overlap patterns in NA. Previous studies examined timing relations in stop-stop word-initial clusters in NA, excluding emphasis (e.g., Alsubaie, 2014). This thesis will examine timing relations in stop-stop and stop/fricative sequences occurring word-initially, word-finally, or at the word boundary (C#C and CC#CC) considering emphasis. This thesis will also consider speech rate which was not considered in previous works on NA. In addition, this thesis will examine variability of the inserted vowels, an aim that was not investigated in previous works on NA.

Najdi Arabic has been chosen as the focus of the current thesis for a number of reasons. Najdi Arabic permits consonant sequences involving emphatic coronals (tˤ, sˤ, ðˤ) word-initially, such as /btˤ/ in *btˤaagah* ‘with energy’, word-finally, such as /btˤ/ in *rabtˤ* ‘linking’, and across a word boundary, such as /btˤ/ in *baab#tˤaalib* ‘a student’s door’ (where # is a word boundary), unlike other Arabic varieties, such as Cairene Arabic which disallows word-initial clusters or Iraqi which disallows word-final clusters. Also, Najdi Arabic is the mother tongue of the researcher; and this will help him to design the word list from Najdi Arabic better than from any other variety of Arabic. Besides, there is evidence that the place of articulation plays a role in the degree of gestural overlap in Najdi Arabic; i.e., lingual/lingual sequences were found to exhibit a lower degree of gestural overlap than lingual/labial[4] sequences in Najdi Arabic. There is also evidence from previous acoustic work (Alsubaie, 2014) that the state of the glottis plays a role in the degree of gestural overlap in Najdi Arabic; voiced/voiced consonant sequences were found to exhibit a greater degree of gestural overlap than voiced/voiceless sequences in Najdi Arabic.

The position of the sequence in the word, whether word-initially, word-finally or across a word boundary, will be considered. Speech rate and the phoneme order of place of articulation within the sequence will also be considered; for example, /btˤ/ in *btˤaagah* 'with energy' will be compared to /tˤb/ in *tˤbaagah* 'lid'. These factors were found to influence the degree of gestural overlap in consonant sequences, and therefore they will be considered. These factors will be discussed in detail in the following chapter when discussing timing relations. The research questions will be stated below, followed by a section in which diglossia in the Arab world is explained. This section is included in the introductory chapter because this thesis will examine the impact of emphasis on consonant sequences in Najdi Arabic, and hence the focus of the literature review in this thesis will be on previous studies examining Arabic varieties. The chapter ends with the structure of the thesis.

1.2 Main research questions

Two key aspects of emphasis motivate the main research questions (RQs) of this thesis. First, emphatic coronals /tˤ, sˤ, ðˤ/ are produced with a secondary articulation in addition to the primary articulation, compared to their plain counterparts /t, s, ð/ respectively. Secondly, emphatic coronals /tˤ, sˤ/ were found to be produced with a less open glottis than their plain counterparts /t, s/, respectively. Hence, two sub-research questions are motivated; the first one will examine consonant sequences considering all the three coronals, whereas the second sub-research question will examine the alveolar stop /t/ and the alveolar fricative /s/ based on the findings reported in the literature that will be discussed in detail in Chapter 3, when discussing the state of the glottis involved during the production of emphatic coronals. The variability of inserted vowels (measured using ICIs) in Najdi Arabic will be examined. The question whether emphasis impact, if any, will vary as a function of the type of vowel insertion will be examined too.

This study aims to answer the following research questions:

[4] The slash (/) indicates that it could be both orders of place of articulation while the dash (-) indicates a single order. Coronal/labial sequences could be coronal-labial (back-front) or labial-coronal (front-back). These symbols are used consistently throughout the thesis.

RQ1: Does emphasis have an impact on the degree of gestural overlap in consonant sequences? In particular,

(a): Does the secondary articulation of emphatic coronals have an impact on the degree of gestural overlap in consonant sequences?

(b): Does the state of the glottis involved during the production of emphatic coronals play a role in the degree of gestural overlap in consonant sequences?

RQ2: If yes, is emphasis impact observed in intrusive vowels, epenthetic vowels, or in both?

ICI occurrence (whether an ICI occurs in the sequence or not), ICI duration, sequence duration, and the individual intervals (e.g., the hold phase, frication durations) within the sequence will be used as measures to determine the degree of gestural overlap in consonant sequences. These measures are used based on previous studies investigating timing relations. ICI occurrence indicates that the two consonantal gestures are not overlapped (apart). This will be referred to as ICI count henceforth. If for example, the ICI occurs more often in an emphatic context than in the plain counterpart, this indicates that the consonantal gestures are apart more consistently in an emphatic context than in the plain counterpart, indicating lower degree of gestural overlap in an emphatic context than in the plain counterpart. ICI duration, if it occurs, indicates how far the two gestures are apart, if apart. If, for example, the ICI duration is longer in an emphatic context than in the plain counterpart, this indicates that the consonantal gestures are apart further in an emphatic context than in the plain counterpart, indicating lower degree of gestural overlap in an emphatic context than in the plain counterpart. Sequence duration and individual intervals can also reflect patterns of gestural overlap. If the sequence duration is, for instance, shorter in a particular context (i.e., emphatic or plain) than in the other, this indicates that there is some degree of gestural overlap occurring in that particular context. More details will be provided in Chapter 2. The degree of gestural overlap is determined as follows:

The lower the ICI count (percentage), the greater the degree of gestural overlap.
The shorter the ICI duration, the greater the degree of gestural overlap.
The shorter the sequence duration and/or an individual interval within the sequence (e.g., the hold phase, frication), the greater the degree of gestural overlap.

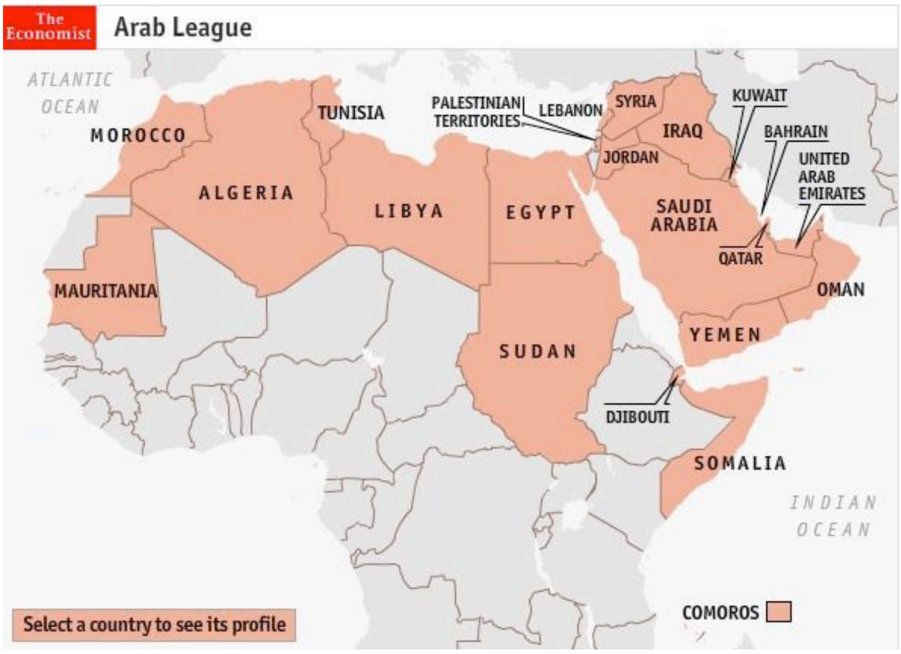
If all those measures were met, then we have a very strong evidence to report greater degree of gestural overlap. If, for instance, only two measures were met, we still have evidence to report greater degree of gestural overlap, but not as strong as when all were met. It will be made clear which measure(s) were used as evidence, where relevant, in the results as well as in the discussion chapter. The current thesis will conduct an acoustic investigation of emphasis impact on the degree of gestural overlap in consonant sequences. The term 'gestural overlap' is mostly used in previous studies that use instruments such as Electropalatography (EPG), Electromagnetic Articulography (EMA) and Magnetic Resonance Imaging (MRI) which can directly detect the articulatory gestures, compared to an acoustic analysis. A number of studies followed an acoustic approach and used the term 'gestural overlap' (e.g., Alsubaie, 2014), and some other studies followed both instrumental and acoustic approaches and used the same term. This thesis investigates gestural overlap through an acoustic study, similar to relevant studies (e.g., Alsubaie, 2014).

Since the focus of this thesis is on Najdi, a variety of Arabic, it is worth discussing the diglossic situation in the Arab world and the cultural significance of Najdi Arabic in the introductory chapter. This is to enhance familiarity of Arabic varieties because most studies that will be discussed in the literature chapters are on Arabic, particularly in Chapter 3 and 4. Thus, the next section will be devoted to Arabic and the diglossic situation in the Arab world, and in particular, in Saudi Arabia, where Najdi is spoken.

1.3 Arabic and its varieties

Diglossia refers to language situation in which two or more varieties, belonging to the same language, are used in the same community, and each has distinct functions (Ferguson, 1959). One is referred to as the high variety (H) and the other code is referred to as the low variety (L). Like most languages in the world, Arabic involves two main varieties: the Standard Arabic (SA, henceforth) variety and the colloquial variety. The colloquial variety varies from one country to another in the Arab world; it frequently varies from one region to another within the same country. For example, SA is used as the H variety in Yemen, while San'ani dialect is used as the L variety in the same country. In Saudi Arabia, SA is used as the H variety and the colloquial variety (e.g., Najdi, Hijaz) is used as the L variety. The SA is used officially (e.g., news, media and religious sermons) and in writing, whereas the colloquial variety is used in everyday oral communication, and in recent years in social media. SA is nobody's mother tongue; it is not used at home. The colloquial variety, in contrast, is the mother tongue which is used at home and for everyday communication. The regional dialect can, however, be used as written form in very restricted functions such as texting among friends and family and in social media applications such as Twitter. As in Figure 1.1, the coloured areas represent the 21 Arabic-speaking countries.

Figure 1.1 Map of the Arab world (from Alhazmi, 2018, p. 35)

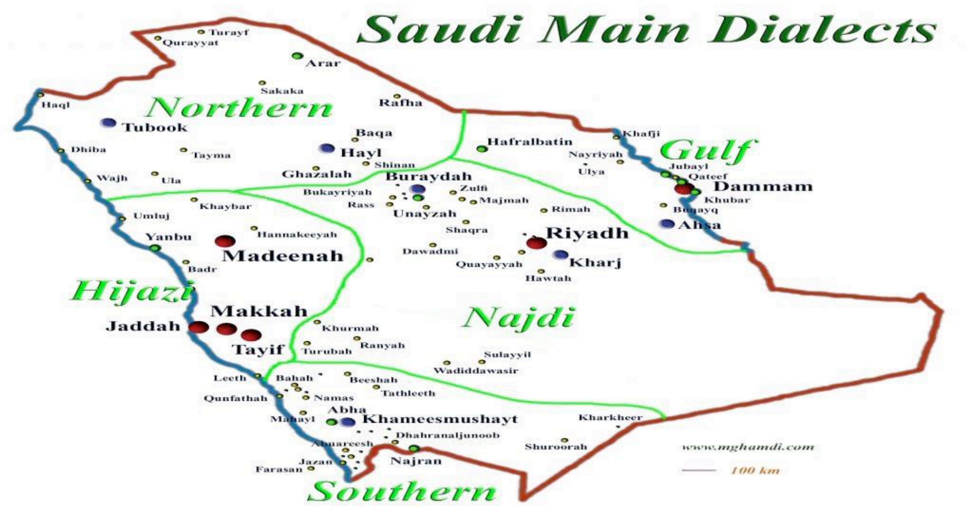


Alorifi (2008, pp. 5) classified Arabic varieties into two main groups: Eastern dialects and Western dialects. The former includes dialects that are used in Egypt and to the east of it, including Saudi Arabia, Yemen, Oman, Kuwait, Jordan and Iraq. The latter includes countries to the west of Egypt, including Libya, Tunisia, Algeria and Morocco.

While previous studies on emphasis that will be discussed in Chapter 3 examined a wide range of Arabic varieties, most previous studies on timing relations in consonant sequences in Arabic that will be discussed in Chapter 2 are restricted to Moroccan Arabic, Libyan Arabic and Najdi Arabic. Some authors made it clear which sub-dialect they examined and others did not. Shaw et al (2009) stated that the variety they examined was the Oujda dialect of Moroccan Arabic, whereas Zeroual et al (2014) just stated that they examined Moroccan Arabic without providing more details. If the authors mentioned specifically where the Arabic variety they examined was spoken, this will be made clear when referring to this study throughout the thesis. The specific sub-variety will not be stated when referring to a certain study in the literature review chapters if the authors of this study did not give more details about where the variety they examined was spoken. This procedure will be followed when referring to previous studies in the literature review chapters.

As in Figure 1.1, Saudi Arabia is the largest country in the Gulf region. Although SA is used as the H variety in all regions of Saudi Arabia, the colloquial variety varies from one region to another: Hijazi Arabic is the colloquial variety in the western region of Saudi Arabia, whereas Najdi Arabic is the colloquial variety in central Saudi Arabia. Aldarsoni (2011, cited in Alhazmi and Alfaifi, 2022, p. 824) divided dialects spoken in Saudi Arabia into five main dialects as in Figure 1.2: Najdi (spoken in central Saudi Arabia), Hijazi (spoken in the western region), Southern (spoken in the southern region), Northern (spoken in the northern region) and Eastern (spoken in the eastern region).

Figure 1.2 Map of Saudi main dialects (taken from Alhazmi and Alfaifi, 2022, p. 821). Gulf refers to the Eastern dialect.



Najdi and Hijazi are two prominent dialects that are widely spoken in Saudi Arabia (Alfaifi, 2019, p. 3). This could be attributed to the fact that the regions where these two dialects are spoken have the highest populations, in comparison to other regions in Saudi Arabia. According to the Saudi Census (2022)[5], the Riyadh region in central Saudi Arabia, where Najdi is spoken, is the first in population size, followed by Makkah region in western Saudi Arabia, where Hijazi is spoken. The population of the Riyadh region is approximately 8,600,000, whereas the population of Makkah region is approximately 8,000,000. Therefore, Najdi and Hijazi were of interest to linguists, compared to other varieties spoken in Saudi Arabia. Early research on varieties spoken in Saudi Arabia has been conducted on Najdi (e.g., Abboud, 1979; Ingham, 1994) and on Hijazi (e.g., Al-Mozainy, 1981). Although there are differences between colloquial varieties spoken in Saudi Arabia (e.g., Najdi Arabic allows word-initial clusters while Hijazi Arabic does not), they are mutually comprehensible. A native speaker of Hijazi can communicate with a native speaker of Najdi without the need to switch to the other person's

[5] See https://portal.saudicensus.sa/portal/public/1/15/45?type=DASHBOARD

variety. All participants in the current study were born and lived in Najd, central Saudi Arabia. Najdi Arabic will be briefly discussed below, and Chapter 4 will be dedicated to Najdi Arabic.

The name of the dialect is attributed to the region in which it is spoken, Najd, located in central Saudi Arabia. Riyadh, the Saudi capital city, represents its centre. Najd was also the homeland of King Abdulaziz, the founder of the Kingdom of Saudi Arabia. Thus, this political and historical importance gives the region cultural prominence (Al-Rojaie, 2020). According to Almuhaimeed (2021), Najdi Arabic is considered prestigious, compared to other varieties spoken in Saudi Arabia, since it is most commonly used in and around Riyadh, the capital city, and is the variety spoken by the royal family in Saudi Arabia (Johnson, 1967; Omar, 1975). As for other spoken Arabic varieties, Najdi Arabic is not taught in schools, but it is used in everyday speech between people.

Najdi is spoken throughout the Najd region. With minor differences between the sub-areas of Najd, particularly in the morphology, they generally share phonological characteristics, including those reported in Chapter 4, in which will be discussed in more detail.

1.4 Structure of the thesis

This thesis is divided into 9 chapters. The current chapter is the introductory chapter in which the primary aim and goals of the study are clarified, the research questions are stated, and the way to address these research questions was explained. A discussion of the diglossic situation in the Arab world and, specifically, in Saudi Arabia is provided. The key points that the following chapters will cover are presented below.

The literature will be reviewed over three consecutive chapters. It will start with theoretical background of timing relations, followed by emphasis, and then a background to Najdi Arabic. Chapter 2 focuses on the timing relations in consonant sequences. This chapter shows how the place of articulation, the state of the glottis, the sequence position in the word, and speech rate all influence timing relations in consonant sequences. The chapter starts with an introduction, in which Articulatory Phonology is briefly explained, and a discussion of how consonantal gestures can overlap when occurring in a sequence is provided. The chapter goes on to discuss the place of articulation effect and the state of the glottis effect on gestural overlap because these two factors are crucial for the thesis aims and research questions. The relation of these two factors to emphasis will be briefly discussed in Chapter 2, because more details of emphasis will be discussed in Chapter 3. The remaining factors: i.e., sequence position in the word and speech rate, will be considered in this thesis because they were found to play a role on gestural overlap; and both factors are also crucial when examining variability in the inserted vowels. Therefore, these will be discussed in Chapter 2.

Chapter 3 focuses on emphasis. The articulatory correlates of emphasis are discussed. The different terms used by different authors to refer to the secondary articulation of emphasis (velarisation, uvularisation and pharyngealization) will be discussed. The acoustic correlates of emphasis will be discussed too. The vocalic cues including vowel duration and vowel formants, and consonantal cues including the hold phase duration, frication duration and Voice Onset Time (VOT) will be discussed. Since VOT reflects the activity of the glottis, a detailed account of the state of the glottis involved during the production of emphatic coronals will be discussed after the VOT sub-section. The remainder of the chapter will be devoted to emphasis spread – its domain, directionality, and blockers of emphasis spread. The chapter concludes with a discussion of the impact of gender on emphasis.

Chapter 4 is devoted to Najdi Arabic, the variety that is the focus of the current thesis. The chapter starts with a brief introduction, in which the main reasons behind choosing this variety of Arabic to be the focus of this thesis are reiterated, followed by a brief summary of the diglossic situation in Saudi Arabia. After that, the sub-varieties of Najdi Arabic are briefly discussed, followed by a brief comparison of Najdi and Standard Arabic. The consonant and vowel inventories of Najdi Arabic are presented. Syllabification and syllable structure of Arabic, and specifically Najdi, will be discussed. The role of sonority sequencing and syllable weight in creating consonant clusters in Arabic will be discussed, followed by a discussion of the main strategies that can be followed to avoid trimoraic syllables that are prohibited in Arabic, including vowel insertion. A detailed discussion of Kiparsky's (2003) analysis and the position of Najdi Arabic within Kiparsky's classification will be provided. Then, a detailed discussion of the main types of vowel insertion (intrusive and epenthetic vowels) will be provided. Since this chapter immediately precedes the methods chapter, it concludes by summarizing the key findings of the reviewed literature and how these findings are relevant to the main research questions of the current thesis. The identified gaps in the literature will be reiterated and the rationale of the main research questions and related hypotheses will be consolidated.

Chapter 5 presents the methodology followed in the current study. This chapter starts with restating the research questions and the related hypotheses. The dependent and independent variables to be considered in this study will be explained. It will be shown that the stimuli were designed in light of these variables. Then, details about the participants, mainly their number, gender and age will be given. The word sets produced by the participants will be presented and details of the procedures followed to collect data will be provided. The remainder of the chapter is devoted to data analysis. The acoustic analysis, primarily segmentation and the extracted measurements, are clarified; and the chapter concludes with an explanation of the statistical analysis used in this study.

The stimuli of the current thesis comprise three word sets. Each word set was carefully designed to address a specific research question. Accordingly, the results of the study are presented in three consecutive chapters; the results of each word set are presented separately. The results presented in Chapter 6 concern the impact of the secondary articulation on the gestural overlap in consonant sequences (word set A). The results presented in Chapter 7 concern the impact of the state of the glottis on the gestural overlap in consonant sequences (word set B). The results presented in Chapter 8 concern the types of vowel insertion and their interaction with emphasis (word set C). Each results chapter will start with the research question and related hypotheses relevant to the word set. The independent variables that are considered in this word set will be restated, and the rationale for including them will be reiterated.

The results of the production experiment will demonstrate not only that the primary articulation can influence the gestural overlap in consonant sequences, but also that secondary articulation plays a role on the degree of gestural overlap. The results will also show that not only closed glottis (a term used by Watson and Heselwood, 2016 for voiced consonants) can influence the gestural overlap in consonant sequences, but also the less open glottis (for emphatic consonants) can play a role on the degree of gestural overlap. In addition, it will be shown that the two types of vowel insertion (intrusive and epenthetic) can be observed in Najdi Arabic, and the impact of emphasis varies as a function of the type of vowel insertion.

Chapter 9 presents the discussion and the conclusion of the results. The chapter starts with the thesis aim and goals, followed by a summary of the key findings of the current study. The remainder of the chapter is divided according to the main research questions and the related hypotheses. The research questions and related hypotheses are restated, with a discussion of whether the hypothesis is supported or not is presented based on the findings of the current thesis. These will be compared to the findings reported in the literature. The chapter ends with a summary of the contributions of the current thesis and a general conclusion.

2 Timing relations in consonant sequences

2.1 Introduction

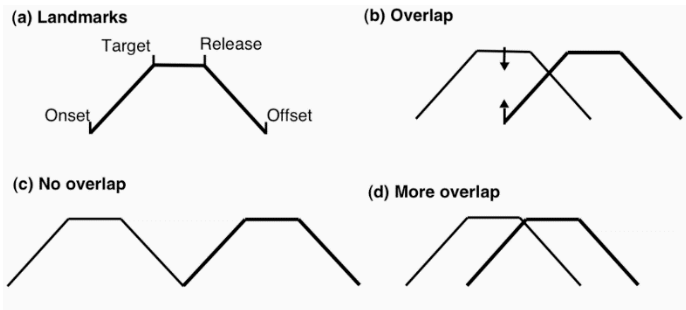
This chapter discusses timing relations in consonant sequences. It starts with a section that introduces Articulatory Phonology, and discusses how articulatory gestures can influence each other when occurring within a sequence. The remainder of the chapter discusses the main influences on timing relations in consonant sequences. It shows how the place of articulation, the state of the glottis, the sequence position in the word and speech rate all affect the gestural overlap. The chapter ends with a general summary.

Speech production is a complex process; it involves complex patterns of articulatory timing. This complexity is observed in connected speech when consonants occurring in a sequence are gesturally overlapped. Phasing relations between articulatory gestures can be accounted for more comprehensibly within the framework of *Articulatory Phonology* (Browman and Goldstein, 1986, 1988, 1989), compared to other models of phonology. Therefore, this model will be introduced below, followed by a detailed discussion of C-Centre stability in consonant clusters to show how gestures in a sequence can influence each other. C-Centre stability refers to a more specific pattern of gestural coordination (which entails specific patterns of overlap), as will be discussed below. Before discussing Articulatory Phonology and patterns of gestural coordination, it is worth emphasising that an acoustic approach is followed in the current thesis; and in line with studies in the framework of Articulatory Phonology, it can be assumed that we can draw conclusions about gestural overlap from acoustic records. Most studies adopting Articulatory Phonology used instruments such as Electropalatography (EPG, henceforth), Electromagnetic Articulography (EMA,henceforth) and Magnetic resonance imaging (MRI,henceforth) to track the articulatory movements. Such instruments will not be used in the current thesis due to the high cost of using them. Similar to relevant studies (e.g., Alsubaie, 2014; Plug et al, 2019), this thesis involves an acoustic analysis: a number of acoustic parameters are used as measures to determine the degree of gestural overlap as pointed out in Section 1.2; i.e., inter-consonantal interval (ICI) count (percentage), ICI duration, sequence duration and individual intervals within the sequence. These measures are based on previous studies on timing relations as will be shown throughout this chapter. It has been claimed that an increase in ICI count/occurrence in a two-consonant sequence indicates a low degree of overlap between the two consonantal gestures; the ICI occurrence indicates that the two consonantal gestures are apart (Wright, 1996; Zsiga, 2000; Shitaw, 2014; Ghummed, 2015). Also, the ICI duration indicates how far the consonantal gestures are apart. The longer the ICI duration is, the lower degree of gestural overlap the sequence will exhibit, indicating that the gestures are pulled apart further; and the shorter the ICI is, the greater degree of gestural overlap the sequence will exhibit, indicating that the gestures are closer between the two consonants (Ghummed, 2015, p.100). ICI is used as a measure to determine the degree of gestural overlap in this thesis, similar to relevant studies (e.g., Alsubaie, 2014; Shitaw, 2014; Ghummed, 2015). I used other measures (i.e., sequence duration and individual intervals) based on the findings in the literature, as will be discussed in more detail in Section 2.2.1. More details about these measures will also be provided in Chapter 5.

2.2 Articulatory phonology and gestural overlap

The articulatory gesture is the basic unit in Articulatory Phonology. Gafos (2002, p.270) defines a gesture as "a spacio-temporal unit consisting of the attainment of some constriction at some location in the vocal tract". Every sound segment is implemented by one or more articulatory gestures. The cycle of the gesture and gestural overlap are illustrated in Figure 2.1.

Figure 2.1 "Gesture landmarks and coordination: (a) shows gestural landmarks, (b-d) show different amounts of overlap resulting from different coordination relations between the landmarks of the two gestures" (taken from Gafos et al (2010, p.2).



As in Figure 2.1 above, (a) shows the gesture landmarks. 'Onset' refers to the articulatory gesture onset/start, then the gesture reaches its 'target'. After attaining the target, the gesture is then 'released' and the gesture ends with the release 'offset'. (b) shows a low degree of overlap between two gestures; as illustrated by the small arrows, the second gesture starts before the release of the first gesture. (c) shows no overlap between the two gestures; the second gesture starts after the release offset of the first gesture. (d) shows a greater degree of overlap between the two gestures than that in (b); the onset of the second gesture coincides with the target of the first gesture. Such coarticulatory effects occur unconsciously during speech production (Farnetani and Recasens, 2010, p.316). Timing relations between sound segments are described as phasing relations by Byrd (1992, p.4). She adds that gestures are temporally overlapped due to those relations, exhibiting an acoustic output that depends on the gestures' behaviour. In brief, a gesture can be influenced by an adjacent gesture in a sequence. This is obvious when considering the C-Centre stability in consonant clusters which will be discussed below.

2.2.1 C-Centre organisation

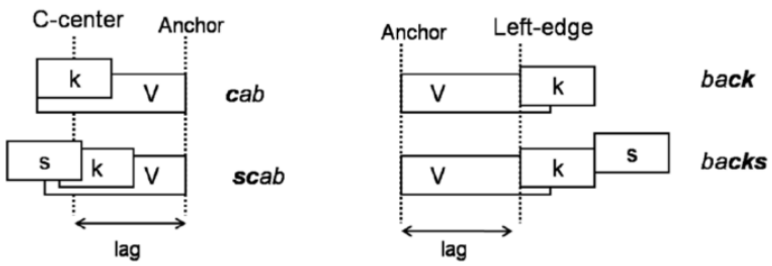
Although the C-Centre will not be examined in the current thesis, it is important to include this section to show that gestures can influence each other when occurring in a sequence, since I am examining consonant sequences in the current thesis.

The coarticulatory effects of consonants within a cluster with adjacent vowels have been investigated in the literature, and it turns out that consonants behave differently in their relationships with adjacent vowels, depending on their word position. Such variation has been viewed in terms of C-Centre organisation which is schematically presented in Figure 2.2. It has been claimed that there is a stability relationship between the onset[6] and the following vowel within a syllable (Browman and Goldstein, 1988; Marin and Pouplier, 2010). The midpoint of the onset is referred to as C-Centre. The distance from the C-Centre of the onset, whether a singleton or a cluster, to an anchor point on the following vowel is observed to be stable in some languages (e.g., Honorof and Browman, 1995 for English; Kühnert et al, 2006 for French; Hermes et al, 2008 for Italian). This distance is referred to as 'lag' as in Figure 2.2,and this is called 'C-centre interval' in most studies. As in Figure 2.2, the C-Centre stability is observed in onset position in the pairs on the left (cab ~ scab) where the C-Centre interval is stable whether /k/ occurs as a singleton or in the cluster, /sk/. Acoustically, this can be characterised by the duration of /k/ which becomes shorter when occurring in the cluster, /sk/. On the other hand, the timing stability observed in the coda position in the pairs on the right (back ~ backs) is Left-edge, by which the interval from the onset of /k/ to the onset of the preceding vowel is stable. It can be noticed that the duration of /k/ in the coda cluster /ks/ is not shortened, unlike /k/ in the onset cluster /sk/, indicating the gestures of the word-initial /sk/ exhibit greater overlap than the gestures of the word-final /ks/. In this sense, the onset is organized globally with the vowel while the coda is organized locally, as suggested by Browman and Goldstein (1988). The consonants in a cluster act as a unit as the number of consonants in the cluster increases. In this sense, they are organized globally; the C-Centre interval to an anchor

[6] The term *onset* is used here similar to early studies examining the C-Centre organization (Browman and Goldstein, 1988; Marin and Pouplier, 2010). These studies were based on English. The term *onset cluster* denotes branching onset (i.e.,both consonants belong to the same syllable),and branching onsets are prohibited in Arabic (Broselow, 1992). Therefore, the terms word-initial and word-final clusters will be used throughout the thesis when referring to studies on Arabic. The terms *onset* and *coda* will be used when referring to studies on other languages, such as English, because the authors of these studies used these terms.

point takes all consonants in the cluster into consideration, hence global organization (Sotiropoulou and Gafos, 2022, p.3). Local organization refers to the stability of the distance from the consonant immediately preceding the vowel to the anchor point in the following vowel, i.e., vowel offset (right-edge stability) (Shaw et al, 2009, 2011). In this sense, the timing interval takes only the vowel and the immediately preceding consonant into consideration, excluding all other consonants that may precede that consonant, hence locally organized.

Figure 2.2 C-Centre organisation (taken from Marin and Pouplier 2010, p.381)



These patterns correspond to two coupling models: competitive (consonants compete each other to overlap with the vocalic gesture, so coupled in-phase with the vowel, corroborating global organization) and non-competitive which is identified in coda position (the consonant immediately following the vowel is coupled anti-phase with the vowel, whereas the following consonants are coupled anti-phase with each other, corroborating local organization) (Browman and Goldstein, 2000; Nam and Saltzman, 2003).

The conclusions of Browman and Goldstein (1988) were based on English, in which the C-Centre stability was observed in word-initial clusters. Follow-up studies in English, however, vary in their results. While some report the C-Centre for initial clusters only (Honorof and Browman, 1995; Goldstein et al, 2009), other studies found the C-Centre for both initial and final clusters (Byrd, 1995). Studies in languages other than English vary in their findings. The C-Centre stability was reported in initial clusters in French (Kühnert et al, 2006), Italian (Hermes et al, 2008) and Romanian (Marin, 2011, 2013); the C-Centre, however, was not confirmed in Arabic varieties (e.g., Shaw et al, 2009, 2011 for the Oujda dialect of Moroccan Arabic; Shitaw, 2013 for Tripolitanian Libyan Arabic). Alsubaie (2014) examined word-initial clusters in Najdi Arabic and concludes that no C-Centre stability was exhibited in general, except in /d/ ~ /bd/ and /g/ ~ /bg/ pairs. He indicates that this exception could be attributed to voicing of both consonants; they are both voiced, while the other examined clusters consisted of consonants of different voicing specification (mixed voicing) such as /t/ ~ /bt/ pairs. More details about this study will be provided later in this chapter when discussing the place of articulation and state of the glottis effects on the gestural overlap.

C-Centre stability has been used as a diagnostic of the syllable structure in different languages. C-Centre stability can provide evidence for complex onsets, indicating that all consonants in the cluster belong to the same syllable. Otherwise, consonants in the cluster do not belong to the same syllable; they are parsed heterosyllabically and hence simplex onset (Sotiropoulou and Gafos, 2022, p.4). Among the key studies that examined C-Centre stability and syllable structure are those carried out by Shaw et al (2009, 2011). Shaw et al (2009), using EMA, investigated temporal stability in word-initial clusters in the Oujda dialect of Moroccan Arabic. Although they suggested C-Centre stability for some word sets such as the pairs *taab* ~ *ktaab* and *baal* ~ *dbaal*, they eventually concluded that the C-Centre interval to the anchor point was not stable, indicating that word-initial clusters in Moroccan Arabic (MA, henceforth) are best characterized as simplex onsets. Their findings are consistent with Dell and El medlaoui (2002) and Boudlal (2001) who argue for simplex syllable onsets in MA in which consonants in an initial cluster as /kr/ in /kra/ are parsed as /k.ra/ C.CV, where (.) is a syllable boundary.

Shaw et al (2011), using EMA, examined the relationship between timing patterns and syllable structure on the Oujda dialect of Moroccan Arabic based on the production of four speakers (except for the word set *kulha~skulha* which was produced by three of the four speakers). This contrasted with their study in 2009 in which they analysed MA data from only one speaker. They found no C-Centre stability, consistent with their findings in their 2009 study, supporting the simplex syllable onset view. In short, the findings of both Shaw et al (2009, 2011) support Broselow (1992) and Kiparsky (2003) who suggest that Arabic dialects do not permit complex onsets. An exception in Shaw et al's (2011) findings, however, is relevant to the /sk/ word-initial cluster as the expected organization (for simplex onsets) was not observed: they found that /k/ duration and the following vowel duration vary between /kulha/ and /skulha/; /k/ is shorter in duration in /skulha/ than in /kulha/, and hence the global organization (C-Centre stability) is more likely to be observed. This indicates that the C-Centre stability cannot always be reliable measure to diagnose the syllable structure of a given language. This claim is supported by Sotiropoulou and Gafos (2022) who suggest other measures that can be considered in addition to the timing stability to diagnose the syllable structure more reliably (see Sotipoulou and Gafos, 2022).

Based on studies on C-Centre stability, it can be inferred that consonants behave differently when occurring in a sequence with other consonants, compared to their being in a singleton. The C-Centre stability is likely to entail a specific pattern of gestural overlap. One manifestation of this likelihood can be seen in the duration of a consonant which varies as a function of being in a singleton or in a sequence. It has also been found that the number of consonants in a sequence influences their timing relations. For example, Ghummed (2015) examined the impact of the number of consonants in a sequence on their timing relations in hetero-syllabic sequences in Tripolitanian Libyan Arabic. He found that the duration of the consonants at the word boundary (C#C) decreases as the number of consonants increases in the sequence across a word boundary. Alsubaie (2014) found that /d/ duration is longer in /daab/ than that in the cluster /bd/ in /bdaabeh/. Shaw et al (2011) found that /k/ is shorter in duration in /skulha/ than in /kulha/, as shown above. This indicates that the consonant duration may provide an indication of the degree of gestural overlap. The shorter duration is an acoustic output that reflects an articulatory pattern; some degree of gestural overlap. The shorter the consonant duration is, the greater the degree of gestural overlap it will exhibit. Therefore, each interval within the sequence (e.g., the hold phase and frication durations) as well as the whole sequence duration will be examined in the current thesis. More details will be provided in Chapter 5 which discusses the methods followed in the current study. Therefore, sequence duration (and the individual intervals within the sequence), along with ICI count and duration, will be used as a measure to determine the degree of gestural overlap in this thesis.

Having introduced Articulatory Phonology and explained how gestures in a sequence can influence each other and may overlap by discussing the C-Centre organisation, the main factors that can play a role on gestural overlap are discussed below.

2.3 Influences on timing relations

A number of factors can influence the timing in consonant sequences including the place of articulation, the state of the glottis of the consonants involved in the sequence, the sequence position, and speech rate. All these factors will be considered in this thesis. Each of these will now be discussed in turn.

2.3.1 Place of articulation effect

Place order effect will be discussed first, followed by a discussion of perceptual recoverability as an explanation for the place order effect. The remainder of this sub-section will be devoted to the identity of the articulators; i.e., the physiological relationship between the articulators and the role of this relationship in the gestural overlap.

Place refers to the location of the constriction in consonant production. If two consonants are in front-back order, the C1 (first consonant in a sequence) constriction is anterior to that of C2 (second consonant in a sequence); for example, in /bt/ sequence, the constriction of /b/ is at the lips which is anterior to the alveolar ridge, the constriction of /t/. If two consonants are in back-front order, the C1 constriction is posterior to that of C2, as in /tb/ sequence.

A lower degree of gestural overlap in back-front than in front-back sequences has been repeatedly reported in the literature in a number of languages[7] (e.g., Byrd, 1996 for English; Chitoran et al, 2002 for Georgian; Kochetov et al,2007 for Korean; Wright,1996 for Tsou; Peng, 1996 for Taiwanese; Zeroual et al,2014 for Moroccan Arabic; Ghummed, 2015 for Tripolitanian Libyan Arabic; Alsubaie, 2014 for Najdi Arabic). Previous studies investigating the place order effect were either instrumental (using instruments such as EPG or EMA) or acoustic. The findings of both approaches are mostly consistent, supporting the place order effect in a number of languages. For example, Hardcastle and Roach (1979), using EPG, investigated stop sequences across a word boundary: /k#t/ and /t#k/ in English. They found that the interval from closure onset of C1 to that of C2 was longer for dorsal-coronal than for coronal-dorsal. Byrd (1994) found that an alveolar was more overlapped by a following velar than a velar followed by an alveolar (i.e., front-back more overlapped than back-front) in English. Byrd (1996) considered place order across a word boundary, such as /dg/ vs. /gd/ in bad#gab and bag#dab in her EPG study of English, and she found that coronal-velar stops were more overlapped than velar-coronal stops. Zsiga (1994) found similar results for sequences across a word boundary in English based on acoustic data.

Similar consistent findings between instrumental and acoustic studies were also reported in Georgian. Chitoran et al. (2002), using Electromagnetic Mid-sagittal Articulometry (EMMA), reported less overlap in back-front than in front-back stop sequences in Georgian in initial positions. Likewise, Chitoran (1999), in an acoustic study, concluded that the inter-burst interval between C1 and C2 is shorter in front-back order than in back-front order which renders a high degree of overlap in front-back order in Georgian.

Both instrumental and acoustic studies on Arabic varieties also support the place order effect. Zeroual et al (2014), using EMA, reported a place order effect in stop sequences occurring word-medially in Moroccan Arabic. Ghummed (2015), based on instrumental (EPG) and acoustic data, found that gestures of two stops across a word boundary (C#C) were more overlapped in the coronal-dorsal sequence than vice versa in Tripolitanian Libyan Arabic. Alsubaie (2014) acoustically investigated stop clusters in word-initial position in Najdi Arabic.

[7] This will be referred to as 'the place order effect' throughout the thesis.

He segmented the inter-consonantal interval (ICI) from release onset of C1 to closure onset of C2, and he found that ICI count was higher in a back-front order than in front-back clusters. He reported a greater degree of gestural overlap in front-back than in back-front, in general, with shorter ICI in front-back clusters than in back-front clusters in Najdi Arabic.

There are multiple explanations for the place of articulation effect. It has been attributed to perceptual recoverability. If there is an overlap and subsequently C1 is not released in back-front order, C1 identification would be reduced because the constriction of C2 lies in front of C1 constriction; i.e., the C1 gesture would be easily hidden by that of C2. This contrasts with front-back order where the C2 constriction lies behind that of C1. This interpretation of place order in terms of perceptual recoverability is in line with Byrd (1992). Using articulatory synthesis, she found that if an alveolar stop in English is substantially overlapped with a labial stop, it is not successfully perceived by the listener; as degree of gestural overlap increases, perception of C1 is more reduced in [d#b] than in [b#d]. Similar results were found by Surprenant and Goldstein (1998) for [p#t] and [t#p] in English. Chitoran et al (2002) also attributed the place order effect they observed in Georgian to perceptual recoverability; they also suggest that great gestural overlap observed in front-back sequences could be attributed to the laryngeal feature; e.g., voiced, voiceless, ejective or aspirated (this will be discussed in detail in the following sub-section 2.3.2). The place order effect was explained by the 'relativized hypothesis' of Gafos et al (2010) who suggest that the longer the ICI is, the less likely the place order effect is exhibited in the sequence. This is consistent with the findings of Plug et al (2019) who found that the place order effect was not exhibited in positions where long ICIs occurred (at the word boundary in CC#CC) in Tripolitanian Libyan Arabic. One of the main measures (to determine the degree of gestural overlap) in the current thesis is the ICI duration. Thus, the findings of this thesis will provide a clearer view of the place order effect on gestural overlap.

Other researchers, however, provide an alternative interpretation (e.g., Kühnert et al, 2006; Zeroual et al,2014), suggesting that the place order effect can be attributed to motor constraints. For example, Kühnert et al. (2006), examined front-back sequences of stop-lateral /pl/, stop-nasal /pn/, fricative-lateral /fl/, fricative-nasal /fn/ and back-front sequences of stop-lateral /kl/ and stop-nasal /kn/ in initial position in French. They indicate that the tongue in /pl/ and /pn/ is free and thus may anticipate the upcoming constriction since it is not involved in producing the bilabial /p/. In /kl/ and /kn/, however, the tongue is involved in producing the velar /k/ and therefore it may not reach its target when producing /l/ or /n/ as early as in the case of /pl/ or /pn/. The tongue tip and tongue dorsum are physiologically coupled and thus they may, to some extent, inhibit the movements of each other. Although Kühnert et al (2006) argued against the perceptual requirement interpretation, their argument was restricted to non-stop-stop clusters, indicating that perceptual recoverability might better explain the gestural overlap pattern observed in stop-stop clusters, whereas other types of sequences such as stop-nasal /pn/ and /kn/ or stop-lateral such as /pl/ and /kl/ can be better explained by physiological factors.

Although Kochetov et al. (2007) attributed the place order effect to perceptual recoverability, they added that it could be also due to the articulator itself. The tongue is, for example, the articulator of both consonants in /kt/ cluster; when the tongue tip moves to reach the target of the alveolar /t/, it seems to be constrained by the gesture of the tongue back for the velar /k/; this takes time, which could be acoustically reflected by a longer interval between C1 release and C2 closure, yielding no or a low degree of gestural overlap. Hardcastle and Roach (1979) attributed the place order effect to articulator constraints; the tongue tip seems to move faster to achieve its target than the tongue dorsum. Likewise, Zeroual et al (2014) attributed the place order effect they observed in Moroccan Arabic to motor system constraints. As mentioned above, Alsubaie (2014) found that front-back word-initial clusters exhibit greater degree of gestural overlap than back-front clusters in Najdi Arabic. He also found that, among front-back initial clusters, /bt/, /bd/ and /bg/ scored the highest overlap in comparison with the remaining initial clusters, /tk/ and /dg/. He calculated the percentage of decrease in ICI duration between the cluster in a back-front order (e.g., /tb/) and the cluster in a front-back order (e.g., /bt/), and he used that as a measure for the degree of gestural overlap. He attributed the finding that /bt/, /bd/ and /bg/ scored the highest overlap in comparison with the remaining word-initial clusters (/tk/ and /dg/), to the motor constraints. /bt/, /bd/ and /bg/ clusters involve the lips and the tongue in their production, which are independent, and both move to reach their targets without interfering with each other; while /tk/ and /dg/ clusters involve only the tongue (tongue tip and tongue dorsum) in their production, and therefore it may take time to achieve the targets of both. In a dorsal/coronal sequence, both are lingual; moving from one constriction to another requires more time because both constrictions cannot be achieved simultaneously. Involvement of the same articulator (e.g., tongue in coronal and dorsal) yields sequential timing, while different articulators (e.g., labial and lingual) yield more simultaneity (Kühnert et al., 2006). Different articulators may differ in speed when moving to reach their targets, yielding differences in influencing other articulators involved in the sequence production (see Jun, 2004; Roon et al 2007, 2021 for more details on articulator velocity).

Shitaw (2014) investigated stop clusters in Tripolitanian Libyan Arabic based on instrumental (using EPG) and acoustic data. He segmented the ICI from release onset of C1 to closure onset of C2. He reported that clusters with two lingual stops exhibit a lower degree of gestural overlap than those with a labial and lingual stops. It is true that he considered emphtic coronals /tˤ/ and /dˤ/, but he did not report the impact of emphasis because it was not an aim of his study.

This thesis will examine coronal/labial and coronal/dorsal sequences to find out whether the identity of the articulators would influence the gestural overlap in Najdi Arabic. In brief, a low degree of gestural overlap was reported in back-front than in front-back consonant sequences. Place order effect was only examined in a word-initial position in Najdi Arabic (Alsubaie, 2014). There is a need to examine the place order effect in various word positions (#CC, C#C, CC#, CC#CC) in Najdi Arabic. Accordingly, the following hypothesis is proposed:

> *Back-front consonant sequences will exhibit a lower degree of gestural overlap than front-back consonant sequences.*

A lower degree of gestural overlap was reported cross-linguistically in lingual/lingual than in labial/lingual sequences[8]. Accordingly, the following hypothesis is proposed:

> *Lingual/lingual consonant sequences will exhibit a lower degree of gestural overlap than labial/lingual consonant sequences.*

The current thesis will examine the coronal emphatic consonants /tˤ/, /sˤ/ and /ðˤ/ which are produced with a secondary articulation in addition to the primary articulation, compared to their plain counterparts /t/, /s/ and /ð/ respectively. This secondary articulation adds complexity to the production of the emphatic coronals due to addition of a posterior gesture, compared to the plain counterparts, particularly when occurring adjacent to another lingual consonant such as the dorsal /g/. As explained earlier, this thesis will examine whether this secondary articulation will play a role in gestural overlap. For example, a sequence such as /gtˤ/ will be compared to /gt/ to find out whether /gtˤ/ will exhibit a lower degree of gestural overlap than /gt/ due to the secondary articulation, and hence more complexity (movements are more constrained), that is involved in /gtˤ/ but not in /gt/. Thus, the following hypothesis is proposed:

Lingual/lingual consonant sequences in an emphatic context will exhibit a lower degree of gestural overlap than lingual/lingual consonant sequences in the plain counterpart.

The motivation of this hypothesis will be discussed in more detail in Chapter 3, which is devoted to emphasis.

[8] This will be referred to as "the identity of articulators effect" throughout the thesis.

Another crucial factor that can influence gestural overlap is the state of the glottis involved during the production of the consonants in a sequence. Therefore, the next sub-section will be devoted to this factor; it will also briefly show how it is relevant to emphasis since more details of the state of the glottis during the production of emphatic consonants will be provided in Chapter 3.

2.3.2 The state of the glottis effect[9]

Cross-linguistically, it has been reported that the state of the glottis involved during the production of the consonants in a sequence plays a role in the gestural overlap of the sequence. If both consonants in a sequence are voiced (sharing the same state of the glottis), they exhibit a greater degree of gestural overlap than if they differ in voicing (voiced/voiceless, having different state of the glottis). This will be referred to as the state of the glottis effect.

There is evidence from previous studies that the ICI is shorter in voiced/voiced sequences than in voiced/voiceless sequences in a number of languages (e.g., Bombian and Hoole, 2013; Pouplier, 2012 for German; Shitaw, 2013 for Tripolitanian Libyan Arabic; Alsubaie, 2014 for Najdi Arabic). Hoole et al. (2009) examined the role of voicing in gestural overlap in German word-initial clusters. They found that voiced/voiced clusters such as /bl/ and /gl/ were more overlapped than voiceless/voiced clusters such as /pl/ and /kl/. Similarly, Bombien and Hoole (2013) concluded that the laryngeal gesture was bound to the gesture of the stop constriction in German. They found that the lag between the /k/ and /l/ constrictions in /kl/ (i.e., ICI) was greater than the lag between the /g/ and /l/ constrictions in /gl/. Gibson et al (2019) examined Standard Peninsular Spanish and they found that voicing of C1 plays a role in gestural overlap, similar to the effect found in German.

The findings of studies on Arabic varieties support the state of the glottis effect. Alsubaie (2014) examined the gestural overlap of word-initial clusters in Najdi Arabic, and reported a place order effect in word-initial clusters in general, as pointed out in Section 2.3.1, but he also found that /bd/ and /bg/ clusters exhibited the shortest ICIs, in comparison with /bt/. He suggests that this could be attributable to voicing, as both consonants in /bd/ and in /bg/ are voiced, whereas /b/ is voiced and /t/ is voiceless in /bt/. Shitaw (2013) investigated the gestural overlap of consonant clusters in Tripolitanian Libyan Arabic, and similarly reported a

[9] As made clear in Chapter 1, ‘the laryngeal specification’ and ‘voicing’ are the terms that were mostly used in previous studies investigating timing relations in consonant sequences. The term ‘state of the glottis effect’ will be used throughout the current thesis because this term can best capture variable states of the glottis in voiced (closed, a term used by Watson and Heselwood, 2016 for voiced consonants) ~ voiceless (wide open) ~ emphatic consonants (less open). Thus, the “laryngeal specification”, “voicing” and “state of the glottis” are used interchangeably in this thesis.

state of the glottis effect, with greater gestural overlap in consonant clusters that share voicing than clusters that differ in voicing.

Although Chitoran et al. (2002) attribute the place order effect that they observed in Georgian (front-back sequences exhibiting greater overlap than back-front sequences) to perceptual recoverability as pointed out in Section 2.3.1, they also propose that it could be attributed to the laryngeal specification of the consonants involved. Based on Georgian syllabification patterns, consonant sequences in a front-back place order always agree in voicing; accordingly, a single laryngeal gesture is licensed and this gesture can extend through both consonants in a sequence. Sequences in a back-front place order, on the other hand, do not agree in voicing and therefore they exhibit a lower degree of gestural overlap than front-back sequences since there is a delay between the laryngeal gesture of C1 and C2 releases.

A number of researchers, including Browman and Goldstein (1992) and Hall (2017), suggest that voicing is the default activity of the glottis. Accordingly, more pressure build-up is expected during the production of a voiceless consonant than during the production of a voiced consonant;and this may result in a longer ICI occurring in voiced/voiceless than in voiced/voiced sequences, indicating lower overlap in the former than in the latter.

In brief, voiced/voiced sequences exhibit greater overlap than voiced/voiceless sequences. This thesis will examine the effect of the state of the glottis on the gestural overlap. Sequences consisting of two voiced consonants (e.g., /bd/) will be compared to sequences consisting of voiced/voiceless consonants (e.g., /bt/). Thus, the following hypothesis is proposed:

Voiced/voiced consonant sequences will exhibit a greater degree of gestural overlap than voiced/voiceless consonant sequences.

This thesis will examine the emphatic coronals /tˤ/ and /sˤ/ in sequences where the adjacent consonant is either the voiced bilabial /b/ or the voiced velar /g/,and these sequences will be compared to sequences that include the plain counterparts of the emphatics. For instance, /btˤ/ and /bsˤ/ sequences will be compared to /bt/ and /bs/ sequences, respectively. It has been reported that the emphatic coronals, /tˤ/ and /sˤ/, differ from their plain counterparts, /t/ and /s/, in the state of the glottis, with less open glottis during the production of the emphatic coronals than during the production of the plain counterparts (the term ‘less open glottis’ will be discussed in more detail in subsection 3.3.1.3 in Chapter 3). Accordingly, the emphatics /tˤ/ and /sˤ/ were reported to pattern with the plain voiced /d/ and /z/, respectively, in the state of the glottis, compared to the plain voiceless /t/ and /s/ respectively (Watson and Heselwood, 2016 for San'ani Arabic and Mehri; Heselwood et al, 2022 for

Shehret[10]). These sequences will be examined to find out whether the state of the glottis will play a role in the effect of the emphatic-plain distinction on timing relations. This thesis will specifically examine whether the less open glottis (of emphatic coronals) will behave similarly to the closed glottis (of voiced consonants) in affecting gestural overlap, compared to the widely open glottis (of the plain voiceless coronals). Thus, the following hypotheses are proposed:

Voiced/emphatic /tˤ/ sequences (i.e., /btˤ/ and /tˤb/) will exhibit a greater degree of gestural overlap than voiced/plain /t/ sequences (i.e., /bt/ and /tb/), and accordingly /tˤ/ will behave similarly with the plain voiced counterpart /d/ in the degree of gestural overlap, compared to the plain voiceless counterpart /t/.

Voiced/emphatic /sˤ/ sequences (i.e., /bsˤ/ and /sˤb/) will exhibit a greater degree of gestural overlap than voiced/plain /s/ sequences (i.e., /bs/ and /sb/), and accordingly /sˤ/ will behave similarly with the plain voiced counterpart /z/ in the degree of gestural overlap, compared to the plain voiceless counterpart /s/.

The state of the glottis during the production of the emphatic coronals and their plain counterparts,and motivation of these hypotheses will be discussed in more detail in Chapter 3.

Having discussed the role of the place of articulation and the state of the glottis in gestural overlap, now we turn to discuss the sequence position effect. This factor is considered in the current study because it is an influential factor on the gestural overlap based on the findings of previous studies, as will be shown below. The sequence position in the word is also crucial for the second main research question, which concerns the two types of vowel insertion that were reported to vary as a function of the sequence position in the word.

2.3.3 Sequence position effect

Sequence position in the word has been found to have an impact on gestural overlap. Cross-linguistically, word-initial sequences have been reported to show a lower degree of gestural overlap than word-final sequences [11]. Hardcastle (1985) and Byrd (1996) reported a position effect on temporal overlap, with a lower degree of overlap in initial position than elsewhere in English. Byrd (1994), using EPG, found that initial clusters were less overlapped than final clusters and clusters across word boundaries in English. Wright (1996) examined stop sequences acoustically, produced by five speakers, in initial and medial positions in Tsou.

[10] Mehri and Shehret are Modern South Arabian Languages.
[11] This will be referred to as 'position effect' throughout the thesis.

He reported that C1 in initial clusters is released by all speakers, a rate that is higher than its release in medial clusters; thus, initial clusters are less overlapped than medial clusters in Tsou. Chitoran (1999) investigated stop sequences acoustically in Georgian produced by two speakers. She concluded that the interval between C1 and C2 releases is longer in initial clusters than in medial clusters, indicating a lower degree of gestural overlap in initial than in medial clusters in Georgian. Kochetov and Goldstein (2005), using EMMA, examined initial and medial clusters in Russian with a coronal or dorsal occurring as a C1. They reported a lower degree of overlap in initial clusters than in medial clusters.

As for the place order effect, the claim that initial clusters exhibit lower degree of gestural overlap than clusters in other word positions has been attributed to perceptual requirements (Wright, 1996, Chitoran et al., 2002, Kochetov and Goldstein, 2005, Kühnert et al., 2006). Gestural overlap in initial position may threaten the perceptual recoverability of obstruents. Thus, word-initial clusters tend to be less overlapped. Kühnert et al. (2006, p. 333) suggest that release of a stop occurring word-initially is its only acoustic trace. C1 in word-medial or word-final clusters can provide acoustic cues (for listeners) from transitions from previous vowel while C1 in an initial cluster cannot since there is no transitional cue from a vowel. According to Wright (1996), clusters where C1 has internal cues (e.g., fricatives) exhibit a high degree of overlap in Tsou unlike clusters where C1 is a stop because "there is transitional information at the edges of the frication that is similar to formant transitions although less robust" (p. 179). In brief, if perceptibility is at stake, no or low degree of gestural overlap is needed to maximise the availability of acoustic cues to phoneme identity (Chitoran et al., 2002; Wright,1996 and Chitoran,1999). In this respect, timing relations in consonantal sequences may be determined by the need for successful perception. Perceptibility is crucial in initial position (Marslen-Wilson, 1987, Chitoran et al., 2002) for the lexical accessibility of the word.

The position effect seems to operate in sequences containing not only stops but also other manners of articulation. For example, Hardcastle (1985) examined stop-liquid clusters in English and reported a lower degree of gestural overlap of /kl/ in word-initial position than across words /k#l/. Based on articulatory data (EPG), Byrd (1996) found that stop-stop clusters and fricative-stop clusters exhibit a lower degree of gestural overlap in word-initial position than in word-final position or across a word boundary. She also reported that a fricative-stop cluster was less overlapped in word-initial position than in word-final position or across words[12].

[12] /s/ was the only fricative she examined.

Gestural overlap was only examined in word-initial clusters in Najdi Arabic (e.g., Alsubaie, 2014). Thus, there is a need to examine gestural overlap in other word positions in Najdi Arabic. This thesis will examine the gestural overlap in word-initial, word-final clusters and in sequences across the word boundary. In brief, a lower degree of gestural overlap has been reported to be exhibited in word-initial than in other word positions. Accordingly, the following hypothesis is proposed:

> *Word-initial clusters will exhibit a lower degree of gestural overlap than word-final clusters and sequences across the word boundary.*

As pointed out above, the sequence position effect is crucial when considering the types of vowel insertion: intrusive and epenthetic, which will be discussed in detail in Chapter 4. It has been reported that the inserted vowel varies as a function of the sequence position in the word. It has been found that intrusive vowels occur in word-initial clusters (e.g., Al-Aqlobi, 2020 for Bisha Arabic and Makkah Arabic as spoken in Saudi Arabia; Plug et al, 2019 for Tripolitanian Libyan Arabic) and in a two consonant sequence at the word boundary (C#C) (Plug et al, 2019 for Tripolitanian Libyan Arabic), whereas epenthetic vowels were found to occur at the word boundary in CC#CC (Heselwood et al, 2015; Plug et al, 2019 for Tripolitanian Libyan Arabic). One of the main research questions[13] of the current thesis is to find out whether the impact of emphasis, if any, will be observed in intrusive vowels, epenthetic vowels or in both. This is motivated by the claim that an intrusive vowel is variable in duration and is influenced by surrounding gestures; it is a transition between two consonantal gestures that sound like a vowel; it is a result of retiming between existing articulatory gestures (Hall, 2006). Therefore, it can be assumed that an intrusive vowel will be prone to be influenced by emphasis, unlike an epenthetic vowel which is inserted to repair illicit syllable structure and has its own articulatory gesture that is not influenced by the place of articulation of surrounding sounds (Hall, 2006). It is true that emphasis can influence lexical vowels by lowering their second formant (F2), but emphasis does not influence the lexical vowel duration (e.g., Almuhaimeed, 2021 for Najdi Arabic) as will be shown in Chapter 3. Having shown that intrusive vowels are variable in duration and are influenced by surrounding consonants, it can be assumed that intrusive vowels duration and voicing proportion will be influenced by emphasis. Hence, greater degree of gestural overlap is expected to be observed in sequences with an intrusive vowel in an emphatic context, compared to sequences with an intrusive vowel in the plain counterpart. The types of vowel insertion and the characteristics of each will

[13] See Section 1.2 in Chapter 1 for the list of the main research questions of the current thesis.

be discussed in detail in Chapter 4. Thus, the relevant main research question and related hypotheses will be more motivated in Chapter 4.

Having discussed the sequence position effect, now we discuss another influential factor on gestural overlap, which is speech rate.

2.3.4 Speech rate effect

Gestures come close to each other in fast rate and are further apart in slow rate (Huinck et al., 2004, p.5). Gestures are phased differently "as a result of changes in speech rate" (Davidson, 1993, p.174). Increasing speech rate can involve several types of gestural coordination. Gestures become shorter at fast speech rate (Gay, 1981), but coordination is still the same. Another type of gestural adjustment is that an increase in speech rate may increase the gestural overlap (Munhall and Löfqvist, 1992; Byrd and Tan, 1996; Davidson, 2003); this will be referred to as the speech rate effect throughout the thesis. According to Ghummed (2015, p.65), shorter ICIs are expected at a fast rate,and hence greater gestural overlap. However, these are not necessarily the same. If gestural coordination is stable but all gestures are shortened, ICIs are shorter, but degree of gestural overlap is still the same. A more reliable measure that can determine the degree of gestural overlap in relation to speech rate effects is the absence/presence of the interval between two consonants; i.e., ICIs may disappear at fast speech rate, indicating greater degree of gestural overlap. Therefore, the ICI count/occurrence is the only measure that will be used to determine the degree of gestural overlap in relation to speech rate effects in the current thesis.

The findings of both instrumental and acoustic studies support the speech rate effect on the gestural overlap. Byrd and Tan (1996) investigated consonant sequences across a word boundary using EPG in English. They reported a high degree of gestural overlap in fast rate. They found that as rate increases, the coarticulation of two consonants across a word boundary increases, exhibiting a high degree of gestural overlap. These overlap results support the acoustic findings of Zsiga (1994) and Hardcastle (1985) who found that /kl/ was more overlapped at a fast speech rate in English.

A speech rate effect on gestural overlap was also examined in a number of Arabic varieties. Gafos (2002) reported a speech rate effect in Moroccan Arabic. He examined homorganic and heterorganic clusters at slow and fast rates. He found that releases are absent between consonants in a cluster in a fast rate, yielding a high degree of gestural overlap. Shitaw (2014) reports that the gestures of two consonants in a cluster show a greater degree of overlap at a fast rate in Tripolitania Libyan Arabic.

Speech rate was also found to be influential on laryngeal gestures (Munhall and Löfqvist, 1992). Munhall and Löfqvist (1992) used transillumination and fiberoptic video recordings to detect the laryngeal gestures (abduction and adduction movements) in English,and particularly across the word boundary in 'kiss#ted'. They report two separate gestures of the glottis at a slow speech rate; one glottal gesture for each consonant. In contrast, they report only one gesture of the glottis as a faster rate for two consonants. They attributed the single gesture of the glottis to consonantal overlap which was greater at the faster rate, and hence the glottal gestures are blending (1992, p.122).

Speech rate has also been found to be influential in assimilatory processes. Heselwood et al. (2011, p. 63) report complete assimilation of /l/ to /r/ across a word boundary at a fast speech rate, but not at a normal rate, in Standard Damascus Syrian Arabic. However, there are also contradictory results in the literature regarding the effect of speech rate on assimilation (see Ellis and Hardcastle,2002, Kochetov and Pouplier,2008).

Being an influential factor, the effect of speech rate is considered in this study. Speech rate was not considered in previous studies on Najdi Arabic; there is a need to examine the speech rate effect in Najdi Arabic. Accordingly, the following hypothesis is proposed:

> *Consonant sequences at a fast speech rate will exhibit a greater degree of gestural overlap than sequences at a normal speech rate.*

2.4 Summary

This chapter focused on timing relations in consonant sequences. It showed how consonantal gestures are phased differently when occurring in a sequence, which is obvious when considering the C-Centre organization. It has been shown that the C-Centre stability is likely to entail a specific pattern of gestural overlap; the duration of a consonant varies as a function of being in a singleton or in a sequence. It has been shown that the duration of consonants decreases as the number of consonants in the sequence increases.

The main factors that influence the gestural overlap were discussed. The place of articulation has been shown to influence gestural overlap in a range of different languages. Back-front sequences exhibit lower degree of gestural overlap than front-back sequences in a range of languages, including Najdi Arabic. Lingual/lingual sequences were found to exhibit lower degree of gestural overlap than labial/lingual sequences in different languages, including Najdi Arabic. The state of the glottis involved in the consonants in the sequence has also been found to influence the gestural overlap. When both consonants in a sequence are voiced (sharing the same state of the glottis), they exhibit greater degree of gestural overlap than when they differ in voicing (having different states of the glottis). It has been briefly shown how these two factors relate to emphasis; the emphatic coronals are produced with a secondary articulation and less open glottis than their plain counterparts. The remainder of the chapter was devoted to the other two main factors that influence timing relations: sequence position and speech rate. It has been consistently reported that word-initial clusters exhibit lower degree of gestural overlap than word-final clusters. It has also been reported that greater gestural overlap is exhibited at a fast speech rate.

This thesis will examine gestural overlap of consonant sequences in Najdi Arabic. The sequence position (word-initially, word-finally or at the word boundary), the order of place of articulation (front-back or back-front), the identity of the articulators (lingual/lingual or labial/lingual) and speech rate (normal or fast) will be considered.

This chapter looked at the timing relations in consonant sequences. Chapter 3 turns to emphasis,and Chapter 4 will discuss Najdi Arabic, as the primary aim of this thesis is to identify whether emphasis has an impact on the gestural overlap of consonant sequences in Najdi Arabic.

3 Emphasis

This chapter is divided into five sections. Section 3.1 introduces emphasis. Section 3.2 discusses the articulatory correlates of emphasis,and section 3.3 concerns the acoustic correlates. Section 3.4 discusses emphasis spread,and section 3.5 looks at differences in gender in relation to emphasis. The chapter concludes with a general summary.

3.1 Introduction

Arabic is well-known for the feature of emphasis. The Arabic language is referred to as the language of /dˤa:d/ which refers to the emphatic stop /dˤ/. Emphasis refers to a secondary articulation with smaller degree of constriction involving the tongue back/root that accompanies a primary articulation with a greater degree of constriction (Ladefoged and Maddieson, 1996, p.354).

Emphatic sounds were of interest to linguists as early as the time of Al-Khaliyl and Sibawayh around 1200 years ago. The coronals /tˤ, sˤ, ðˤ, dˤ/ are the only emphatic consonants in Classical Arabic. Sibawayh in his book, *Al-Kitaab*, classifies Arabic consonants into two classes:

1. *mutˤbaqah* 'covered' which correspond to the four emphatic coronals /tˤ, sˤ, ðˤ, dˤ/. The term *Itˤbaaq*, used by Sibawayh, refers to the process by which the tongue front makes contact with the palate front part,and the tongue back is raised up towards the palate (Hassan and Esling, 2011, p.217).

2. *munfatiħah* 'open' which correspond to other sounds (Al-Nassir, 1993, p.50).

Al-Nassir (1993, pp.50-1) indicates that Sibawayh was aware that there are two articulations involved during the production of emphatic sounds, but did not give their precise locations.

Some researchers include pharyngeals and pharyngealised coronals in the same class, such as Watson (2002), who suggests that pharyngeals can be seen as the emphatic counterparts of the laryngeals. According to Harrell (1957, cited in Watson, 2002), pharyngeals and pharyngealised sounds were referred to as *mufaxxam* 'intensified' by early Arab grammarians.

Arabic dialects differ with respect to the number of emphatic sounds in their phoneme inventories. Khattab et al. (2006) classify Arabic varieties, based on the emphatic consonants they possess, into two groups:

1. Bedouin dialects that have the three coronal emphatics /tˤ, sˤ, ðˤ/

2. Sedentary dialects that have /tˤ, sˤ, dˤ/ and, in some varieties, /zˤ/.

Najdi Arabic (NA) has three emphatic consonant phonemes: /tˤ/, /sˤ/ and /ðˤ/. For example, the word /tˤa:b/ 'he recovered' forms a minimal pair with the word /ta:b/ 'he repented', the word /sˤab/ 'he poured' forms a minimal pair with /sab/ 'he cursed',and the word /ðˤa:g/ 'he's angry' forms a minimal pair with /ða:g/ 'he tasted' in NA. According to Khattab et al.'s (2006) classification, NA falls in the Bedouin group with respect to emphasis.

The next section will discuss the articulatory correlates of emphasis, followed by the acoustic correlates. The remainder of the chapter will be devoted to emphasis spread to show how emphasis can have an impact on the surrounding sounds, as the current thesis will examine the inter-consonantal interval (ICI), along with sequence duration and individual intervals, to determine the degree of gestural overlap of consonant sequences with an emphatic coronal, compared to sequences with the plain counterpart.

3.2 Articulatory correlates

This section presents the articulatory correlates of emphatic sounds. It will discuss the two main terms used to characterise the secondary articulation of emphatics, uvularisation and pharyngealization. Then, the relationship between the primary and the secondary constrictions will be discussed.

3.2.1 Brief introduction

Two articulatory gestures are required for emphatics to be produced, primary and secondary (Abercrombie, 1967). The secondary articulation of emphatics involves a retraction of the tongue. Ali and Daniloff (1972) conclude that the secondary articulation of emphatic sounds involves three configurations: tongue back retraction, tongue body depression and a considerable tension of the pharynx. As explained by Watson (2002, p.270), emphasis involves an enlargement of the mouth cavity and a decrease in volume of the pharyngeal cavity; the oral cavity enlargement is the main articulatory correlate.

According to Watson (2002, p. 269), emphasis was initially characterised as velarisation by some linguists such as Nasr (1959) and Obrecht (1968) claiming that the pharyngeal dorsum is raised towards the soft palate; later, however, studies based on the findings of laboratory analysis showed that the production of emphatics involves an upper pharynx constriction, not at the soft palate (Al-Ani 1970; Broselow, 1976; Ghazeli, 1977; Card, 1983; McCarthy, 1986; Jarrah, 1993). Those who adopt the velarisation view tend to accompany it with pharyngealisation. For example, Obrecht (1968; cited in Jongman et al., 2011) describes emphatics in Lebanese as velarised and pharyngealised.

Bellem (2007, p.28) notes that the secondary articulation of Arabic emphatics is described as secondary pharyngealisation or uvularisation. She explains that many researchers prefer *pharyngealisation* to describe Arabic emphatics "since this term focuses on a general role of the pharynx in the production of emphatics" (p. 45). Alarifi (2010) used the term *pharyngealisation* to refer to emphatics in his study on NA because, he argued, most studies on Arabic concluded that the secondary articulation is a pharyngealised constriction. To sum up, two terms have been mainly used to describe emphasis: uvularisation (e.g., Zawaydeh, 1998) and pharyngealisation (e.g., Watson, 1999). These two terms will be discussed in turn.

3.2.2 Uvularisation

A number of researchers suggest that the secondary articulation involved in emphatics is uvularisation (e.g., Catford, 1977; McCarthy, 1994; Zawaydeh, 1998; Zeroual, 1999; Halle et al., 2000). Catford (1977) describes emphatics as uvularised due to tongue retraction towards the upper pharynx. Ghazeli (1977) took films using cinefluorography of himself (a Tunisian Arabic speaker) and found that the constriction was in the uvular region. Zawaydeh (1999), in her endoscopic study in Ammani Jordanian Arabic, reports that the secondary articulation of emphatics is uvularisation. She considers emphatics as uvularised and emphasis spread as uvularisation spread. The findings of Zawaydeh and de Jong (2011) support those of Zawaydeh (1999); they refer to the secondary articulation in Ammani Jordanian Arabic as uvularisation (p. 257). Other researchers conclude that emphasis is best referred to as uvularisation by comparing between the primary constriction of uvulars and secondary constriction of emphatics. For example, McCarthy (1994) and Halle et al. (2000) report that uvulars and emphatics have the same constriction in the upper pharynx. Similarly, Zeroual (1999) in his fiberscopic study found that the constriction involved in the production of uvular /q/ is similar to the secondary constriction involved in the production of emphatics /tˤ/ and /sˤ/ in Moroccan Arabic.

3.2.3 Pharyngealisation

Bellem (2007) notes that many researchers prefer using the term *pharyngealisation* to refer to emphatic consonants because this term does not rule out the role of the pharynx when producing emphatics (p.28). Based on instrumental data in a number of Arabic varieties, several researchers suggest that the secondary articulation involved in the emphatic sounds is pharyngealization (e.g., Al-Ani, 1970 for Iraqi and Jordanian; Bukshaisha, 1985 for Qatari; Zeroual et al., 2011 for Moroccan Arabic). Some other studies did not rule out simultaneous uvularisation and pharyngealisation. Ali and Daniloff (1972) conclude that emphatic sounds involve the palatine dorsum being depressed and the pharyngeal dorsum being moved backward towards the pharyngeal back wall, during their production in Iraqi Arabic. They also found that the velum is lowered towards the tongue dorsum as the dorsum is rising. Such findings suggests that the configuration involved in emphasis can be pharyngealisation and uvularisation. Similarly, Hassan and Esling (2011) conclude that the secondary constriction is 'pharyngealisation' in their Iraqi Arabic data, but they do not rule out a uvularised effect.

Other researchers report a similar characterisation of the secondary articulation of emphasis, pharyngealisation, based on acoustic as well as instrumental data. For example, Al-Tamimi and Heselwood (2011), using nasoendoscopy and videofluoroscopy in addition to acoustic data, conclude that pharyngealisation is the articulatory configuration involved with emphatic consonants in Jordanian Arabic, except in the context of the high vowel /u:/ where the configuration is best described as uvularisation; they reported a raised F3 with /u:/, suggesting that the secondary articulation is higher due to coarticulation (p.187).

It has been further reported that the epiglottis can play a role during the production of emphatic consonants. The epiglottis was found to be retracted along with the tongue back towards the pharynx back wall, suggesting a pharyngeal constriction (Laradi, 1983). The role of the epiglottis is supported by Heselwood and Al-Tamimi (2011) in their nasoendoscopic study in Jordanian Arabic. Although they found that the epiglottis was more retracted during the production of pharyngeals than during the production of emphatics, there was still evidence that the epiglottis plays a role in the production of emphatic consonants. Using nasoendoscopy, Al-Tamimi and Heselwood (2011) found that the secondary constriction is in the lower oropharynx where the epiglottis is folded backwards and downwards. This is similar to the constriction they observed in the pharyngeal consonants in Jordanian Arabic.

Other researchers suggest that emphatics share some features with the true pharyngeals /ħ,ʕ/, indicating that emphatics are best described as pharyngealised. According to Broselow (1976), pharyngeals share the feature [+constricted pharynx] with pharyngealised sounds. This is supported by Laufer and Baer's (1988) study in which they found that both pharyngeals and emphatic sounds, based on audio and visual recordings, share a similar pharyngeal constriction in Hebrew and Arabic, with more extreme constriction for pharyngeals. As indicated above, Watson (2002, pp. 270-1) considers oral emphatics and pharyngeals to belong to one class characterised by the feature [guttural]. She, however, distinguishes between them based on [guttural] spread which can extend from oral emphatics and affect surrounding vowels and consonants, but cannot extend beyond adjacent vowels from pharyngeals[14]. Also the tongue, during the production of pharyngealised coronals, is reported to be in a greater state of tension than during production of pharyngeals (Watson, 2002, p.273).

Having discussed the variable labels used in the literature to refer to the secondary articulation of emphasis in different varieties of Arabic (mainly uvularisation and pharyngealisation), claims about the location of the secondary constriction can also vary within the same variety of Arabic. For example, Zawaydeh and de Jong (2011) state that the main phonetic correlate of emphasis in Ammani Jordanian Arabic is uvularisation, based on data collected from six speakers from Amman, the capital city of Jordan. Al-Tamimi and Heselwood (2011), however, claim that it is pharyngealisation in the same variety except in the context of the high back vowel /u/; they examined data collected from seven Jordanian speakers (three from Amman, three from Irbid and one from Karak), and they did not report any variation between the three areas of Jordan, and thus they refer to the variety they examined as Jordanian Arabic. Hassan and Heselwood (2011) attempt to provide an explanation of the variable conclusions of the secondary articulation of emphasis within the same variety of Arabic. They (p.20) speculate that different conclusions regarding the secondary constriction location in the same variety of Arabic could be attributed to inter-speaker variation; speakers may differ in how close the tongue posterodorsum approaches to the uvula. They also indicate that both uvularisation and pharyngealisation could occur simultaneously in the sense that there could be a narrowing in the upper oropharynx and the tongue dorsum, which at the same time, approximates to a lowered uvula. The question then should be which articulatory movement is stronger and lasts for a longer time.

Variation in the articulatory configuration associated with emphatic consonants across Arabic varieties could be justified; Al-Masri and Jongman (2004, p.96) claim that we cannot simply conclude that the correlates of emphasis are the same across all Arabic dialects. Al-Tamimi and Heselwood (2011) consider the different labels used by researchers about the location of the secondary articulation,and they suggest that the question to ask is "how low or how high it is in the oropharyngeal zone. Is it high enough to be described as uvularisation, or low enough to be described as pharyngealisation, or even epiglottalisation?" (p.186).

To sum up, the precise configuration varies between and within dialects,and researchers attempting to capture aspects of this variation has resulted in the recurrent use of two secondary articulation labels which are associated with adjacent constriction areas: *uvularisation* and *pharyngealisation*. As shown above, most authors interested in emphasis

[14] Spread of the feature of emphasis will be discussed in detail in Section 3.4.

concentrated on the secondary articulation of emphatic sounds, but a few researchers attempted to shed light on the primary articulation of emphatic consonants as another potential cue that can distinguish an emphatic consonant from the plain counterpart. This will be discussed below.

3.2.4 Primary articulation

While some researchers have claimed that the secondary articulation associated with emphasis does not affect the primary articulation (e.g., Norlin, 1987; Laufer and Baer, 1988), other researchers suggest otherwise. In general, the primary articulation of emphatic consonants has been claimed to be more posterior than that of the plain counterparts (e.g., Al-Ani, 1970; Laradi, 1983; Bukshaisha,1985; Kriba,2004, Al-Tamimi and Heselwood,2011, Hermes, 2015). Finch (1984) refers to emphatics as alveolars and to their plain counterparts as post-dentals, referring to their primary articulation. Although Al-Ani (1970) refers to both plain /ð/ and emphatic /ðˤ/ as inter-dentals, he refers to emphatics /tˤ, sˤ, dˤ/ as post-dental and to their non-emphatic counterparts as dentals in Baghdadi Iraqi Arabic. Hussain (1985) describes /sˤ/ as post-alveolar and /s/ as alveolar in Gulf Arabic. The tongue tip, when producing /tˤ/, was found to be slightly retracted to the alveolar area in comparison to /t/ (e.g., Al-Ani, 1970; Ali and Daniloff,1972; Odisho, 1973; Laradi,1983; Bukshaisha, 1985). Hermes (2015) found that the blade of the tongue is more lowered in /sˤ/ than in /s/ in Lebanese Arabic.

The primary and secondary articulation may also differ in their timing. It has been claimed that the secondary articulation can start earlier than the primary articulation. For example, Watson (2002, p. 277) indicates that the pharynx narrowing, involved in production of the secondary articulation, occurs before the closure of the primary articulation. This explains the anticipatory emphasis spread (leftward) which is more common in Arabic varieties than the carry-over emphasis spread (rightward)[15]. Interestingly, differences in timing between the primary and secondary articulation have also been reported in other languages. For example, Sproat and Fujimura (1993) report that the production of English /l/ involves two gestures, the tongue tip and the tongue dorsum; they referred to them as a consonantal gesture and a vocalic gesture respectively. In syllable-initial position, the two gestures occur simultaneously and both attain their targets at the same time. In syllable-final position, however, the tongue dorsum reaches its target at the onset of the tongue tip gesture; they argue that the tongue dorsum moves slowly, compared to the tongue tip,and therefore it has to start earlier (see Browman and Goldstein, 1995 for more details).

[15] Emphasis spread and its directionality will be discussed in detail in Section 3.4.

According to Watson (2002), there is a contingent relationship between the two articulations of emphatics; the secondary articulation of oral emphatics (non-primary [guttural] using Watson's terms) depends on the primary articulation which restricts the pharyngeal constriction by adding tension to the dorsum of the tongue (Ali and Danilof, 1972; McOmber, 1996; Zemánek, 1996).

Having discussed the articulatory differences between emphatic consonants and their plain counterparts, mainly involving the tongue back/root in producing emphatics, compared to the plain counterparts, it is worth explaining how all this discussion relate to the research questions of the current thesis,and to the theoretical background of timing relations in consonant sequences that was discussed in the previous chapter. This will be explained below.

3.2.5 This study

Having discussed the articulatory correlates of the secondary articulation of emphasis, it is worth restating the relevant research question and hypothesis and how the reviewed literature here is relevant to the reviewed literature in Chapter 2 (timing relations in consonant sequences). As pointed out earlier, one aim of this thesis is to answer the following research question:

Does the secondary articulation of emphasis have an impact on the degree of gestural overlap of consonant sequences?

To answer this research question, the following hypothesis is proposed to be tested:

Lingual/lingual consonant sequences in an emphatic context will exhibit a lower degree of gestural overlap than lingual/lingual consonant sequences in the plain counterpart.

Recall from Chapter 2, which discussed timing relations in consonant sequences, that cross-linguistically lingual/lingual sequences observe lower degree of gestural overlap than lingual/labial sequences (e.g., Shitaw, 2014 for Tripolitanian Libyan Arabic; Alsubaie, 2014 for Najdi Arabic). This has been attributed to the identity the articulators involved in producing the sequence. The articulators of lingual/lingual sequences such as /gt/ (i.e., tongue dorsum and tongue tip) are inter-dependent, while the articulators of lingual/labial sequences such as /tb/ (i.e., tongue tip and the lips) are independent. The secondary articulation of emphasis adds more complexity (by adding a posterior gesture) to the production of sequences comprising emphatic coronals and lingual consonants (e.g., /gtˤ/), compared to the production of the plain coronals and lingual consonants (e.g., /gt/). A sequence such as /gtˤ/ involves the tongue dorsum, the tongue tip and the tongue back, whereas a sequence such as /gt/ involves the tongue dorsum and the tongue tip. Lingual/lingual sequences and lingual/labial sequences will be examined in the current thesis to answer the above research question and test the above hypothesis. For instance, the timing relations in /gtˤ/ will be compared to those in /gt/ to figure out whether the lingual/lingual sequences in an emphatic context (such as /gtˤ/) will exhibit lower degree of gestural overlap than lingual/lingual sequences in the plain counterpart (such as /gt/).

Having discussed the articulatory correlates of emphasis, we now turn to the acoustic correlates. This is important since the current thesis will examine emphatic coronals acoustically.

3.3 Acoustic correlates

The acoustic correlates of emphasis can be related to the consonant (trigger of emphasis) or to the adjacent vowel. This section will start with the consonantal cues (hold phase, frication durations, and Voice Onset Time), followed by the vocalic cues (vowel duration and formants). A few studies examined both vocalic and consonantal correlates of emphasis, including Almuhaimeed (2021) who examined Najdi Arabic. It should be noted that both vocalic and consonantal cues are not observed in all Arabic varieties as reliable acoustic cues of emphasis as will be shown below. Consonantal cues will be discussed first since the current thesis investigates the impact of emphasis on consonant sequences, and hence the consonantal cues will be examined. Then, the vocalic cues will be discussed prior to discussing emphasis spread, which is mainly observed via vocalic cues, and particularly vowel formants.

3.3.1 Consonantal cues of emphasis

A number of acoustic correlates can distinguish emphatic consonants from their plain counterparts. The duration of the emphatic consonants (the hold phase for the stop and frication for the fricative) and Voice Onset Time (VOT) are the main correlates. They will be discussed in turn.

3.3.1.1 Duration of emphatic consonants

It has been reported that there are durational differences between emphatic consonants and their plain counterparts in a number of studies. Bukshaisha (1985) describes emphatic consonants as tense sounds. She found that emphatic /sˤ/ was longer than plain /s/ in Qatari Arabic because of the greater intensity required for /sˤ/ due to the pharyngeal constriction during which the articulators maintain their configuration for longer duration. Similarly, Kuriyagawa et al. (1988) reported that emphatic /sˤ/ was longer than plain /s/ in Standard Jordanian Arabic. In addition, the hold phase (HP) of emphatic stops was reported to be longer in duration than that of plain counterparts. For example, Bukshaisha (1985) reports a longer closure duration in /tˤ/ than in /t/ because of the greater intensity required for /tˤ/. Similar results were reported by Al-Nuzaili (1993) in Yemeni Arabic. Almuhaimeed (2021) reported a longer /tˤ/ HP than /t/ HP in Najdi Arabic. The articulation of emphatic sounds is more complex than their plain counterparts when considering the secondary articulation. Thus, it could be inferred that emphatics require more time to be articulated in comparison to their plain counterparts.

Other researchers did not find differences between the duration of emphatic and plain sounds, such as Ali and Daniloff (1972 for Iraqi Arabic), Hussain (1985 for Gulf Arabic), El-Dalee (1984 for Egyptian Arabic), Al-Masri and Jongman (2004 for Jordanian Arabic, as spoken in northern Jordan), Boxberger (1981 for Modern Standard Arabic) and Bin-Muqbil (2006 for Modern Standard Arabic). Alarifi (2010) found no significant durational differences in Najdi Arabic between /sˤ/ and /s/, nor between /ðˤ/ and /ð/. Similarly, Almuhaimeed (2021) did not find a significant difference in frication duration between /sˤ/ and /s/ in Najdi Arabic (/s/ was the only fricative she considered).

3.3.1.2 Voice Onset Time (VOT)

Another acoustic feature that can distinguish between an emphatic and a plain counterpart is the Voice Onset Time (VOT) of /t/~/tˤ/. Across a number of Arabic dialects, emphatic /tˤ/ is repeatedly reported to have a shorter VOT than its plain counterpart /t/, meaning that the vocal folds tend to start vibration earlier when producing a vowel after an emphatic /tˤ/ than when producing it after a plain counterpart /t/ (Ghazeli, 1977, Al-Nuzaili, 1993, Khattab et al., 2006). It seems that /tˤ/ is in what Esling and Harris (2005, pp. 355-7) call the 'pre-phonation' state. Ghazeli (1977) indicates that this difference in VOT might be attributed to the fact that /t/ is aspirated, with aspiration noise audible in a VOT longer than 25-30ms (Laver, 1994). Generally /t/ is aspirated while /tˤ/ is not in many Arabic varieties, as reported by Al-Ani (1970) and Odisho (1973, cited in Bellem, 2007) for Iraqi Arabic, Bukshaisha (1985) for Qatari Arabic, Al-Nuzaili (1993) for Yemeni Arabic and Boxberger (1981) for Modern Standard Arabic as produced by a Saudi speaker. The same finding has been reported for Najdi Arabic. Bellem (2007) examined data collected from seven Saudi speakers (KACST Database)[16], five from central Najd [Riyadh region], one from Buraidah and one from Albaha; overall, mean /t/ VOT was 35ms whereas mean /tˤ/ VOT was 16ms across all speakers. Alarifi (2010) also reported significantly shorter mean VOT in /tˤ/ than in /t/, 20ms and 54ms respectively in Najdi Arabic

[16] "The database, available on three CDs, is part of a speech technology project at the Computer and Electronics Research Institute of King Abdulaziz City for Science and Technology in Saudi Arabia. See www.kacst.edu.sa." (Bellem, 2007, p. 67)

(p. 27). A more recent study on Najdi Arabic supports the claim that /tˤ/ VOT is shorter than /t/ VOT (Almuhaimeed, 2021).

In contrast, a number of studies indicate that VOT in other Arabic dialects cannot be used to distinguish /t/ and /tˤ/. For example, Heselwood (1996) examined two Arabic varieties, Baghdadi Iraqi Arabic and Cairene Egyptian Arabic. He found a difference in VOT between /t/ and /tˤ/ produced by Iraqi speakers (mean /t/ VOT=31 ms and mean /tˤ/ VOT=16 ms). His Egyptian speakers, however, produced similar VOT values for both /t/ and /tˤ/ (mean /t/ VOT=33 ms and mean /tˤ/ VOT=35 ms; both are voiceless aspirated). This slight aspiration for both /tˤ/ and /t/ was reported by Shaheen (1979) in Egyptian Arabic as well. Similarly, Rifaat (2003) did not find a significant difference between /t/ and /tˤ/ VOT values in his Egyptian data. Speakers of Najdi Arabic, however, were found to distinguish between VOT values for /tˤ/ and /t/ (Alarifi, 2010; Almuhaimeed, 2021), as pointed out above. This suggests that VOT values, as a parameter for /t/-/tˤ/ distinction, is dialect specific (Bellem, 2007).

Having discussed the VOT, which reflects the activity of the glottis, now we turn to elaborate on the state of the glottis during the production of the emphatic coronals (tˤ, sˤ). This is crucial for the thesis aims and research questions, as will be shown at the end of the following sub-section.

3.3.1.3 State of the glottis in emphatic consonants

As discussed above, VOT values reflect the state of the glottis after the release when producing /t/ and /tˤ/. A 30ms or longer VOT value indicates that the glottis is widely open and laryngeal tension is reduced, whereas a lower VOT value suggests that the glottis is narrowed and laryngeal tension is increased (Catford, 1977). This state of the glottis can be active during the hold phase. According to Khattab et al. (2006, p.136), a narrow glottal aperture during the hold phase indicates that the vocal folds are about to vibrate immediately after release; consequently no aspiration noise would be audible. This assumption seems consistent with what Esling and Harris (2005) call the 'pre-phonation' state, which can explain why the vocal folds tend to start vibration earlier when producing a vowel after an emphatic /tˤ/ than when producing it after a plain counterpart /t/. This also corroborates Sibawayh's inclusion of /tˤ/ in the *majhūr* group, in which all other sounds, apart from /q/ and /ʔ/, are voiced (Al-Nassir, 1993). Sibawayh's classification of Arabic consonants will be discussed in detail below. This VOT pattern (shorter in /tˤ/ than in /t/) is to be expected given the articulatory configuration associated with emphasis. The secondary constriction in emphatics can have the effect of narrowing the glottis and hence voicing starts earlier in the case of /tˤ/ when compared to /t/, resulting in a lower VOT value for /tˤ/. The wider glottal opening associated with plain /t/, on the other hand, would result in more aspiration. This claim is supported by Zeroual (1999) in his study on Moroccan Arabic which reports a narrower glottal opening associated with /tˤ/ than /t/ based on a fiberscopic evidence.

The early Arabic grammarian, Sibawayh, classified Arabic consonants into *majhūr* and *mahmūs* groups. The emphatic /tˤ/ was included in the *majhūr* group in which all other sounds are voiced, apart from /q/ and /ʔ/; all sounds in the *mahmūs* group are voiceless. This could indicate that /tˤ/ was voiced in the past. Sibawayh suggests that /tˤ/ would be realized as voiced plain /d/ without *itˤbaaq*, referring to emphasis (Al-Nassir, 1993). Based on a diachronic study, Garbell (1958; cited in Khattab et al,2006, p. 137) suggests that /tˤ/ was historically voiced. From impressionistic work, /tˤ/ is reported as being voiced in San'ani Arabic in certain environments, when occurring word-initially or between two vowels (Watson, 1993; cited in Watson, 2002, p.13). Such observations may have led Khattab et al. (2006) to infer that unaspirated /tˤ/ in Arabic varieties nowadays could be "a reflex of an earlier voiced /dˤ/" (p. 137). The inclusion of /tˤ/ in the *majhūr* group was examined by Heselwood and Maghrabi (2015) who conclude that, based on aerometric, laryngographic and spectrographic data, /tˤ/ shares a similar state of breath and airflow controlled by glottal states with the other sounds in the *majhūr* group. Additional support comes from Watson and Heselwood (2016) who found that the emphatic /tˤ/ patterns with the plain voiced /d/ in San'ani Arabic and the Modern South Arabian Languages (MSAL, henceforth) because both /tˤ/ and /d/ have a common glottal state (closed) and they lack the voiceless turbulence/aspiration and open glottis exhibited by /t/. Observations such as these led Heselwood (2020) to propose that Arabic consonants are best described as breathed (referring to the consonants included in the *mahmūs* group) or unbreathed (referring to the consonants included in the *majhūr* group) rather than voiceless and voiced.

The alveolar fricative /sˤ/ was also considered along with /tˤ/ in MSAL. Heselwood et al (2022), using Laryngography, found that /sˤ/ patterns with voiced consonants in many ways in Shehret. It behaves like /tˤ/ in that it is not usually voiced but there is no aspiration and the glottis seems to be in a constricted state rather than an open state (just like the stop /tˤ/). They found that the emphatic fricative /sˤ/ and the plain voiced counterpart /z/ pattern together in their state of the glottis, which is more constricted (using Heselwood et al's terms) and in their frication duration, which is shorter, compared to the plain voiceless fricative /s/. Putten (2019) examined the rhyme scheme in the Qur'an. He concluded that the lines rhyme according to both being *majhūr* or both being *mahmūs*, considering Sibawayh's classification. When the line ends with the emphatic /sˤ/, the consonant that it rhymes with is *majhūr* which suggests that in early Arabic, at the time of the Qur'an, /sˤ/ was different from what it is now. It was more like /tˤ/ in the state of the glottis (narrowed) and that fits with what has been observed in the MSAL. These results support the claim that the plain voiced and emphatic fricatives can be grouped in the same laryngeal category in contrast to voiceless fricatives, supporting Heselwood et al's proposed phonological laryngeal contrast for fricatives as well as for stops "breathed" (voiceless) vs "unbreathed" (voiced and emphatics).

In brief, the emphatic coronals /tˤ/ and /sˤ/ differ from their plain counterparts, /t/ and /s/, respectively, in their state of the glottis which is narrowed during the production of the emphatics but widely open during the production of the plain counterparts. Watson and Heselwood (2016, p. 33) assert that the plain voiceless sounds involve "voiceless turbulence" which is absent in the emphatic voiceless sounds. 'less open' glottis will be used to refer to the state of the glottis involved in emphatic coronals throughout the current thesis although some authors of previous studies used different terms, such as 'constricted glottis' (e.g., Heselwood et al,2022) as shown above. The term 'constricted glottis' may indicate that there is a phonological feature [constricted glottis] present in these sounds;and to avoid being misinterpreted as claiming that there is an active [constricted glottis] feature in emphatic sounds, the term 'less open' will be used in this thesis, which can indicate that the glottis is relatively more constricted, i.e. *less open* in emphatics than in their voiceless plain counterparts.

3.3.1.3.1 This study

Recall from Chapter 2, which discussed timing relations in consonant sequences, that the state of the glottis plays a role in the gestural overlap of consonant sequences; i.e., when both consonants are voiced (sharing the same state of the glottis), they exhibit a greater degree of gestural overlap than when they differ in voicing (having different states of glottis) (e.g., Hoole et al,2009 for German; Gibson et al,2019 for Spanish; Shitaw,2013 for Tripolitanian Libyan Arabic; Alsubaie, 2014 for Najdi Arabic). Previous studies examining the role of the state of the glottis on gestural overlap did not include emphatic coronals. There is evidence that the emphatic /tˤ/ is produced with a less open glottis than the plain /t/,and therefore it has been reported that /tˤ/ patterns with the plain voiced /d/ in the state of the glottis, compared to the plain voiceless /t/ in both Arabic and MSAL (e.g., Watson and Heselwood, 2016). There is also evidence that the emphatic /sˤ/ is produced with a less open glottis than the plain /s/,and therefore /sˤ/ patterns with voiced consonants in the state of the glottis in MSAL (e.g., Heselwood et al, 2022) and in Qura'nic Arabic (Putten, 2019). There is a need to examine the state of the glottis of /s/ in an Arabic variety; it will be examined using the ICI voicing proportion. Both /tˤ/ and /sˤ/ are obstruents; what applies to /tˤ/ could also apply to /sˤ/. In contrast, there is no motivation to hypothesise otherwise.

This thesis will examine the emphatic coronals /tˤ/ and /sˤ/, compared to their plain voiceless counterparts /t/ and /s/, respectively, and to their plain voiced counterparts /d/ and /z/, respectively, to find out whether the emphatic coronals will behave similarly in the degree of gestural overlap with their plain voiced or voiceless counterparts. Accordingly, the following hypotheses are proposed to be tested:

Voiced/emphatic /tˤ/ sequences (i.e., /btˤ/ and /tˤb/) will exhibit a greater degree of gestural overlap than voiced/plain /t/ sequences (i.e., /bt/ and /tb/), and accordingly /tˤ/ will behave similarly with the plain voiced counterpart /d/ in the degree of gestural overlap, compared to the plain voiceless counterpart /t/.

Voiced/emphatic /sˤ/ sequences (i.e., /bsˤ/ and /sˤb/) will exhibit a greater degree of gestural overlap than voiced/plain /s/ sequences (i.e., /bs/ and /sb/), and accordingly /sˤ/ will behave similarly with the plain voiced counterpart /z/ in the degree of gestural overlap, compared to the plain voiceless counterpart /s/.

Both /tˤ/ and /sˤ/ are hypothesised to behave like their plain voiced counterparts, /d/ and /z/, compared to their plain voiceless counterparts, /t/ and /s/, based on the state of the glottis which is less open in the emphatics but wide open in their plain voiceless counterparts. The dental /ðˤ/ was excluded because both the emphatic /ðˤ/ and its plain counterpart /ð/ share the same state of the glottis,and thus there is no motivation to hypothesise that they will behave differently based on the state of the glottis only.

Having discussed the consonantal cues of emphasis and shown how emphatic coronals are distinct from their plain counterparts in the state of the glottis, now we discuss the vocalic cues of emphasis (mainly vowel duration and vowel formants).

3.3.2 Vocalic cues of emphasis

3.3.2.1 Vowel duration

While most Arabic dialects show no significant differences in vowel duration between emphatic and plain contexts (El-Dalee, 1984; Norlin,1987 for Egyptian Arabic; Kriba,2009 for Libyan Arabic as spoken in Zliten northern Libya; Al-Masri and Jongman, 2004 for the northern dialect of Jordanian Arabic), other researchers suggest otherwise for some dialects. Hussain (1985) found that the vowel following /tˤ/ is longer than that following /t/ in Gulf Arabic.

Hassan (1981) reported a longer vowel duration preceding /sˤ/ than that preceding /s/ in Iraqi Arabic. Abudalbuh (2010) reported that vowel duration was longer in an emphatic context than in the plain counterpart in Jordanian Arabic. Kriba (2004) reported inconsistent findings of vowel duration in Libyan Arabic. He found that vowel duration following /tˤ/ was longer than that following /t/; however, no differences in vowel duration were found between /sˤ/ and /s/ contexts. Almuhaimeed (2021) examined emphasis spread in Najdi Arabic,and she found no significant differences in vowel duration between an emphatic context and the plain counterpart.

3.3.2.2 Vowel Formants

Second vowel formant (F2, henceforth) lowering is the most consistently reported acoustic correlate of emphatics in different varieties of Arabic including Moroccan (Mohamed, 2001), Egyptian (Norlin, 1987), Gulf Arabic (Hussain, 1985), Iraqi (Al-Ani, 1970; Hassan and Esling, 2011), Tunisian (Ghazeli, 1977), Qatari (Bukshaisha,1985), Jordanian (Al-Tamimi and Heselwood, 2011),and Najdi Arabic (Alarifi, 2010; Alhammad,2014; Alfraikh,2015; Almuhaimeed, 2021).

The extent of F2 lowering varies across vowels. The low vowel /a/ appears to be more susceptible than the other vowels. Jongman et al. (2007) found that F2 lowering is greatest in /a/ and least observed in /u/ in monosyllabic words. Jongman et al. (2011) conclude that F2 is lowered in both the vowel preceding and the vowel following the emphatic; and greatest F2 lowering is in /a/ and least F2 lowering is in /i/ then /u/ in Jordanian Arabic, as spoken in Irbid.

Boxberger (1981) examined emphasis in Modern Standard Arabic (MSA, henceforth) based on data produced by a single Saudi speaker[17]. She considered only F2 of long vowels /i:/, /u:/ and /a:/. She found that F2 is lowered in all time points during /a:/, unlike /i:/ and /u:/, whether preceding or following the emphatic sound. Acoustic studies that examined Najdi Arabic speakers have unanimously reported F2 lowering of the vowel /a/ adjacent to emphatics, compared to those adjacent to their plain counterparts (Alarifi,2010; Alhammad, 2014; Alfraikh,2015; Almuhaimeed, 2021). Alarifi (2010) reported that F2 was significantly lowered only at vowel onset in /i:/, at onset and midpoint in /u:/ and at onset, midpoint and offset in the low vowels /a/ and /a:/. In addition, /a/ is realized as back [ɑ] in Najdi Arabic as reported by Alfraikh (2015). This is in line with Mohamed (2001) who indicates that there is a compatibility between the low vowel /ɑ/ and the pharyngeal articulation; i.e., the oral cavity becomes wider during the articulation of a low vowel when compared to other vowels (El-Dalee, 1984). It has been reported that different emphatic consonants could influence vowel

[17] She did not give more details about this informant.

formants differently. For example, Bin-Muqbil (2006) found that the F2 difference is statistically significant with /sˤ/ but not significant with /tˤ, dˤ, ðˤ/ in MSA.

First vowel formant (F1, henceforth) increase can also be observed in an emphatic context as reported in Iraqi (Al-Ani, 1970), Moroccan (Mohamed, 2001), Jordanian Arabic (Khattab et al., 2006), Qatari (Bukshaisha, 1985) and Gulf Arabic (Hussain, 1985). It has been reported that F2 and F1 were closer to each other in vowels adjacent to an emphatic consonant than in those adjacent to a plain counterpart in Iraqi Arabic (Hassan, 1981). Alarifi (2010) found that F1, following an emphatic consonant in monosyllabic words, was significantly higher at vowel onset but not at midpoint or offset in /i:/ and /u:/. In the case of the low vowels /a/ and /a:/, however, F1 was significantly higher at onset and offset in both short and long low vowels. In contrast, other researchers found no significant effect on F1 as reported by Card (1983 on Palestinian Arabic), Norlin (1987 on Egyptian), and Bin-Muqbil (2006 on MSA). Although Alarifi (2010) reported a higher F1 in an emphatic context than in a plain counterpart in certain environments in Najdi Arabic, as pointed out above, Almuhaimeed (2021) concludes that F1 is not a reliable acoustic cue of emphasis in Najdi Arabic. Since emphasis involves the movement of the tongue back, as shown earlier (Section 3.2), F2 decrease is expected because the movement of the tongue to a back position entails F2 decrease (Kent et al., 1992). In this sense, F2 is an acoustic cue of the tongue backing. F2 lowering of adjacent vowels has been reported to be associated with emphasis more consistently than F1 raising as indicated by Watson (2002, p. 270) and Hassan (2005, p. 130), but we cannot deny that F1 could play a role in the emphatic-plain distinction.

The role of the third vowel formant (F3, henceforth) in the plain-emphatic distinction has not been considered as much as that of F2 and F1 in works on emphasis. For example, Norlin (1987) is among a few studies in which the role of F3 is examined, and he found no differences in F3 in open /a:/ between plain and emphatic contexts in Egyptian Arabic. Almuhaimeed (2021) examined the role of F3 in Najdi Arabic (NA), and she concluded that F3 is not a reliable acoustic cue of emphasis in NA. An earlier study on NA, however, shows that F3 can play a role in the emphatic-plain distinction for some vowels (Alarifi, 2010). Alarifi reported that F3 was not significantly raised in /i:/ and /a:/ at all vowel points after an emphatic consonant in NA; it was, however, significantly raised in /u:/ at onset and midpoint. Short /a/ shows a significantly higher F3 at vowel midpoint and offset after an emphatic consonant. Alarifi's results support the claim that the role of F3 can be associated with the vowel quality (Norlin, 1987). To sum up, the effect of emphasis on vowel formants is more evident in F2 (lowering), followed by F1 (raising),and then followed by F3 which is not examined as much as the other two formants in works on emphasis.

The behaviour of vowel formants in an emphatic context supports the fact that acoustic cues can reflect articulatory cues. The emphasis effect on vowel formants suggests that there is a coarticulatory effect between the consonant and the adjacent vowel. Ali and Daniloff (1972) and Hussain (1985) indicate that tongue retraction, involved in the production of an emphatic consonant, keeps its configuration during the articulation of an adjacent vowel. The first two formants can be acoustic cues to tongue height and backing; i.e., F1 increase suggests the movement of the tongue to a lower position and F2 decrease suggests its movement to a back position (Kent et al.,1992). This is consistent with Watson's (2002, p. 270) claim that F2 lowering is a more robust and consistent cue of emphasis than F1 rising.

An interpretation of the physiology behind F2 lowering and F1 raising could be provided by the activity of the genioglossus and geniohyoid muscles. They were found to play a role in the production of emphatic sounds. For example, Kuriyagawa et al. (1988), based on electromyographic (EMG) data in Standard Jordanian Arabic, report that the geniohyoid and the rear part of the genioglossus are active when producing plain /t/ and /s/ but less active when producing the counterpart emphatic /tˤ/ and /sˤ/; both muscles were found to be more active for the vowel immediately following the emphatic consonant. We might speculate that both muscles need to be activated to be able to perform the great effort needed for the tongue to be pulled forward (after being retracted) out of the pharynx during the production of the vowel following the emphatic consonant. As shown above (in Section 3.2), Watson (2002, p. 270) points out that the oral cavity is enlarged and the pharyngeal cavity is reduced through emphasis; this oral cavity enlargement gives the emphatic sound its so-called 'darkening' or 'heaviness' (Harrell, 1957). The mouth cavity enlargement and decrease in volume of the pharyngeal cavity result in F2 lowering and F1 raising, respectively, as explained by Watson (2002, p.270). Hence, F2 lowering as a main acoustic correlate of emphasis suggests that the oral cavity enlargement is the main articulatory correlate.

Finally, vowel duration can play a role in the effect of emphasis on vowel formants. Short vowels are more prone to the effect of emphasis effect than long vowels (Norlin, 1987; Rajouni et al., 1987; Engstrand and Krull, 1988). Long vowels have time to regain their steady state, unlike short vowels (Strange, 1989). Card (1983) and Norlin (1987) also suggest that the effect of emphatic consonants on long vowels is weakened as they have sufficient time to regain their steady state and formant values, due to their longer durations, while the effect can cover the whole short vowel. Alarifi (2010), however, reported that F2 was significantly lowered at onset, midpoint and offset in both short and long low vowels: /a/ and /a:/ in Najdi Arabic. Thus, the role of vowel duration on emphasis effect on vowel formants could be dialect specific.

Having discussed the vocalic correlates of emphasis and how emphatic consonants can affect the surrounding sounds, now we elaborate on that by discussing emphasis spread in the next section. It should be noted that although emphasis spread will not be examined (i.e., duration and formants of adjacent vowels will not be examined) in the current thesis, it is important to include this section to show that emphatic consonants can influence adjacent sounds since I am examining emphasis impact on consonant sequences in the current thesis. Besides, the findings on emphasis spread can help design the word list of this thesis, such as excluding segments that may block or weaken the impact of emphasis, as will be shown below.

3.4 Emphasis Spread

The process of emphasis spread is an articulatory effect according to Mustafawi (2006, p. 87). Hassan and Esling (2011, p.220), using Firth's prosodic terms (1957), state that the feature of emphasis is a prosody that is "extending over units that can encompass more than one segment" (p.220). Consonants that are adjacent to an emphatic can be pharyngealised, or the F2 of the adjacent vowel is lowered; these are the two main criteria that were used to determine emphasis spread in the literature. This section is divided into three main parts. The first two sub-sections will discuss the domain and directionality of emphasis spread. Sub-section 3.4.3 will be devoted to segments that can block emphasis spread.

3.4.1 Emphasis Spread domain

In most varieties of Arabic, when there is an emphatic phoneme, neighbouring sounds become emphatic as well. The domain of emphasis spread varies across Arabic varieties. While it rarely spreads beyond the adjacent vowel in Abha Saudi Arabic (Younes, 1991), it extends to cover the whole syllable in Iraqi Arabic (Hassan, 1981). Emphasis can also extend to cover the whole word in Cairene Arabic (Watson, 1999), in Qatari Arabic (Bukshaisha, 1985), in Palestinian Arabic (Davis, 1995) and in Najdi Arabic (Alfraikh, 2015; Almuhaimeed, 2021). Almuhaimeed (2021) reports that emphasis spread extends across morpheme boundaries; it covers prefixes and suffixes in Najdi Arabic. It has been also reported that emphasis can extend across the word boundary. Watson (1999) reports that emphasis spread can extend across a word boundary in Cairene, if the preceding word ends with a stop as in /wal<u>ad#tˤa</u>wi:l/ 'a tall boy'. Emphasis can also spread to the following word if the sequence is syllabified with preceding word as in /<u>ilʔu:dˤa#k</u>bi:ra/ 'the room is large' (Watson, 2002, p.274). Bukshaisha (1985) reports that emphasis can extend across the word boundary to the preceding word if the emphatic consonant occurs word-initially in Qatari Arabic.

According to Watson (2002, p.271), what determines the domain of emphasis spread is how dependent the secondary articulation is on the primary one. As pointed out earlier, the secondary articulation of oral emphatics depends on the primary articulation which restricts the pharyngeal constriction by adding tension to the dorsum of the tongue (Ali and Danilof, 1972; McOmber, 1996; Zemánek, 1996). This contingent relationship between the two articulations results in spreading of the [guttural] feature further from emphatics when compared to the true pharyngeals in which the [guttural] spread is local and restricted to adjacent short vowels.

Another point that may account for the varying domain of emphasis spread is the observation that emphatic consonants may be less pharyngealised in one Arabic variety than in another (Watson, 2002, p. 279). Also, an emphatic consonant, within the same variety, could be less pharyngealised than the others (e.g., Lehn 1963 for Cairene; Ghazeli 1977 for Tunisian). As pointed out earlier, it has been reported that different emphatic consonants may influence vowel formants differently. For example, Bin-Muqbil (2006) found that the F2 difference is statistically significant after /sˤ/ but not significant after /tˤ, dˤ, ðˤ/ in Modern Standard Arabic (MSA).

3.4.2 Emphasis Spread directionality

While a few studies report that emphasis can spread in both directions (rightward and leftward) without restrictions (e.g., Younes, 1993 for Egyptian Arabic), it has been reported that some Arabic varieties display an asymmetry between progressive (rightward) emphasis spread and regressive (leftward) emphasis spread. In general, leftward emphasis spread is reported in a number of Arabic varieties without restrictions (e.g., Younes, 1993 for Palestinian Arabic; Herzallah, 1991 for Northern Palestinian Arabic; Davis, 1995 for Southern and Northern Palestinian Arabic). It has been also reported that emphasis can spread across the word boundary in a leftward direction (Bukshaisha, 1985 for Qatari Arabic). Leftward spread can extend to the preceding word, if the emphatic is the initial consonant and the final consonant in the preceding word is a stop, as in /ʕidda<u>t#tˤurug</u>/ ‘a number of ways’ in San’ani Arabic (Watson, 2002). Most varieties of Arabic, on the other hand, observe that rightward emphasis spread is restricted (e.g., Younes, 1993 for Palestinian Arabic). For instance, it has been found that rightward emphasis spread is restricted to the following low vowel in Northern Palestinian Arabic (Herzallah, 1991; Davis, 1995). Zawaydeh (1999) reports that leftward emphasis spread is categorical whereas rightward emphasis spread is gradient in Ammani Jordanian. Zawaydeh (1998) claims that leftward spread is encoded in the phonological grammar since it is categorical, whereas rightward spread, being gradient, is due to phonetic factors.

Alhammad (2014) concluded that emphasis spreads across the syllable boundary in Najdi Arabic. Although she did not give details about formant values, she reported that F2 of the low vowel /a/ is lowered in both directions; however, F2 was not influenced by emphasis in the case of /i:/ and /u:/. Alfraikh (2015) examined only the low vowel /a/ and considered F1 and F2 at the vowel midpoint in Najdi Arabic. She found that in monosyllabic words, emphasis spreads in both directions to the same degree (F2 is lowered and F1 is raised). In disyllabic words, however, emphasis spreads in both directions but to different degrees (F2 is lowered and F1 is raised in both); i.e., leftward spread is greater whereas rightward spread is gradient. She concluded that emphasis spreads through the entire word (across syllable boundaries) similar to Alhammad (2014). Similarly, Almuhaimeed (2021) reports that emphasis can spread throughout the word in both directions whether the emphatic consonant occurs word-initially, medially or finally in Najdi Arabic.

The current thesis will consider the order of place of articulation when designing the word sets, as pointed out in Chapter 2. Thus, the emphatic coronal can occur as a C1 or as a C2 in a C1C2 sequence occurring word-initially, word-finally or across a word boundary. The emphatic coronal can occur after the potential inter-consonantal interval (ICI) (right) or before the potential ICI (left), if any, in these sequences.

3.4.3 Opaque segments

Another manifestation of the asymmetry between leftward and rightward emphasis spread is the observation that certain sounds resist the coarticulatory effect of emphasis and hence block emphasis spread in some varieties of Arabic. These will be referred to as 'opaque segments' throughout this section. Such segments may include /i, j, ʃ, ʒ, w, tʃ, dʒ/ depending on the variety. Younes (1993) found that in Palestinian, rightward spread can be blocked by /w/. Herzallah (1991) and Davis (1995) found that rightward emphasis spread can be blocked by /i, j, ʃ, w, u/ in Northern Palestinian. Davis (1995) found that, in Southern Palestinian, rightward spread is blocked by high front phonemes /i, j, ʃ, dʒ/. Hassan and Esling (2011) also report that /ʃ/ and /i/ can block, or at least weaken, emphasis spread in Iraqi Arabic. Rightward spread can be blocked by /i:/ in San'ani (Watson, 2002); it can also fail to extend into suffixes unless they immediately follow the emphatic. Alarifi (2010) concludes that rightward emphasis spread is greatly weakened by /i:/ and /u:/ in Najdi Arabic. Similarly, Alhammad (2014) reports that F2 is not influenced by emphasis in the case of /i:/ and /u:/ in Najdi Arabic. Alfraikh (2015) reports that rightward emphasis spread can be blocked by /i:, j, ʃ, dʒ / but not short /i/ in Najdi Arabic. Almuhaimeed (2021), a more recent study, found that /i:, i, u:, u, j, ʃ, dʒ/ can block emphasis spread in Najdi Arabic.

In contrast, a few studies did not find such segments to block emphasis spread. For example, Bukshaisha (1985) examined these potential blockers (opaque segments) in Qatari Arabic and found that they are transparent to emphasis spread; for example, in /i:/ in /naʃi:tˤ/ 'active', /e:/ and /j/ in /be:t#tˤa:jir/ 'flying home', emphasis spreads throughout the whole word in the former and both words in the latter. Zawaydeh and de Jong (2011) found that palatal sounds, including /j/, do not block emphasis spread in Ammani Jordanian Arabic. These results suggest that claims that such sounds act as blockers to emphasis spread is dialect specific.

These opaque segments, discussed above, may act as blockers to emphasis spread due to the different articulatory configurations the vocal tract adopts during the production of such sounds in an emphatic vicinity. Ghazeli (1977) found that /i/ and /i:/ block emphasis spread in Tunisian Arabic because, he explains, they involve a forward movement of the tongue that is contradictory to the retraction of the tongue dorsum that takes place during the articulation of emphatic consonants. Card (1983) suggests that sounds that have a high F2 frequency, including /i:, e:, ʃ, j/, can block the feature of emphasis from spreading. After concluding that rightward emphasis spread (triggered by a primary emphatic) can be blocked by [dorsal] vocoids (using Watson's terms), mainly /i, j/, whereas the leftward spread is unbounded in Cairene, Watson (2002, p.276) suggests that the two configurations of emphatic and [dorsal] are incompatible in the sense that the pharyngeal constriction of the emphatics cannot take place at the same time as the pharyngeal expansion of the [dorsal] vocoids. The [dorsal] vocoids, however, fail to block leftward emphasis spread in Cairene. Watson (2002, p.277) attributed this asymmetry to the differences in timing between the primary and secondary articulations. During the production of an emphatic coronal, the pharynx starts to narrow before the hold phase of the primary articulation, facilitating anticipatory emphasis spread; in this direction, the articulatory configuration involved for the pharyngeal constriction 'overrides' that for the [dorsal] vocoids. In the rightward direction, in contrast, the articulatory configuration involved for the [dorsal] vocoid production 'overrides' that of the emphatic. Due to their potential ability to block or weaken emphasis impact, these opaque segments will not be considered when designing the word sets of the current thesis.

3.4.4 Summary

This section discussed how emphasis can spread to affect surrounding consonants and vowels. It has been shown that if emphasis spreads, adjacent consonants are pharyngealized and the F2 of the adjacent vowels is lowered. The current thesis will examine the effect of emphasis on gestural overlap of consonant sequences, particularly the inter-consonantal interval (ICI: non-lexical vocoidal segments that occur between two consonants; in other words: the interval between two consonants in a sequence). Previous research examined the effect of emphasis on adjacent consonants impressionistically to find out whether these consonants are pharyngealized. Also, previous research examined the effect of emphasis on formants of adjacent vowels. This thesis focuses on the effect of emphasis on duration of adjacent consonants and the interval in between (ICI), an aim that has not been considered in previous studies. This thesis will also investigate variability of the inserted vowels by examining the ICI and how these inserted vowels interact with emphasis impact, if any. These inserted vowels will be discussed in detail in the next chapter (Section 4.8).

As mentioned above, this thesis will examine emphatic coronals occurring in different word positions (domain), with two orders of place of articulation: front-back and back-front (directionality);and segments that may weaken emphasis impact (opaque segments) will be excluded from the word list.

Gender will be considered in this thesis because it has been found in previous research that gender can interact with emphasis, as will be shown below. Thus, we turn now to discuss gender and emphasis in the following section.

3.5 Gender and Emphasis

In general, emphasis tends to be more exhibited in males' speech than in females' speech in Arabic (e.g., Lehn, 1963; Kahn 1975; Ahmed, 1979 for Cairene Arabic; Wahba, 1996 for Egyptian Arabic; Abudalbuh, 2010 for Jordanian Arabic; Alfraikh, 2015 for Najdi Arabic). Youssef (2013) suggests that emphasis, in general, is characteristic of masculinity and low social status,and emphasis in the speech of females is therefore less strongly pronounced. Harrell (1957, cited in Almuhaimeed, 2021) found that females realise /dˤ/ in /dˤalaal/ 'blacksliding' as /d/ in /dalaal/ in Cairene. He also found that /r/ in the word /raagil/ 'man' can be realized as plain /r/ or emphatic /rˤ/; he indicates that females pronounced it as plain /raagil/ more than males do.

The findings of the interaction between gender and emphasis, reported in the literature, are based on articulatory correlates or acoustic correlates. Al-Tamimi and Heselwood (2011) found, based on their nasoendoscopic data on Jordanian Arabic, that the degree of epiglottal retraction in an emphatic context was higher than that in a plain counterpart across gender. They, however, reported that the epiglottis was more retracted in males' speech than in that of females in an emphatic context. Based on their videofluoroscopic data, they report that males compress the pharyngeal space when producing an emphatic consonant more than females do. They speculate that such differences could be due to other factors in addition to gender, such as social class and geographical location (rural or urban), which were not considered in their study. Other researchers based their findings on acoustic correlates, mainly vowel formants and VOT. Omari and Jaber (2019) found that F2 lowering and F1 rising were greater in male speech than in female speech in Jordanian Arabic. Alzoubi (2017) found that F2 lowering was greater in males than females in Ammani Jordanian Arabic. He also found a similar effect of gender on VOT as an acoustic cue that contributes to the emphatic-plain distinction. Alfraikh (2015) examined /tˤ, sˤ, ðˤ/ in Najdi Arabic and she considered gender. She reported more emphasis in male than in females' speech. She found that F2 was more lowered in the speech of males than in that of females in mono and disyllabic words in both directions. She based her conclusion on data collected from four speakers (two males and two females).

Some researchers, however, report different results regarding gender differences. Although Kahn (1975) reported more emphasis in male than in female speech in Cairene Arabic, she found that Saudi female informants showed more emphasis than men. Al-Masri and Jongman (2004) found that F2 is more lowered in females' speech than in that of males in Jordanian Arabic, as spoken in northern Jordan. Almuhaimeed (2021) found that F2 lowering in an emphatic context was greater in the speech of females than in that of males in Najdi Arabic. Rifaat (2003) did not find differences in /tˤ/ vs /t/ VOT values between males and females in Egyptian Arabic. Therefore, gender differences could be dialect specific.

Other researchers report different gender effects on emphasis based on the manner of articulation of the emphatic consonants. Almbark (2008) reported variability in her results of gender interaction with emphasis in Syrian Arabic (four speakers from Damascus, southern dialect, and four from Aleppo, northern dialect of Syrian Arabic). She found that F2 lowering of the vowel following the emphatic stop was greater in female speech than in male speech, whereas F2 lowering of the vowel following the emphatic fricative was greater in male speech than in female speech. In this sense, part of Almbark's findings is consistent with previous studies reporting that emphasis is more exhibited in female speech (e.g., Almasri and Jongman, 2004 for Jordanian), whereas another part is consistent with previous studies reporting that emphasis is more exhibited in male speech (e.g., Khattab et al 2006,for Jordanian).

Other studies do not rule out factors, other than gender, that can play a role on the male-female distinction in emphasis as shown above (e.g., Al-Tamimi and Heselwood, 2011). Khattab et al.(2006) investigated vowel formant values and VOT values with regard to /tˤ/ vs /t/ in Jordanian Arabic. They reported that realisations of /tˤ/ were all perceptually rated as fully emphatic for all five male speakers and for only two out of five female speakers. This may indicate more emphasis in males' speech than in that of females. They, however, noted that their female speakers are from different areas in Jordan. Two, whose realisations of /tˤ/ were rated as fully emphatic, were from Irbid, northern Jordan, whereas the other three female speakers, whose realisations of /tˤ/ ratings varied, were from Amman, the capital city of Jordan. This could be attributed to gender, geographical location or an interaction of the two, as Khattab et al. (2006, p.154) inferred. In addition, they found that VOT values of /tˤ/ were significantly lower than those of /t/ across genders. Male speakers exhibited shorter /tˤ/ VOT values than those of /t/, compared to female speakers. The fact that their results seem incompatible with those of Al-Masri and Jongman (2004), who concluded that female speakers exhibited lower F2 values than males, could be accounted for on a geographical basis. All female speakers in Al-Masri and Jongman's study were from northern Jordan, whereas only two female speakers were from Irbid, northern Jordan, in Khattab et al's study, and it was only those two speakers whose realisations of /tˤ/ were all rated as fully emphatic. However, the other three female speakers, whose realisations of /tˤ/ ratings were varied, were from Amman. Thus the question whether the conditioning factor is the gender, geographical location, or an interaction of both, is still open (Khattab et al., 2006, p.157). Social class could also play a role in emphasis. Royal (1985) observed in her data from female Cairene speakers that less emphasis is produced by those who belong to a higher social class.

Overall, previous studies on gender differences reveal that gender, as a social factor, seems to predict contrast between emphatic and plain consonants in various varieties of Arabic. Regarding Najdi Arabic, there are two studies that considered gender as shown above. Both, however, report contradictory results. While Alfraikh (2015) found that F2 lowering in an emphatic context was greater in the speech of males than that of females, Almuhaimeed (2021) found that F2 lowering in an emphatic context was greater in the speech of females than that of males. Both studies recruited a similar number of speakers: four speakers (two males and two females) in Alfraikh (2015) and five speakers (two males and three females) in Almuhaimeed (2021). Alfraikh only examined F2 lowering, whereas Almuhaimeed examined several acoustic parameters, including the hold phase of a stop, frication noise of a fricative, VOT, adjacent vowel duration and formants (F1, F2 and F3). Almuhaimeed, however, did not find any significant differences between males and females in all these parameters, apart from F2 lowering as pointed out above. In general, gender appears to be a potential social factor that can interact with emphasis. There is still a need to consider gender to have a clearer view of its interaction with emphasis in Najdi Arabic. Accordingly, gender is considered in the current thesis,but I cannot formulate a hypothesis to predict whether the impact of emphasis, if any, will be more exhibited in the speech of males or in that of females in NA since there are contradictory results in the literature, particularly for NA. Gender is considered because the results of the current thesis will provide a clearer view of gender behaviour in relation to emphasis impact; it will be figured out whether the results of the current thesis will agree with those of Alfraikh or with those of Almuhaimeed.

3.6 Summary

This chapter focused on emphasis, discussing the different descriptions of the secondary articulation of emphasis. Two key terms were used to refer to emphasis – namely, pharyngealisation and uvularisation. Whether the secondary articulation is described as pharyngealization or uvularisation, it involves a tongue back/root gesture. It has been shown that the secondary articulation of emphasis adds more complexity (by adding a posterior gesture) to the production of emphatic coronals, compared to their plain counterparts. The main acoustic correlates of emphasis were discussed. A number of studies have reported durational differences between the emphatic consonants and their plain counterparts, mainly the hold phase and VOT, with a longer hold phase duration in the emphatic stop than in the plain counterpart, including Najdi Arabic. The VOT of /tˤ/ is shorter than the VOT of /t/ in a number of Arabic varieties, including Najdi Arabic.

It has been also shown how the emphatic coronals (tˤ, sˤ) differ from their plain counterparts (t, s respectively) in their state of the glottis, with a less open glottis during the production of the emphatic coronals than during the production of the plain counterparts. Therefore, it has been reported that /tˤ/ patterns with the voiced plain /d/ in the state of the glottis, compared to /t/; and /sˤ/ patterns with the voiced plain /z/ in the state of the glottis, compared to /s/.

The impact of emphasis on surrounding sounds manifests as emphasis spread. The domain and directionality of emphasis spread are variety specific. Certain sounds were found to block emphasis spread and they are variety-specific too. Gender was found to play a role in the impact of emphasis. Other factors such as social class and geographical location were discussed.

Having discussed timing relations in consonant sequences in Chapter 2 and emphasis in Chapter 3, the next chapter will be devoted to Najdi Arabic, which is the examined variety of the current thesis. To reiterate, the primary aim of this thesis is to investigate the impact of emphasis on gestural overlap of consonant sequences in Najdi Arabic.

4 Najdi Arabic

4.1 Brief introduction

This chapter will introduce Najdi Arabic (NA, henceforth), the variety that is the focus of the current thesis. As clarified in the introductory chapter, NA has been chosen to be the focus of the current thesis because there is evidence that both the place of articulation and the state of the glottis play a role in gestural overlap in NA (Alsubaie, 2014). In addition, NA permits consonant sequences occurring word-initially, word-finally and across a word boundary, unlike many other Arabic varieties, such as Cairene Arabic, which disallows word-initial clusters or Iraqi which disallows word-final clusters. Also, NA is the mother tongue of the researcher, so that designing the word list from NA will be easier for him than designing word lists from any other variety that is not his mother tongue.

This chapter is divided into ten sections. Section 4.1 is a brief introduction. A brief summary of the varieties of Arabic will be provided in Section 4.2. Section 4.3 will discuss the sub-varieties of NA as explored in previous studies. Section 4.4 will present a brief comparison of NA and Standard Arabic. Sections 4.5 and 4.6 will introduce the consonant and vowel inventories in Najdi. Section 4.7 will be devoted to the syllable structure and syllabification in Arabic varieties in general, and in NA in particular. In this section, it will be shown how word-initial and word-final clusters are created in NA and how the sonority sequencing can shape consonant clusters in NA, followed by a detailed account of the superheavy syllables and strategies employed to avoid trimoraic syllables that are problematic in Arabic. Then, a detailed discussion of Kiparsky's (2003) classification of Arabic dialects and the position of NA within this classification will be provided. Section 4.8 will discuss the types of vowel insertion (intrusive and epenthetic), followed by a summary of the chapter in Section 4.9. The chapter ends with a summary of the literature review of the current thesis and how to fill in the gaps identified in the literature in Section 4.10.

4.2 Varieties of Arabic

The Arabian Peninsula has been believed to be the origin of the Arabic language, particularly its central and northern parts (Watson, 2002, p.6). The spread of Arabic beyond the Peninsula is attributed to the rise and spread of Islam, which originated in the part of the Arabian Peninsula now known as Saudi Arabia, since Arabic is the language of the Islamic holy book, Qur'an (ibid, p.6). As pointed out in Chapter 1, Arabic language has a standard form and many regional varieties such as Cairene, Jordanian, Libyan and Moroccan Arabic dialects. In other regions of the world, other languages can be classified as standard or regional varieties.

Standard Arabic is used officially and taught formally in schools in Arab countries. Each Arab country has a number of varieties of Arabic which differ from each other. Some dialects are so different that they are not mutually comprehensible such as Kuwaiti and Moroccan Arabic. In addition, there are different varieties within the same country such as Hijazi and Najdi in Saudi Arabia. This diglossic situation in the Arab world, and in Saudi Arabia in particular, was discussed in detail in Chapter 1 (see Section 1.3 for more details). In general, three terms have been frequently used in the literature to refer to the standard form of the Arabic language; these are Standard, Classical and Modern Standard Arabic. Standard Arabic (SA), will be used throughout this thesis to refer to the standard language in general; and Classical Arabic (CA), will be used to refer to old Arabic (the language of Qur'an) where relevant.

4.3 Sub-varieties of Najdi Arabic

Early works on NA include that of Lehn (1967), who investigated Najdi as spoken in Shaqra and Riyadh, Johnstone (1967) who based his findings on Unaiza, Abboud (1964, 1979) who focused on Ha'il which is located approximately 600 km to the north of Riyadh, and Prochazka (1988) who focused on Riyadh, Qassim, Najran and Bisha. These studies were restricted to either one tribe or a specific area in Najd with none being representative of all areas in Najd.

Ingham restricted his early research to the dialects of the Dhafir tribe (1982) and the Al Murrah tribe (1986, 1991). Ingham (1994) provides a more comprehensive account of NA as used in Northern, Central and Southern Najd. He examined the three varieties of NA syntactically, morphologically and phonologically. He found that they mainly differ in morphology, such as object pronoun suffixes as in /kta:bik/ 'your book (sg.m.)' in central Najd versus /kta:bak/ in northern Najd. Although such features may lead to considerable differences between the sub-varieties in terms of syllabification, Ingham concluded that they generally share phonological features. The findings of recent studies focused on central Najd (e.g., Alghmaiz 2013, Alqahtani 2014) support Ingham's analysis. This thesis will also focus on central Najd, as spoken in Riyadh and the Alaflaj governorate, located about 280 km to the south of Riyadh as shown in Figures 4.1 and 4.2. This is the researcher's mother tongue; accordingly, the researcher can judge whether a phonological feature or process can occur in central Najd or not.

Figure 4.1 Map of main regions of Saudi Arabia. Riyadh region, where Najdi Arabic is spoken, is located in central Saudi Arabia (from d-maps.com).

Figure 4.2 A zoomed in map of Riyadh region. The circled city (Layla) is the main city of Alaflaj governorate, which is located to the south of Riyadh, the capital city (from d-maps.com).

4.4 Najdi Arabic and Standard Arabic

NA shares a number of features with Standard Arabic (SA, henceforth), when compared to other Arabic varieties. Johnstone (1967, p.1), Abboud (1979, p.33) and Ingham (1994, p.5) observe that NA exhibits some features of SA. It has /ðˤ/ which does not exist in other Arabic varieties, such as Cairene and Lebanese. It also exhibits the *-in* suffix, which is used to express indefinite nouns and adjectives, and is similar to *tanwīn* in SA, as in /kta:.bin/ 'a book' and /bin.tin/ 'a girl'. The particle *gid* functions similarly to the SA *qad*. NA exhibits several innovations as well. Although there are similarities between NA and SA, it should be made clear that the SA form is not assumed to be the underlying form of NA lexical items. SA and NA are different; they have different phonological rules. It should be noted that throughout this chapter, examples of SA are provided as opposed to examples of NA only to clarify a phonological feature that exists in NA.

A number of features that distinguish NA from SA and other Arabic varieties include the fronting of /k/ to [ts] as in /kibi:r/ [tsibi:r] 'old,sg,m', and the *b-* prefix used to mark future, as in NA /b-ta:kil/ 'she will eat' as opposed to SA /sa-taʔkul/. /k/ fronting will be discussed in detail in the next section. For the sake of the purpose of the current study, only phonological features will be our concern.

4.5 Najdi Arabic Consonants

As indicated by Watson (2002, p.14), Arabic varieties spoken in the Arabian Peninsula seem to share most characteristics of the phoneme inventory of SA. NA shares the whole consonant phoneme inventory of SA except /dˤ/ which merged with /ðˤ/ as in NA /ðˤala:l/ as opposed to SA /dˤala:l/ 'illusion'. Table 4.1 shows the NA consonantal phoneme inventory.

Table 4.1 Consonantal Phoneme Inventory in Najdi Arabic (from Alfaifi, 2019).

	Bilabial	Labio-dental	Dental	Alveolar	Alveo-palatal	Palatal	Velar	Uvular	Pharyngeal	Glottal
Stop	b			t d tˤ			k g	q		ʔ
Fricative		f	θ ð ðˤ	s z sˤ	ʃ			χ ʁ	ħ ʕ	h
Affricate				(ts)	dʒ					
Nasal	m			n						
Lateral				l						
Flap				r						
Glide	w					j				

As in Table 4.1, the uvular /q/ is attested in NA,but is restricted to words borrowed from SA and religious terminology, as in /qurʔa:n/ ‘Qur’an’ and /qalʕah/ ‘castle’; elsewhere it has the reflex /g/ as in NA /ga:l/ as opposed to SA /qa:l/ ‘he said’. Glottal /ʔ/ occurs in NA but is restricted to intervocalic position, as in /saʔal/ ‘he asked’. Interestingly, intervocalic /ʔ/ is often realized as pharyngeal [ʕ] by some NA speakers, particularly by uneducated people, as in /suʔa:l/ [suʕa:l] ‘question’ (Ingham 1994, p.14).

As pointed out earlier, the velar /k/ is often fronted to [ts] as in /kibi:r/ [tsibi:r] ‘big’ and /g/ can be fronted to be [dz] as in /gidir/ [dzidir] ‘pot’. As Johnstone (1967, p.2) shows, they generally occur in the context of front vowels as in /gili:b/ [dzili:b] ‘a well’ and in /kibi:r/ [tsibi:r] ‘big’, but not /ʃo:g/ *[ʃo:dz] ‘nostalgia’. Such processes might be subject to social factors such as age, gender and education as Al-Rojaie (2013) suggests for the affrication of /k/ in Qaṣīmī (see Al-Rojaie 2013 for more details). Al-Essa (2009) indicates that /k/ fronting is associated with two behaviours in NA: /k/ is fronted to [ts] in the environment of front vowels when occurring in the stem as in /kibi:r/ [tsibi:r]; accordingly, she describes /k/ affrication here as a phonological feature; on the other hand, /k/ is fronted in the 2nd person fem. pronoun when suffixed to the stem word as in /be:tits/ 'your (sg.f.) house'; this type of affrication is described as a morphophonemic feature. Accordingly, /ts/ is included in the NA consonantal inventory since /k/ and /ts/ can occur in a minimal pair as in /be:tik/ 'your (sg.m) house' ~ /be:tits/ 'your (sg.f.) house'. The morphophonemic variable can be also fronted in the context of back vowels as in /ʤo:ts/ 'they came to you (sg.f.)'. It seems that /k/ fronting as a phonological feature is also constrained by word position. This could account for /k/ in a word like /bta:kil/[18] 'she will eat' which does not undergo fronting. /k/ fronting has been also reported in other Arabic varieties such as Jordanian and Iraqi,but in this case results in [tʃ] in the context of front vowels (Watson, 2002, p.17), in a similar environment to /k/ fronting in NA. /k/ fronting in Arabic varieties needs further research to have a comprehensive account of this behaviour which is beyond the scope of the present study.

Since the velar /g/ is included in the word list of the current thesis, the word list is designed to position /g/ in an environment where it is not expected to be fronted to [dz]. For example, /g/ in /baag#saalim/ 'he robbed Salem' occurs in the vicinity of the low vowel /a/, where /g/ is not expected to be fronted to [dz]. This is one of the main reasons why the data of the current thesis were chosen to be elicited, similar to previous relevant studies, over spontaneous speech in order to control such considerations (more details about the choice of the elicited scripted speech over spontaneous speech will be provided in Chapter 5, which concerns the methods of the current study).

The lateral /l/ has an emphatic counterpart [lˤ], but is restricted to the word /ʔalˤlˤa:h/ 'God' on its own or in phrases, as in /ʔinʃa:lˤlˤah/ 'God's willing' and in /jalˤlˤah/ 'let's go' as in many other Arabic varieties. /r/ may be pharyngealized when adjacent to /u/, as in [grˤu:ʃ] 'coins' and [murˤrˤ] 'bitter' similar to Bedouin Hijazi Arabic (Al-Mozainy, 1981, p.26). Several other Arabic dialects have emphatic /r/ as a marginal phoneme, such as Cairene (Watson, 2002, p.10).

For the purpose of the current thesis, the consonants that will be examined include the bilabial stop /b/, the alveolar stops /tˤ, t, d/, the velar stop /g/, the alveolar fricatives /sˤ, s, z/, and the dental fricatives /ðˤ, ð/ in different word positions. The rationale for including these consonants and for designing the word list will be briefly explained at the end of the current chapter, when showing how this thesis will fill in the gaps identified in the literature. More details about the word list will be provided in Chapter 5, which concerns the methods of the

[18] This word is included in the thesis data.

current study. Having introduced the consonant inventory in NA, the following section will introduce the vowel inventory.

4.6 Najdi Arabic Vowels

NA has eight vowels: five long (i:, u:, a:, e:, o:) and three short (i, u, a) (Alqahtani, 2014). The Standard Arabic diphthongs generally have the reflex /e:/ in NA, which corresponds to SA /aj/ as in /be:t/ as opposed to SA /bajt/ 'house', and /o:/ which corresponds to SA /aw/ as in /lo:n/ as opposed to SA /lawn/ 'colour' similar to many Arabic varieties. However, /aw/ does occur in NA in word-final position as a masculine plural marker as in /ra:ħaw/ 'they went' and /ga:law/ 'they said' (Johnstone, 1967, p.2), where it does not correspond to SA /aw/. Rather, /aw/ in NA is the reflex of the SA *-u:* masculine plural marker, as in (1) below, whereas /aw/ in SA is always substituted with /o:/ as in /go:l/ as opposed to SA /qawl/ 'saying' and in /lo:ħah/ as opposed to SA /lawħah/ 'board'.

(1)

Najdi Arabic	Standard Arabic	
ga:law	qa:lu:	'they m. said'
ra:ħaw	ðahabu:	'they m. went'

Similar to relevant studies (e.g., Alsubaie, 2014; Shitaw, 2014; Plug et al, 2019), the current thesis will only consider the low vowels /a/ and /a:/ in all word sets, for consistency (see Chapter 5). In the context of emphatics, /a:/ is backed to [ɑ:] in NA (Johnstone 1967, Alfraikh 2015). The impact of emphasis on vowels was discussed in Section 3.3.2.

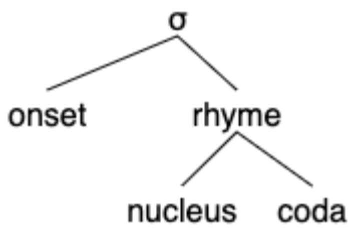
Following this discussion of NA consonants and vowels, the next section is concerned with the syllable structure and syllabification in Arabic and in NA. Since the current thesis examines consonant sequences in Najdi Arabic, it is important to discuss the syllable structure and syllabification, and particularly the status of word-initial and word-final sequences.

4.7 Najdi Arabic syllable structure and syllabification

4.7.1 Introduction

Before discussing syllable structure, it should be noted that Moraic Theory (Hayes, 1989) and Constituency Theory will be followed to represent the syllable structure in this thesis. According to Bosch (2011), the Constituency Theory is the most common view that is widely followed in the analysis of syllable structure. According to the constituency model, the syllable consists of arranged constituents (onset, nucleus and coda) (Davis, 1986; Selkirk, 1982). Two main approaches are suggested to represent the order of constituents in a syllable in this theory: flat structure and hierarchical structure. The hierarchical structure, as shown in Figure 4.3, will be employed in the syllable structure analysis in this study because it is more common and widely used, compared to the flat structure (Bosch, 2011; Fudge, 1969; Selkirk, 1982).

Figure 4.3 The hierarchical structure of the syllable. The syllable consists of the arranged main constituents (onset, nucleus and coda).



As in all Arabic varieties described to date, the onset in Najdi Arabic (NA) must have at least one consonant and the syllable can be open or closed. The minimum syllable is CV. Clusters of two consonants are tolerated in NA both word-initially and word-finally. Table 4.2 shows all possible syllable types that occur in NA according to Abboud (1979), Ingham (1994) and Alqahtani (2014). The superheavy syllables (CVVC, CCVC, CVCC and CCVVC) are problematic in Arabic varieties. These types of syllables will be discussed in detail later in the current chapter in sub-section 4.7.5.

Table 4.2 All possible syllable forms of NA

Type	Example ('.' is a syllable boundary)	Syllable weight
CV	ʃa.ra 'he bought'	light
CVV	sa:.lim 'Salem'	heavy
CVC	galˤ.bah 'his heart'	heavy
CVVC	ʃa:l 'scarf'	superheavy
CCVC	btal.ʕab 'she will play'	superheavy
CVCC	galˤb 'heart'	superheavy
CCVVC	kta:b 'book'	superheavy

There is a complex relationship between short vowels and syllable structure in NA. Ingham (1994, p.18) reports that high short vowels, /i/ and /u/, may occur in non-final open syllables, while the low short vowel /a/ can occur in closed syllables, as in /ki.tab/ ‘he wrote’, /kti.bat/ ‘she wrote’, and in /glu.bat/ ‘she turned’. When a guttural occurs in an open syllable, however, the low short vowel /a/ can occur before or after the guttural (AL-Sweel, 1990, pp. 76-7), such as /ħa.mal/ ‘he carried’, /χa.latˤ/ ‘he mixed’ and /ta.ʕab/ ‘he got tired’. NA native speakers, however, produce words like /ga.lab/ ‘he turned’ and /ʃa.rab/ ‘he drank’ in which /a/ occurs in non-final syllables without a guttural. Accordingly, sonorants may behave like gutturals in this process. This view might be supported by Abboud’s (1979) account of the two phonological processes, low vowel deletion (LVD) and low vowel raising (LVR), in NA. He observed that a word such as /ka.tab/ ‘he wrote’, in which low short vowels occur, can undergo both processes when adding a suffix with an initial vowel as in (2-a) below:

(2)

(a) /ka.ta.baw/ → /kta.baw/ (LVD) → /ktibaw/ (LVR) ‘they wrote’.
(b) /sa.ka.naw/ → /skanaw/ (LVD) ‘they dwelled’, where /aw/ is the suffix.

The LVR rule, however, does not operate in (2-b) above. Although he does not account for this, it could be inferred that LVR cannot be applied when adjacent to a sonorant, in this case /n/ in /sakanaw/. The environment in which this process can be at work needs further research which is beyond the scope of the current study.

Vowels can be shortened in verbs that have a stem-internal long vowel (CVVC), generally referred to in the literature as ‘hollow verbs’. They are described as hollow because they have a glide in the second position of the word stem which is substituted by a vowel, /a:/ in the 3rd person in the perfect form as in /za:d/ ‘it increased’, and /i:/ in the imperfect form as in /jizi:d/ ‘it increases’. It also becomes /u:/ in the imperfect form if the stem glide is /w/ as in /jigu:l/ ‘he says’ (see Chekayri, 2007, pp. 166-7 for more details). Vowels are shortened when followed by a subject suffix (-t, -ti, -tu, -na). Low vowel /a:/, after being shortened, is raised to [i] as in /ga:l+t/ [gilt] ‘I said’, in /ga:l+ti/ [gilti] ‘you said, sg.f.’, in /ga:l+tu/ [giltu] ‘you said, pl.’, and in /ga:l+na/ [gilna] ‘we said’.

Having introduced the syllable forms and the relationship between vowels and syllable structure in NA, the following sub-sections will discuss consonant sequences in NA, as these will be examined in the current thesis. It is worth discussing the Sonority Sequencing Principle and how it shapes the structure of consonant sequences in NA. Then, how word-initial and word-final clusters are created in NA will be explained, followed by a discussion of the superheavy syllables and strategies employed to avoid trimoraic syllables that are problematic in Arabic. After that, Kiparsky’s (2003) classification of Arabic varieties will be discussed. After having an overview of the consonant sequences in NA and Kiparsky's classification, the position of NA within Kiparsky's classification will be discussed.

4.7.2 Sonority Sequencing Principle (SSP)

The sonority sequencing principle (SSP, henceforth) suggests that the vowel, which is the nucleus, is the most sonorant segment in the syllable and the margins of the syllable are less sonorous than the vowel (Clements, 1990). Several sonority scales have been proposed (e.g., Selkirk 1984; Clements 1990; Parker 2008). The sonority scale as suggested by Selkirk (1984) and Clements (1990) is presented in Figure 4.4:

Figure 4.4 Sonority Scale (Selkirk, 1984; Clements, 1990)

(most sonorous) Vowels → Glides → Liquids → Nasals → Obstruents **(least sonorous)**

In two consonant clusters, the consonant immediately adjacent to the vowel should be more sonorous than the peripheral consonant. In initial clusters (C1C2V), C2 should be more sonorous than C1; and in final clusters (VC1C2), C1 should be more sonorous than C2. Accordingly, the sonority pattern is described as rising sonority in an initial cluster and as falling sonority in a final cluster. The SSP can be violated in two ways according to Clements (1990) and Carlisle (2001): plateau sonority (equal in sonority) and sonority reversal. An epenthetic vowel is inserted as a 'repair mechanism' for sequences that violate the SSP. Violation of the SSP is a common motivation of epenthesis in Arabic varieties, such as word-final clusters in Lebanese (Abdul-Karim, 1980) and in Madinah Hijazi Arabic (Jarrah, 1993). In general, word-initial clusters that violate the SSP are tolerated in NA, whereas word-final clusters that violate the SSP are broken up by vowel epenthesis (Alqahtani, 2014; Alfaifi, 2019). /bint/ 'girl', /bard/ 'cold', /barg/ 'lightning' and /kalb/ 'dog' obey the SSP in Najdi Arabic (NA). Where sequences violate the SSP, an epenthetic vowel is inserted as in /ħukm/ [ħuku̲m] 'decree', /baħr/ [baħa̲r] 'sea'. When word-final clusters are followed by vowel-initial suffix, they are not broken up by epenthesis even if they violate the SSP as in /ħabl+ah/ [ħablah] *[ħabi̲lah] 'his rope' (Alhammad, 2018, p.32).

According to Clements (1990), syllables that obey the SSP are preferred by all languages. There are, however, exceptions, i.e., clusters that violate the SSP occur in many languages, when they involve sequences of /s/ or /z/ plus following stop, such as the Oujda dialect of Moroccan Arabic word [sbulha] 'her ear' (Shaw et al., 2011), in which [sb] occurs word-initially, and this violates the SSP following Clements' sonority scale (see Figure 4.4). As discussed in Chapter 2, when discussing the C-Centre organization, such clusters have been investigated by

Shaw et al and they attributed that exception to the different affiliation of initial clusters; i.e., complex onset and simplex onset. They examined whether initial clusters in Moroccan Arabic exhibit the complex onset or the simplex onset using Electromagnetic Articulography. They conclude that initial clusters in Moroccan Arabic affiliate into two syllables as in [s.bulha] (simplex onset view). The SSP cannot be operative in this Moroccan Arabic word, i.e., the word-initial cluster, since the consonants in the initial cluster (/s/ and /b/) do not belong to the same syllable. A number of views have been proposed to account for some exceptions in some languages such as [s] in word-initial clusters as in English, including extrasyllabicity (Vaux and Wolfe, 2009) and degenerate syllables (Selkirk, 1981; Goad, 2012). Kiparsky (2003) analysed the consonant that does not belong to the same syllable of the adjacent consonant in the sequence, as a semisyllable (a mora unaffiliated with syllable). Kiparsky's account of semisyllables will be discussed in detail in Section 4.7.5.

It can be claimed that sonority sequencing cannot provide a full account for how word-final clusters surface in Arabic dialects. Farawaneh (2016) found that sonority sequencing cannot explain some permitted word-final clusters in Palestinian Arabic. In NA, /bs/ in /ħabs/ 'jail' is not broken up by epenthesis in NA although both /b/ and /s/ are obstruents (plateau sonority, following Clements' sonority scale). Such exceptions can, however, be accounted for by the sonority scale suggested by Parker (2008) who introduced a modified and more comprehensive sonority scale, presented in Figure 4.5

Figure 4.5 Modified Sonority Scale (Parker, 2008)

(More sonorous)

Low vowels
Mid vowels
High vowels
Glides
Liquids
Nasals
Voiced fricatives
Voiced affricates
Voiced stops
Voiceless fricatives
Voiceless affricates
Voiceless stops

(Less sonorous)

This modified scale can account for clusters such as /bs/ in /ħabs/ 'jail' because voiced stops are more sonorous than voiceless fricatives. Alfaifi (2019) examined word-final clusters in NA, and he concluded that word-final clusters with rising sonority violate the sonority sequencing, following Parker's scale. Accordingly, Parker's scale is a more reliable scale in the sense that it accounts for observed clusters in NA, compared to Clements's scale.

As shown above, /sb/ is a violation of the SSP in Moroccan Arabic. This is based on Clement's scale in which /s/ and /b/ form a plateau sonority (obstruent-obstruent). This seems to support the claim that scales of sonority should be language-specific (Haddad, 1984; Davis, 1990). Although the SSP has been considered as universal by some authors (e.g., Clements, 1990), it cannot account for all syllable structures. Therefore, some authors claim that some other phonetic factors (non-sonority factors) can better account for consonant clusters (Davidson, 2010).

In general, word-initial clusters that violate the SSP are tolerated in NA, while word-final clusters (with rising sonority) violate the SSP (based on Parker's scale), and thus are broken up by vowel epenthesis (Alqahtani, 2014; Alfaifi, 2019)[19]. This thesis will examine obstruent-obstruent sequences, such as /bd/, /db/, /bz/ and /zb/, occurring word-initially and finally. This thesis will also examine /btˤ/, /bt/, /tˤb/, /tb/, /bsˤ/, /bs/, /sˤb/ and /sb/ sequences, occurring word-initially (#CC), word-finally (CC#) or across the word boundary ((C)C#C(C)) in NA. Following Alqahtani (2014) and Alfaifi (2019), the sequences that are expected to be broken up by an epenthetic vowel, in the current thesis, include /bz#/, /tˤb#/, /tb#/, /sˤb#/, and /sb#/ in a word-final position. It can be noted that all are in back-front place order, except /bz#/ which is in front-back place order. Place order may also affect clusters: Alfaifi (2019, p.130) found that back-front word-final clusters tend to be broken up by an epenthetic vowel in NA,but he did not do any statistical analysis to validate this claim because it was not an aim of his study. The order of place of articulation (front-back vs back-front) and the laryngeal specification (voiced vs voiceless) will be considered in the current thesis. Therefore, the current thesis will provide a more comprehensive view of consonant sequences in NA.

Having introduced the SSP and its role in shaping the structure of NA consonant clusters, now we turn to discuss how word-initial and word-final clusters are created in NA.

[19] More examples will be provided in the next sections.

4.7.3 Word-initial clusters in Najdi Arabic

As shown in Table 4.2 above, NA permits word-initial clusters unlike Standard Arabic (SA) in which initial clusters are prohibited (Al-Ani, 1970, p.78). According to Abboud (1979), Ingham (1994), Alghmaiz (2013) and Alqahtani (2014), word-initial clusters in NA can be created by two ways. First, high vowels /i, u/ do not occur between two word-initial consonants as in /kta:b/ 'book' and /flu:s/ 'money', unlike other Arabic varieties that allow high vowels /i, u/ to occur in an unstressed open syllable as in Cairene Arabic /ki.ta:b/ 'book' and /fu.lu:s/ 'money'. This phenomenon is referred to as *high vowel deletion* in the literature of Arabic varieties (Alqahtani, 2014). Unlike Cairene and other Arabic varieties that allow the low vowel /a/ to occur in a light syllable when followed by another light syllable as in Cairene /ba.ʔa.rah/ 'cow', the low vowel /a/ does not occur between two word-initial consonants when followed by a light syllable as in /bga.rah/ 'cow' in NA. Alqahtani (2014) suggests that NA tends to reduce the number of light syllables unlike Cairene; this process has been referred to as *trisyllabic elision* by Rakhieh (2009) when he observed a similar behaviour in Ma'ani Arabic, as spoken in southern Jordan, and it is more frequent at a fast speech rate. Alqahtani (2014), however, notes that NA speakers produce words like /ma.li.kah/ 'queen', where (.) is a syllable boundary, in which the low vowel /a/ occurs in a light syllable, followed by another light syllable. He attributed that to the Standard Arabic phonology by which such words are governed because this only occurs in loan words from SA.

Short vowels do not occur in a non-final light syllable in NA (Ingham, 1994; Alqahtani, 2014); this may create a word-initial cluster as in /kti.bat/ 'she wrote' as opposed to the Cairene /ka.ta.bit/. A short vowel does not also occur when followed by a CVVC syllable as in /tsˤu:m/ 'you fast, sg.m.' and in /dmu:ʕ/ 'tears' as opposed to Cairene /tu.sˤu:m/ and /du.mu:ʕ/ respectively (this phenomenon is reported in Bedouin Hijazi Arabic by Al-Mozainy, 1981; and in San'ani by Watson, 2002). Besides, short vowels do not occur when followed by CVV or CVG, where G is a geminate, as in /tsa:.miħ/ 'you forgive, sg.m.' and in /tmaθθil/ 'you act, sg.m.' as opposed to the Cairene /ti.sa:.miħ/ and /ti.massil/ respectively (this behavior has been reported in Aljabal dialect of Libyan Arabic, as spoken in Al-Jabal Al-Gharbi in Libya, by Harrama, 1993). Having discussed the first way of creating word-initial clusters in NA, now we discuss the second way: CV-metathesis, below.

CV-metathesis is another process in NA by which word-initial clusters can be created. It is triggered by gutturals in non-word-final position (AL-Sweel, 1990), as in /gahwah/ [ghawah] 'coffee', /naχlah/ [nχalah] 'palm tree' and /taʁris/ [tʁaris] 'she planted'. This process has been referred to as the *Gahawa syndrome* by Blanc (1970; cited in De Jong, 2007, pp. 151-3) and as

Guttural Resyllabification by Ingham (1994, p.19). The emphatics, by contrast, do not trigger CV metathesis (Alqahtani, 2014, p.238) as in /matˤ.baχ/ *[mtˤa.baχ] 'kitchen'.

As in SA (Haddad, 2005), some word-initial clusters in NA seem to be broken up by prosthesis, particularly verbs of the imperative form. Alqahtani (2014, p.11) reports that a glottal stop has to precede the prosthetic vowel in order to avoid onsetless syllables that are not permitted in NA as in /ʤmaʕ/ [ʔiʤdmaʕ] 'collect! (sg.m)'. A similar process has been reported in Ma'ani Jordanian Arabic (Rakhieh, 2009) and Urban Hijazi Arabic (Al-Mohanna, 1998). In addition, such process can be applied to the perfect forms VII, VIII and X (Abboud, 1979) as in /nkisar/ [ʔinkisar] 'it got broken' and in /ktitab/ [ʔiktitab] 'he got registered' (Abboud, 1979) (see McCarthy, 1981, pp. 384-5 for verb forms in SA).

Geminates are not permitted in word-initial position, as in the majority of Arabic varieties (Boudlal, 2001, Kiparsky, 2003, Watson, 2007). However, prosthesis can be motivated by an initial geminate resulting from coronal assimilation in NA as in (3):

(3)

a) /ti.dar.ris/ → /t.dar.ris/ → /ddar.ris/ → /ʔiddarris/ 'you teach, sg.m.'

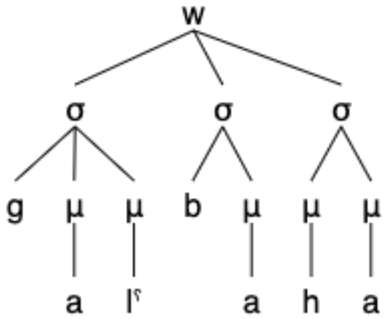
b) /tizahhib/ → /tzahhib/ → /zzahhib/ → /ʔizzahhib/ 'you prepare, sg.m.' (from Alqahtani, 2014, p.177).

4.7.4 Word-final clusters in Najdi Arabic

As pointed out in Section 4.7.2 above, word-final clusters are tolerated in Najdi Arabic as shown in Table 4.2 above but they can be broken up by vowel epenthesis if they violate the SSP (Alqahtani, 2014; Alhammad, 2018; Alfaifi, 2019).

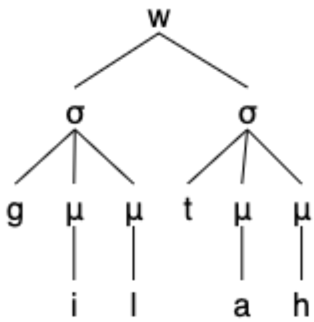
Superheavy syllables in Arabic (CVVC and CVCC) occur word-finally as in /mif.taːħ/ 'key', but are not tolerated in a non-final position in the word in the majority of Arabic varieties (Kiparsky, 2003, Watson, 2007). Watson (2007) used CVXC to refer to these superheavy syllables, where X can be a consonant or a vowel. When morphological concatenation creates an internal CVXC syllable, two solutions are proposed: mainly vowel epenthesis or mora sharing (these superheavy syllables will be discussed in detail in Section 4.7.5). An epenthetic vowel is inserted to avoid superheavy syllables occurring in a non-final position in NA similar as in Taif Arabic, spoken in Taif city in the western region of Saudi Arabia (Al-Mohanna, 1994). When a CVC1C2 syllable is followed by a suffix with an initial consonant in NA, the epenthetic vowel is likely to appear after C2 as in /galˤb+ha/ [galˤba̲ha] 'her heart', as shown in Figure 4.6.

Figure 4.6 When a CVC1C2 syllable is followed by a suffix with an initial consonant in Najdi Arabic, the epenthetic vowel appears after C2 as in /ɡalˤb+ha/ [ɡalˤbaha] 'her heart'.



When a CVC1C2 syllable is followed by a suffix with an initial vowel, there is no need for epenthesis because C2 will be affiliated as the onset for the following vowel, as in /gilt+ah/ [gil.tah] 'I said that' (Alhammad, 2018, p.32) as shown in Figure 4.7.

Figure 4.7 When a CVC1C2 syllable is followed by a suffix with an initial vowel, there is no need for epenthesis because C2 will be affiliated as an onset for the following vowel as in /gilt+ah/ [gil.tah] 'I said that'.



The quality of the epenthetic vowel, in final clusters (CVC1C2), broadly seems to be a copy of the stem vowel as in /ħukm/ [ħukum] 'decree' and in /nahr/ [nahar] 'river'. Alqahtani (2014, p. 194), however, noted exceptions such as /ʕagl/ [ʕagil] 'mind', /fasˤl/ [fasˤil] 'class' and /sˤabr/ [sˤabur] 'patience'. He uses the feature [+phar] to account for these exceptions. He attributed this behaviour to the quality of both final consonants. If C1 is not [+phar] in the context of /a/ and C2 is /l/ as in /ʕagl/ and in /fasˤl/, the epenthetic vowel is /i/; if C2 is /r/ as in /sˤabr/, the epenthetic vowel is /u/. He excluded emphatic sounds from having the [+phar] feature in this particular case. Alhammad (2018, p. 64), however, provides another interpretation. She suggests that vowel harmony is blocked if it will result in changing the syntactic category of the word. For example, [ʕagil] 'mind' is a noun but [ʕagal] 'he became wise/mindful' is a verb. More examples are provided in (4) below:

(4)

Noun:		**Verb:**	
fasˤi̲l	‘class’	fasˤa̲l	‘he quit’
sˤabu̲r	‘patience’	sˤaba̲r	‘he became patient’

To avoid this issue, a different vowel quality is inserted: /i/ or /u/; hence, /ʕagl/ [ʕagi̲l] ‘mind’, /fasˤl/ [fasˤi̲l] ‘class’ and /sˤabr/ [sˤabu̲r] ‘patience’.

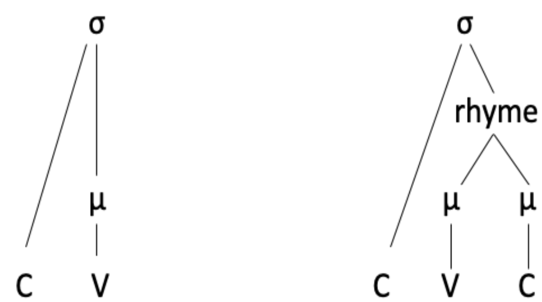
Based on the above discussion, it can be inferred that clusters in NA behave differently according to position. Word-initial clusters occur in NA because high vowels do not occur between two word-initial consonants, a process that is referred to as *unstressed vowel deletion* in the literature (Alqahtani, 2014). Another process for creating word-initial clusters is CV-metathesis. These clusters tolerate the SSP violation in the sense that they are not broken up by epenthesis. Word-final clusters that violate the SSP, on the other hand, can be broken up by epenthesis in NA, as in /baħr/ [baħa̲r] ‘sea’, and in /ħabl/ [ħabi̲l] ‘rope’ but /gilt/ ‘I said’ *[gili̲t] and /ħilm/ ‘dream’ *[ħili̲m].

Having discussed word-initial and word-final clusters in NA and how the SSP can shape their structure, now we turn to discuss the superheavy syllables that are prohibited in Arabic.

4.7.5 Superheavy syllables

Syllable weight is another constraint that plays a role in shaping consonant clusters, in addition to the sonority sequencing. Syllable weight is determined by the number of moras in the syllable (McCarthy, 1979; McCarthy and Prince, 1990). Hence, a light syllable has a single mora (monomoraic syllable) and a heavy syllable has two moras (bimoraic syllable), as illustrated in Figure 4.8.

Figure 4.8 The diagram to the left represents a light syllable, whereas the diagram to the right represents a heavy syllable

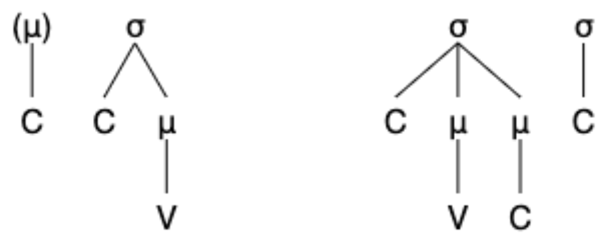


Both are allowed in Arabic. According to the bimoraicity constraint (Broselow, 1992), bimoraic syllables are permitted as the maximum weight of the syllable in Arabic. The superheavy syllables (CVVC [raaħ] 'he left' and CVCC [galˁb] 'heart' appear to form a trimoraic syllable which is not permitted in Arabic according to the bimoraicity constraint. Vowel insertion is one common strategy that can be employed to avoid trimoraic syllables, a process which entails resyllabification, so that the maximum weight of the syllable is kept as two moras. Vowel insertion will be discussed where relevant in this section, particularly when discussing Kiparsky's account in sub-section 4.7.5.2, and a detailed discussion of the types of vowel insertion will be provided in Section 4.8. The peripheral consonant in consonant clusters occurring word-initially, word-medially or word-finally is considered as a stray consonant, a term used by Kiparsky (2003). A number of approaches were suggested to account for this stray consonant. Some were suggested to account for the stray consonant as occurring word-initially or word-finally (i.e., extraprosodic), some for CVVC syllables (i.e., vowel shortening and mora sharing), and some for a specific word position (i.e., onset for empty nucleus as occurring word-finally, and a rhyme for an empty onset as occurring word-initially). Kiparsky's (2003) account tackles both vowel insertion and the stray consonant. Thus, these accounts will be briefly discussed first, then a detailed discussion of Kiparsky's account will be provided next.

4.7.5.1 Stray consonant

The peripheral consonant in word-initial or word-final clusters that may receive the third mora is analysed as an extraprosodic consonant, which belongs to its own syllable (McCarthy and Prince, 1990). As in Figure 4.9, the leftmost consonant in a word-initial cluster (<u>C</u>CV as in the diagram to the left) is analysed as an extraprosodic consonant that receives a mora (extrametrical), whereas the rightmost consonant in a word-final cluster (VC<u>C</u> as in the diagram to the right) is analysed as an extraprosodic consonant,but does not have moraic status because, when followed by a suffix, it could be syllabified as an onset for a following syllable.

Figure 4.9 The leftmost consonant (as in the diagram to the left) is a stray consonant with a mora, whereas the rightmost consonant (as in the diagram to the right) is a stray consonant without a mora.

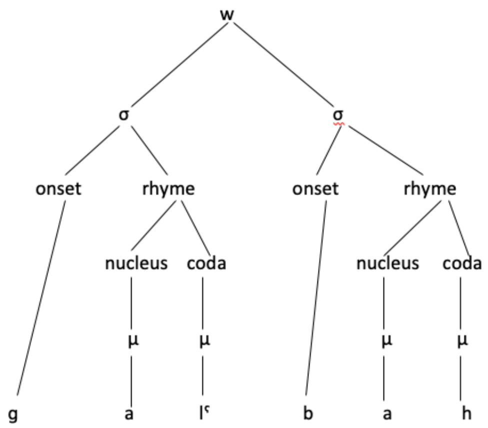


Resyllabifying the last consonant in a word-final cluster as an onset for the following syllable emerges from the fact that Arabic disallows onsetless syllables (Ito, 1989; Broselow, 1992). Onsetless syllables are prohibited in NA, thus Almuhaimeed (2021) claims that resyllabification can be employed to avoid this issue in NA, as in:

/galˤb+ah/ → /galˤ.bah/ not */galˤb.ah/ 'his heart'

As in Figure 4.10, the following suffix -ah in /galˤbah/ would be an onsetless syllable if /b/ were not resyllabified as its onset.

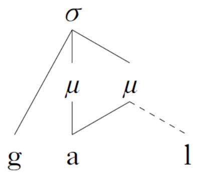
Figure 4.10 The stray consonant /b/ in /ɡalˤb/ 'heart' is resyllabified as an onset for the following suffix -ah in /ɡalˤbah/ 'his heart' to avoid onsetless syllable.



The final consonant in a word-final cluster is analysed as an onset for an empty nucleus (Selkirk, 1981). In a similar approach, Selkirk considers the first consonant in a word-initial cluster as a rhyme for an empty onset. This, however, violates the fact that onsetless syllables are prohibited in Arabic (Broselow, 2018).

As mentioned earlier, vowel shortening can be employed as a strategy to avoid problematic superheavy syllables (i.e., CVVC → CVC) in a number of Arabic varieties such as Cairene Arabic (Watson, 2007). Mora sharing can also be implemented to avoid trimoraic syllables in Arabic, following the Adjunction-to-Mora constraint proposed by Broselow (1992). According to mora sharing, one mora can dominate two constituents; i.e., the last consonant and the preceding vowel in the superheavy syllable (CV<u>VC</u>) can be dominated by a single mora; they share a single mora as shown in Figure 4.11.

Figure 4.11 Adjunction-to-Mora links the second part of the long vowel and the final consonant in the word /gaal/ 'he said' (from Watson, 2007, p. 351).



Another way of avoiding trimoraic syllables comes from Kiparsky's (2003) study which analyses the stray consonant as a semisyllable, moras unaffiliated with syllables. As pointed out earlier, among these analyses of the stray consonant, Kiparsky's (2003) analysis seems to be the most ambitious analysis for the syllable structure of Arabic (Broselow, 2018). Therefore, the next section will be devoted to discussing Kiparsky's analysis of the stray consonants and how they are represented in the syllable structure, Kiparsky's classification of Arabic varieties, and the position of NA within Kiparsky's classification.

4.7.5.2 Kiparsky (2003)

As stated above, Kiparsky (2003) analyses the stray consonant as a semisyllable, moras unaffiliated with syllables. Semisyllables, "arise where a constraint License-μ, which requires all moras to be licensed by syllables, is outranked by markedness constraints on the form of syllables and feet" (Kiparsky, 2003, p.151). According to the Prosodic Licensing Principle (Ito, 1986, 1989), each segment must be attached to a higher-level prosodic constituent. Assignment of the unsyllabified mora to Foot, which is the next higher level, violates the constraint on Foot size in Arabic, therefore, Kiparsky suggests that the unsyllabified moras is attached directly to the prosodic word level, which does not have any restrictions with regards to size. For Kiparsky, Arabic varieties differ in their licensing of semisyllables. He classified Arabic dialects into three groups: VC-, C- and CV-dialects, with the main diagnostic to determine Arabic dialect type being the epenthetic vowel site in medial -CCC- sequences. Similar classifications were followed by Selkirk (1981), Ito (1986, 1989) and Broselow (1992). Kiparsky (2003), however, specified a number of characteristics for each dialect type in addition to the epenthetic vowel site in a medial -CCC- sequence. These characteristics will be discussed later in this subsection. He describes dialect types as VC-dialects, when the epenthetic vowel occurs after the left-most consonant in the CCC cluster, as in Iraqi /giltla/ [gil<u>i</u>tla] 'I said to him'; CV-dialects, when the epenthetic vowel occurs after the medial consonant, as in Cairene /ʔultluh/ [ʔult<u>i</u>luh] 'I said to him'; and C-dialects, when no epenthetic vowel occurs and the cluster remains intact, as in Moroccan [qultlu] 'I said to him'. In this sense, the medial consonant is syllabified as a coda in Iraqi, and as an onset in Cairene.

Farawaneh (2009) refers to Iraqi as a coda language and to Cairene as an onset language, similar to Broselow's (1992) onset dialects. Although Cairene and Iraqi differ in the site of epenthesis in a three consonant sequence (CCC), as shown above, they behave similarly in a four consonant sequence (CCCC). Ito (1989, p.241) reports that CCCC sequences are broken up by an epenthetic vowel after the second consonant as in Iraqi /gil-t-l-ha/ [giltilha] and in Cairene [ʔultilha] 'I said to her'. Owens (2006) and Alqahtani (2014) classify NA as a CV-dialect, as the epenthetic vowel occurs after the medial consonant in CCC sequences, as in /galb+ha/ [galba̲ha] 'her heart'.

According to Kiparsky (2003), medial -CCC- sequences are retained in C- and VC-dialects at the word level. For example, /t/ in /giltlu/ 'I told him' is unsyllabified and receives a mora that is attached to the word node as in Figure 4.12; hence, it is a semisyllable. In CV-dialects, an epenthetic vowel is inserted instead; hence, no semisyllables occur, as in Figure 4.13. At the post-lexical level, semisyllables are not permitted in VC-dialects, hence epenthesis here to give CCC > CvCC.

Figure 4.12 /t/ in /giltlu/ 'I told him' is unsyllabified and it receives a mora that is attached to the word node in C- and VC-dialects (word level).

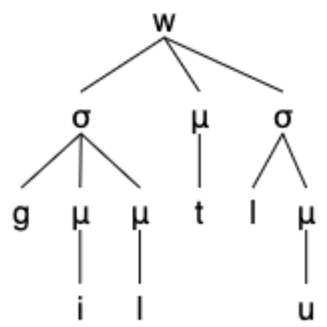
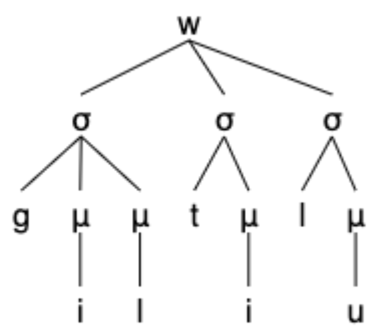


Figure 4.13 In CV-dialects, an epenthetic vowel is inserted after C2 in CCC sequences. Thus, an epenthetic vowel appears after /t/ in /giltlu/ 'I told him'.



In a word-final cluster, the last consonant is unsyllabified and it receives a mora that is attached to the word node in C- and VC-dialects (word level). In CV-dialects, the last consonant is unsyllabified,but it does not receive a mora; hence, no semisyllables occur. In a word-initial cluster, the first consonant is a semisyllable in C- and VC-dialects (word level). In CV-dialects, an epenthetic vowel is inserted instead; hence, no semisyllables occur.

As pointed out above, Kiparsky examined a number of characteristics that can be found in one type or can be shared by two types of Arabic varieties. The main characteristics include the epenthetic vowel site in medial -CCC- sequences, metathesis of medial -CCiC- to -CiCC-, final clusters (CC#) and initial clusters (#CC). NA was not included in his investigation. Table 4.3 summarises the main characteristics that are allowed for each type according to Kiparsky.

Table 4.3 A summary of the main characteristics that are allowed for each type of Arabic varieties according to Kiparsky (2003).

	CV-dialects	VC-dialects	C-dialects
Medial -C1C2C-	epenthesis after C2	epenthesis after C1	No epenthesis
Metathesis	X	√	X
CC#	√	X	√
#CC	X	√ (possible prothesis)	√

No epenthetic vowel is inserted in medial -CCC- sequences in C-dialects and VC-dialects (word level), the epenthetic vowel is inserted after the medial consonant in CV-dialects and after the first consonant in VC-dialects (postlexical). Metathesis of medial -CCiC- to -CiCC- sequences only occurs in VC-dialects as in /yiktibu/ [yikitbu] ‘they write’, while it does not occur in CV-dialects, in which -CCiC- is retained as in [yiktibu] ‘they write’. C-dialects elide the medial vowel, as in /yiktibu/ [yiktbu] ‘they write’. Final clusters occur only in CV- and C-dialects, as in /kalb/ ‘dog’ and /ħabs/ ‘jail’. Final clusters can, however, be broken up by an epenthetic vowel, if they violate the sonority sequencing principle as in /ʔakl/ [ʔakil] ‘food’ and in /naml/ [namil] ‘ants’. Initial clusters occur only in VC- and C-dialects, dialects in which high vowels do not occur in open syllables, resulting in initial clusters. In VC-dialects, the initial cluster can be broken up by an initial prosthetic vowel.

As pointed out earlier, Owens (2006) and Alqahtani (2014) classify NA as a CV-dialect, as the epenthetic vowel occurs after the medial consonant in CCC sequences. They, however, did not consider the other characteristics specified by Kiparsky (2003). Therefore, the position of NA within Kiparsky’s classification will be discussed below.

4.7.5.3 The position of NA within Kiparsky's classification

As discussed earlier in Sections 4.7.3 and 4.7.4, NA allows word-initial clusters as in /ktaab/ 'book', a feature of C-dialects and VC-dialects which do not add a prosthetic vowel to the cluster. NA also allows word-final clusters as in /bint/ 'girl' and in /kabs/ 'pressing', but word-final clusters are broken up by an epenthetic vowel if they do not conform to the Sonority Sequencing Principle as in /ʕagl/ [ʕagil] 'mind'. In common with CV-dialects, the epenthetic vowel occurs after the second consonant in a medial -CCC- sequence created by morpheme concatenation, as in /galb+ha/ [galbaha] 'her heart'. In contrast to VC-dialects, NA does not exhibit metathesis in medial -CCiC-, as in /yaktibuun/ *[yakitbuun] 'they write'. Based on Kiparsky's four main criteria shown in Table 4.3 above, NA meets the first three characteristics of CV-dialects,but fails to meet the last one. While Kiparsky's classification explains much variation of syllabification in Arabic varieties, it cannot be generalised to capture certain phenomena of syllabification in all dialects. Watson (2007) tested Kiparsky's criteria on a number of dialects of Arabic. She found that Cairene meets all the characteristics of CV-dialects, but San'ani does not. She found that while San'ani, similar to NA, disallows metathesis of medial -CCiC- to -CiCC- sequences, allows final clusters and positions the epenthetic vowel after the second consonant in a medial -CCC- sequence, it does allow initial clusters. San'ani, similar to NA, thus retains characteristics of CV-, VC- and C-dialects. Therefore, she proposed to classify San'ani as a Cv-dialect, distinct from CV-dialects by the small (v) because it retains most features of CV-dialects,but it shares some features with both VC- and C-dialects. Similarly, it seems reasonable to classify NA as a Cv-dialect because it retains most features of CV-dialectsbut allows initial clusters, a feature of both VC- and C-dialects.

Having discussed a number of analyses suggested to avoid trimoraic syllables that are prohibited in Arabic, it can be noted that the analysis of the approaches discussed so far is based on moraic theory. Additional support comes from studies adopting Articulatory Phonology. Shaw et al (2009, 2011), who based their analysis of Oujda dialect word-initial consonant clusters on articulatory data, found that the left-most consonant in a word-initial cluster does not belong to the same syllable of the right-most consonant (CCV) in a word like [s.bulha] 'her ear', since consonants in word-initial position do not exhibit the C-Centre stability[20]. Thus, they suggest that word-initial clusters in Moroccan Arabic are viewed as simplex onsets since both consonants in the cluster do not belong to the same syllable.

As stated earlier, vowel insertion is a common strategy that can be employed to avoid trimoraic syllables in Arabic. A detailed discussion of vowel insertion and the main types of

[20] The C-Centre stability was discussed in detail in Chapter 2 (see Section 2.2.1).

vowel insertion will be provided in the next section. This section is crucial for Research Question 2 of the current thesis, which concerns the variability of vowel insertion and their interaction with emphasis impact, if any.

4.8 Vowel insertion

Vowel insertion is, in general, used as a repair mechanism according to the phonotactic rules of a language or dialect. Vowel insertion is common strategy to avoid a trimoraic syllable which is problematic in Arabic varieties, as discussed above. The argument here is whether the inserted vowels are alike. Research has been carried out to examine the types of vowel insertion and it turns out that they are not phonetically and phonologically alike. Intrusion was initially examined following Articulatory Phonology (Browman and Goldstein, 1988, 1992); and it turns out that this model[21] can account for these inserted vowels more comprehensibly, compared to other models of phonology. Research in Articulatory Phonology identifies different types of vowel intrusion: epenthetic and excrescent vowels (Browman and Goldstein, 1992, 1995; Gafos, 2002; Gick and Wilson, 2006).

In brief, based on the literature, two main types of vowel insertion are identified. The first type of vowel insertion is often referred to as an *excrescent* (Levin, 1987) and *intrusive* vowel, as used by Hall (2006). This type has been also called transitional or automatic (see Levin, 1987; Hall, 2006). The term *intrusive* will be used to refer to this particular type throughout this thesis. The other type is known as an *epenthetic vowel.* These two types will be discussed in detail below since they are crucial for Research Question 2 of the current thesis, which concerns the variability in inserted vowels and how this will interact with emphasis impact, if any. This research question and related hypotheses will be restated at the end of this section (see Chapter 1, Section 1.2 for the list of the main research questions of the current thesis).

Hall (2006) provides a more comprehensive account of the types of vowel insertion. She distinguished between epenthetic vowels and intrusive vowels. The diagnostics of each, according to Hall (2006), are summarised in Table 4.4. An epenthetic vowel involves the process of the “insertion of a vocalic articulatory gesture” (Hall, 2006, p.387). An intrusive vowel is defined as “retiming of existing gestures to produce a vowel-like transition between consonants” (Hall, 2006, p.387). This type tends to occur in heterorganic consonant clusters, in which retiming between articulatory gestures are likely to occur. Intrusive vowels are regarded as a phonetic process due to conflict in two articulatory goals; they are not like epenthetic

[21] Articulatory Phonology was introduced in Chapter 2 (see Section 2.2).

vowels that are inserted by the speaker to break up illicit consonant clusters (Gick and Wilson, 2006). In this sense, the epenthetic vowel involves an additional tongue (vocalic) gesture while the intrusive vowel does not. This is consistent with Gafos's (2002) claim that excrescent (i.e., intrusive) vowels do not have their own gesture. Hall's distinction was based on a typological survey and her findings support those of earlier studies that adopted Articulatory Phonology. Excrescent (i.e., intrusive) vowels seem to appear as a result of no or low degree of gestural overlap between the consonantal gestures, resulting in a short interval in which this type of vowel insertion may appear. Harrell and Brunot (2004), for instance, report a vowel-like element observed in word-initial clusters in Moroccan Arabic which was interpreted as a transition between consonants by Gafos (2002), and as a short vowel by Boudlal (2001). Similarly, this short period is referred to as *open transition* by Gafos et al. (2010). This open transition could be a vowel-like sound if it is long (and may be voiced) or just a release of C1 if short.

Table 4.4 A summary of the diagnostics of inserted vowels according to Hall (2006, p. 391).

Intrusive vowels	***Epenthetic vowels***
a) The vowel's quality is either schwa, a copy of a nearby vowel or influenced by the place of the surrounding consonants.	The vowel's quality may be fixed or copied from a neighbouring vowel. A fixed-quality epenthetic vowel does not have to be schwa.
b) If the vowel copies the quality of another vowel over an intervening consonant, that consonant is a sonorant or guttural.	If the vowel's quality is copied, there are no restrictions as to which consonants may be copied over.
c) The vowel generally occurs in heterorganic clusters.	It is not influenced by place of articulation of surrounding sounds
d) The vowel is likely to be optional, have a highly variable duration or disappear at fast speech rates.	The vowel's presence is not dependent on speech rate.
e) The vowel does not seem to have the function of repairing illicit structures. The consonant clusters in which the vowel occurs may be less marked, in terms of sonority sequencing, than clusters which surface without vowel insertion in the same language.	The vowel repairs a structure that is marked, in the sense of being cross-linguistically rare. The same structure is also likely to be avoided by means of other processes within the same language.

Epenthetic vowels can be inserted prior to phonological rules. Accordingly, epenthetic vowels are regarded as independent phonological units that serves as syllable nuclei and hence are visible to phonological rules. Intrusive vowels, by contrast, are not independent phonological units and do not form syllable nuclei, and hence they are invisible to phonological rules (Hall, 2006). However, epenthetic vowels may reject stress. Davis (1995) reported an epenthetic vowel in Southern Palestinian Arabic (SPA) as in [batˤi̱nha] 'her stomach'; the syllable *tˤin* in [batˤi̱nha] should be able to bear stress since it is a penultimate heavy syllable according to SPA stress parameters, however it is not assigned stress since epenthetic [i] is unable to bear stress in this (VC-)dialect (Davis, 1995, p. 496). This is inconsistent with the claim that epenthetic vowels are visible to the phonology because if true, it should be capable of attracting stress here. Therefore, Hall (2006) states that "this makes stress behaviour probably the least useful phonological diagnostic for intrusive vowels" (p.396).

Intrusive vowels were found to permit phonological processes to pass through (Hall, 2006). Ghummed's (2015) empirical findings support Hall's account when he found that voice assimilation was not blocked by transitional intrusive vowels while epenthetic vowels, which are longer and usually voiced, were found to block voicing assimilation in Tripolitanian Libyan Arabic (TLA). Schwa epenthesis was found to block voicing assimilation in Modern Hebrew (Kenstowicz and Kisseberth, 1977; cited in Plug et al., 2019). Davis (1995) points out that emphasis spread is blocked by an epenthetic vowel in Southern Palestinian Arabic, which occurs to prevent a sequence of three consonants as in /batˤn+ha/ [batˤi̠nha] 'her stomach'[22].

As in Table 4.4, an epenthetic vowel is generally inserted in a sequence of consonants in order to repair, or to prevent, illicit clusters of consonants in a certain language. Heselwood et al. (2015) and Plug et al (2019) report epenthesis in three and four stop sequences in TLA, which only allows up to two stops in word-initial and word-final positions. Heselwood et al (2015) found that the sequence /tk#t/ was broken up by an epenthetic vowel after the first consonant /t/. They also report an epenthetic vowel inserted within the four-stop sequence /tk#tk/ at the word boundary. On the other hand, intrusive vowels are the result of variability in the timing of articulatory gestures in a sequence of two consonants; i.e., when two gestures are not overlapped, a vowel-like transition occurs between the two consonantal gestures.

Studies on second language (L2) acquisition provide further evidence that epenthetic vowels are inserted due to problematic combinations encountered by speakers. For example, Broselow (1983) examined the production of Egyptian and Iraqi learners of English. She found that her Egyptian and Iraqi speakers adopt vowel epenthesis to avoid problematic clusters that do not exist in their first languages (L1). Egyptian speakers inserted an epenthetic vowel in the word-medial sequence (after the second consonant in -CCC- sequence) as in /ʧildren/[ʧildi̠ren] 'children', whereas Iraqi speakers inserted an epenthetic vowel before the second consonant in the word-medial sequence as in [ʧili̠dren]. Broselow argues that the different sites of the epenthetic vowels are due to transfer of a phonological rule from their L1. "The reason that

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[22] The epenthetic vowel here is [i] and the lexical vowel /i/ has been reported in a number of studies as opaque to Emphasis Spread (depending on direction and dialect). Emphasis spread was discussed in detail in Chapter 3 (see Section 3.4).

vowel intrusion does not particularly target marked clusters is that it has no power to repair these clusters" (Hall, 2006, p.409).

Further evidence in support of the epenthetic vowel having a dedicated gesture while the intrusive vowel does not is provided by Hall (2003) who found that intrusive vowels seem to be optional and may disappear at a fast rate because of the great degree of gestural overlap between the gestures, unlike epenthetic vowels (Hall, 2006, p.391). Intrusive vowels are often variable in duration, and may disappear at fast speech rates as reported for Moroccan Colloquial Arabic (Heath, 1987; Gafos, 2002). Although the duration of epenthetic vowels decreases as speech rate increases, they are still occurring regardless of the speech rate. In relation to the duration of the inserted vowel, epenthetic vowels tend to be longer than intrusive vowels. Hall (2003, p.3) found that epenthetic vowels were typically longer and voiced; this could be attributed to the claim that an epenthetic vowel has an articulatory gesture (tongue body gesture) and thus it requires a longer time to be produced, compared to an intrusive vowel that results from retiming of the gestures of the surrounding consonants (Hall, 2006).

Plug et al (2019) suggest that an epenthetic vowel is voiced because it has its own gesture, just like lexical vowels. Intrusive vowels were found to be dependent on the voicing status of adjacent sounds since they are a result of retiming of articulatory gestures of the surrounding consonants. Epenthetic vowels, on the other hand, were found to be mostly voiced whether they occur between two voiceless or voiced sounds. These two patterns were observed in TLA (Plug et al, 2019). It should be noted that epenthetic vowels and lexical vowels acoustically differ in their durations and formants (Hall, 2011). Although epenthetic vowels are phonological segments, having their own gestures, they differ from lexical vowels. Hall (2013) acoustically examined the differences between epenthetic vowels and lexical vowels in Lebanese Arabic. She found that they differ in their formants and durations. Epenthetic vowels are characterized with a lower F2, higher F1 and shorter duration, compared to lexical vowels. This is consistent with Ramirez (2006) who found that epenthetic vowels were shorter in duration than lexical vowels in Spanish.

Having discussed Hall's account of the types of vowel insertion (epenthetic and intrusive vowels), now we turn to discuss recent acoustic studies that support Hall's findings.

Several studies were conducted to examine the variability of inserted vowels following Hall (e.g., Ridouane and Fougeron, 2011 for Tashlhiyt; Kirby, 2014 for Khmer; Bellik, 2018 for Turkish; Plug et al, 2019 for Tripolitanian Libyan Arabic; Al-Aqlobi, 2020 for Bisha Arabic and Makkah Arabic). The focus here will be on varieties of Arabic: Tripolitanian Libyan Arabic (TLA), Bisha Arabic (BA) and Makkah Arabic (MA). These studies generally support Hall's diagnostics. Each study adopted a number of Hall's diagnostics. Al-Aqlobi examined the quality of the inserted vowel, the effect of the environment in which the inserted vowel occurs (i.e., heterorganic vs. homorganic clusters), and whether the inserted vowel occurs in marked or unmarked consonant clusters. He generally found that intrusive vowels occur in word-initial clusters, whereas epenthetic vowels occur in word-medial and word-final clusters in BA and MA. Plug et al followed different diagnostics to examine inserted vowels variability in TLA. They mainly examined the duration, voicing and transparency of phonological processes (i.e., voicing assimilation) to investigate inserted vowels variability. They examined the inserted vowels using the inter-consonantal interval (ICI); they segmented the ICI from release onset of C1 to closure onset of C2. They examined whether the ICI exhibits the characteristics of intrusive vowels or epenthetic vowels. They generally found that intrusive vowels occur in word-initial clusters, similar to Al-Aqlobi (2020), and in two consonant sequences at the word boundary (C#C), whereas epenthetic vowels occur in four consonant sequences at the word boundary (CC#CC). The ICI observed in word-final clusters, however, was found to share characteristics of both intrusive and epenthetic vowels, similar to Heselwood (2015) who found variability in ICI duration in this position in TLA, indicating that not all ICIs exhibit the characteristics of intrusive vowels. Plug et al. used the two terms: SHORT ICI and LONG ICI initially in their study and they concluded that SHORT ICIs share characteristics of intrusive vowels, whereas LONG ICIs share characteristics of epenthetic vowels. Shitaw (2014) similarly referred to any element appearing between two consonants as an ICI regardless of its duration or voicing in TLA. In the current thesis, the inserted vowels will be examined using the ICI; it will be investigated whether the ICI exhibits the characteristics of intrusive or epenthetic vowels. For the sake of the purpose of the current study, the ICI duration and voicing proportion will be used as a diagnostics to examine variability in inserted vowels, if any, in Najdi Arabic (NA).

Having discussed the main differences between the two types of vowel insertion (intrusive and epenthetic) and relevant studies that examined these types in Arabic, now we explain how this is relevant to the aims and research questions of the current thesis in the following sub-section.

4.8.1 This study

As discussed in Chapter 2, which concerns timing relations in consonant sequences, the degree of gestural overlap varies as a function of the sequence word position: word-initial clusters exhibit a lower degree of gestural overlap than word-final clusters do, which can be characterised by no ICI occurring between the two consonants or shorter ICI duration if it occurs. As discussed in the above section, intrusive vowels are transitions between two consonantal gestures that sound like a vowel; they are the result of retiming between two existing consonantal gestures. They are not independent phonological units and are variable in duration, depending on the environment in which they occur. Therefore, it can be assumed that intrusive vowels duration will vary as a function of the sequence position in the word. This claim is consistent with the findings of Plug et al (2019) and Gafos et al (2010). Duration of epenthetic vowels, on the other hand, is not expected to vary as a function of word position since their insertion is not a result of a low degree of overlap between the articulatory gestures of the adjacent consonants; they are, rather, independent phonological units and inserted to repair illicit syllable structures and hence have their own gesture (Hall, 2006).

Having said that, an interesting question that arises here is how both types of inserted vowels interact with emphasis; if there is an impact of emphasis, is it going to be observed in intrusive vowels, epenthetic vowels, or in both? This is motivated by the claim that intrusive vowels are variable in duration whereas epenthetic vowels are not. These inserted vowels will be investigated by examining the ICI in the current thesis, similar to relevant studies (e.g., Heselwood et al, 2015; Plug et al, 2019). Gafos et al (2010) found that as ICI duration increases, the effect of the order of place of articulation weakens[23]. As discussed above, it has been reported that intrusive vowels occur in word-initial clusters (e.g., Al-Aqlobi, 2020 for BA and MA; Plug et al,2019 for TLA) and in a two consonant sequence at the word boundary (C#C) (Plug et al,2019 for TLA). Epenthetic vowels were found to occur in word-final clusters (Al-Aqlobi, 2020). Plug et al (2019), however, found that the ICI occurring in word-final clusters in TLA has characteristics of both intrusive and epenthetic vowels following Hall's diagnostics. Besides, Alqahtani (2014) and Alfaifi (2019) found that word-final sequences (CC#) that violate the sonority sequencing are broken up by an epenthetic vowel in Najdi Arabic. Accordingly, the following hypotheses are proposed:

Intrusive vowels will occur in word-initial sequences (#CC), two-consonant sequences across the word boundary (C#C) and in word-final sequences (CC# that obey the sonority sequencing), whereas epenthetic vowels will occur in four-consonant sequences at the word boundary (CC#CC) and in word-final sequences (CC# that violate the sonority sequencing in Najdi Arabic).

Emphasis impact, if any, will be observed in intrusive vowels but not in epenthetic vowels.

[23] 'Place order effect' was discussed in detail in Chapter 2 (see Section 2.3.1).

An epenthetic vowel is expected to occur in a four-consonant sequence at the word boundary (CC#CC) based on the claim that epenthetic vowels occur to repair illicit syllable structures. NA allows up to two consonants in a sequence (Alqahtani, 2014). Heselwood et al (2015) and Plug et al (2019) report an epenthetic vowel occurring at the word boundary in CC#CC in TLA. Heselwood et al argue that TLA does not permit clusters of more than two consonants. Therefore, inserting an epenthetic vowel in this site is the only strategy to break up a four consonant sequence (CCCC). NA is expected to behave similarly for two reasons. First, NA does not permit sequences of more than two consonants. Therefore, inserting an epenthetic vowel at the word boundary in CC#CC sequences is the only way to break up a four consonant sequences without generating another prohibited CCC sequence. Second, the site of an epenthetic vowel at the word boundary in CC#CC sequences could be an extension of CV-dialects epenthesis pattern in CCvC sequence, where *v* is an epenthetic vowel. Similarly, Heselwood et al (2015) explain that the intrusion of an epenthetic vowel in word-final position as an extension of the VC-dialect epenthesis pattern in CCC sequences, in which an epenthetic vowel is inserted after the leftmost consonant since TLA is classified as a VC-dialect. An epenthetic vowel is also expected to occur in word-final sequences that violate the sonority sequencing, based on the findings of Alqahtani (2014) and Alfaifi (2019) that word-final sequences are broken up by an epenthetic vowel if they violate the sonority sequencing. Besides, emphasis impact, if any, is expected to be observed in intrusive vowels,but not in epenthetic vowels, since intrusive vowels are variable in duration and voicing according to the environment in which they occur, unlike epenthetic vowels. It is true that emphasis can influence lexical vowels, by lowering their F2 as discussed in Chapter 3, it has also been reported that emphasis cannot affect the duration of lexical vowels (e.g., Almuhaimeed, 2021 for NA). The focus in the current thesis is on duration and voicing, not formants. Although epenthetic vowels have their own gesture, they are different from lexical vowels, as discussed above in Section 4.8 (see Hall, 2013).

4.9 Summary

This chapter was devoted to Najdi Arabic which is the focus of the current thesis. The consonant and vowel inventories of NA were introduced. The syllable structure and syllabification were discussed. It has been shown how the sonority sequencing can shape consonant clusters in NA. Word-initial clusters that violate the SSP are tolerated, while word-final clusters that violate the SSP are broken up by epenthesis in NA. The strategies that can be implemented to avoid trimoraic syllables in Arabic, including vowel insertion, mora sharing and Kiparsky’s (2003) analysis of the stray consonant in trimoraic syllables as a semisyllable, were discussed. It has been shown that Kiparsky's analysis provides a more comprehensive account; it tackles both vowel insertion and the stray consonant. Therefore, a detailed discussion of Kiparsky's classification of Arabic dialects was provided. NA was described as a CV-dialect by Owens (2006) and Alqahtani (2014), as the epenthetic vowel occurs after the medial consonant in CCC sequences. The position of NA within Kiparsky's classification was discussed, and it has been shown that NA is best described as a Cv-dialect, after considering the main characteristics specified by Kiparsky. The chapter ended with a discussion of the types of vowel insertion. It has been shown that there are two types of vowel insertion: epenthesis and vowel intrusion. The main distinction between them is that an epenthetic vowel has a dedicated articulatory gesture, and hence an independent phonological unit; whereas an intrusive vowel is a result of retiming between existing gestures, and they are not independent units; they are variable in duration and voicing.

Having reviewed the relevant literature in Chapters 2, 3, and 4, we now turn to summarise the gaps identified in the literature and contributions of the current thesis, and how the current thesis will fill in these gaps. This is necessary before discussing the methods and the results of the current study in the following chapters.

4.10 Summary of the literature review and the identified gaps

The literature was reviewed over three consecutive chapters. Chapter 2 discussed timing relations in consonant sequences, Chapter 3 concerns emphasis and Chapter 4 was devoted to Najdi Arabic (NA), as the aim of the thesis is to examine the impact of emphasis on gestural overlap of consonant sequences in NA. This section starts with restating the main research questions of the thesis, followed by a summary of the key findings of the literature and the identified gaps. Then, the remainder of the section will be devoted to the contribution of the current thesis and how this study will fill in the gaps identified in the literature.

This study aims to answer the following research questions (RQs):

RQ 1: Does emphasis have an impact on the degree of gestural overlap in consonant sequences? In particular,

RQ 1, a: ***Does the secondary articulation of emphatic coronals have an impact on the degree of gestural overlap in consonant sequences?***

RQ 1, b: ***Does the state of the glottis involved during the production of emphatic coronals play a role in the degree of gestural overlap in consonant sequences?***

RQ 2: If yes, is emphasis impact observed in intrusive vowels, epenthetic vowels, or in both?

The review of the literature in emphasis (Chapter 3) shows that emphatic coronals are characterised by two main characteristics: a secondary articulation (tˤ, sˤ, ðˤ) and less open glottis (tˤ, sˤ) during their production, in comparison to their plain counterparts. The first characteristic of emphasis (secondary articulation) adds more complexity (by adding a posterior gesture) when producing an emphatic coronal in a sequence with another lingual consonant such as the velar /g/, which involves the movement of the tongue dorsum. This complexity, however, may not be observed when producing the plain coronals in a consonant sequence since they lack a secondary articulation. Based on the literature reviewed on timing relations (Chapter 2), a relevant factor was found to be influential on gestural overlap, namely place of articulation. Cross-linguistically, when two consonants in a sequence involve the tongue during their production (such as /t/ which involves the tongue tip and /g/ which involves the tongue dorsum), they exhibit a lower degree of gestural overlap than when each consonant involves an independent articulator (such as /b/ which involves the lips and /t/ which involves the tongue tip). In this sense, the tongue tip and tongue dorsum during the production of /tg/, for instance, constrain the movement of each other to attain their targets in the vocal tract because they are physiologically coupled, resulting in a lag between C1 release and formation of the closure of C2. The constriction of C2 cannot be attained until after the release of C1. This is acoustically observed as an inter-consonantal interval (ICI) occurring in between. The lips and the tongue tip in /bt/ sequence, on the other hand, do not constrain the movement of each other; each articulator can move freely to attain its target without the influence of the other articulator. The tongue tip in /t/ can attain its target before the labial gesture for /b/ is released because both articulators are independent from each other. This can be acoustically characterised as no release of C1 and accordingly no ICI occurring. The constriction of the tongue tip in /t/ can also be attained immediately after the release of C1. This can be acoustically characterised by a short ICI.

Having shown how the consonantal gestures in lingual/lingual sequences (e.g., /tg/) constrain the movement of each other, in comparison to lingual/labial sequences (e.g., /bt/), emphatic coronals add more complexity (by adding a posterior gesture) when produced with another lingual consonant in a sequence because they involve a secondary articulation involving the tongue back in addition to their primary articulation involving the tongue tip, in comparison to their counterparts. This secondary articulation is expected to constrain the movement of the tongue tip or the tongue dorsum in two lingual sequences such as /gtˤ/ vs /gt/. The gestural overlap of the sequences /btˤ/ ~ /bt/ and /gtˤ/ ~ /gt/, for instance, is investigated in this study. No role of the secondary articulation on gestural overlap is expected between /btˤ/ and /bt/ since the articulators, the lips and the tongue tip, are independent. On the other hand, /gtˤ/ is expected to exhibit a longer ICI and, hence lower degree of gestural overlap, than /gt/ because the articulators involved in /gtˤ/ are the tongue dorsum, the tongue tip and the tongue back; these articulators are expected to constrain the movement of each other, and therefore there will be a delay between the constrictions of both consonants, which can be acoustically characterised as a long ICI. The articulators involved in /gt/, on the other hand, are the tongue dorsum and the tongue tip; although they are both lingual and thus they constrain each other, an additional active articulator (the tongue back) is present in /gtˤ/ but not in /gt/, and hence more complexity (i.e., movements to be more constrained) will be observed in /gtˤ/ than in /gt/.

Emphatic coronals have not been considered in previous studies that examined timing relations in consonant sequences (e.g., Shaw et al,2009, 2011; Shitaw, 2013; Ghummed, 2015; Alsubaie, 2014). The only study that included the emphatic stop /tˤ/ is conducted by Shitaw (2014) in Tripolitanian Libyan Arabic. He, however, did not examine the impact of emphasis on the gestural overlap; he did not carry out any statistical analysis to examine the impact of emphasis in his data because that was not a goal of his study. He examined stops in general, including the emphatic alveolar stop, as discussed in Chapter 2 (Section 2.3.1). Therefore, the current thesis will fill in this gap in the literature by investigating the impact of the secondary articulation of emphasis on gestural overlap of consonant sequences, considering the three emphatic coronals /tˤ, sˤ, ðˤ/. Accordingly, the following research question and related hypotheses will be tested:

RQ1,a: Does the secondary articulation of emphatic coronals have an impact on the degree of gestural overlap in consonant sequences?

Hypothesis (a): lingual/lingual consonant sequences will exhibit a lower degree of gestural overlap than labial/lingual consonant sequences.
Hypothesis (b): lingual/lingual consonant sequences in an emphatic context will exhibit a lower degree of gestural overlap than lingual/lingual consonant sequences in the plain counterpart.

My review of the literature in emphasis (Chapter 3) shows that the less open glottis is another characteristic that can be observed in emphatic coronals but not in their plain counterparts. This is observed in the emphatic stop /tˤ/ and the emphatic fricative /sˤ/. The state of the glottis during the production of the emphatic fricative /ðˤ/ was not examined in previous studies because the two voiced phonemes (emphatic /ðˤ/ and plain /ð/) can be assumed to share the same glottal state. Hence, no motivation is there to examine them, unlike the case of the stops /tˤ, t/ and fricatives /sˤ, s/. The state of the glottis involved when producing the stop /tˤ/ was examined in Arabic (e.g., Watson, 1993; Watson and Heselwood, 2016 for San'ani Arabic) as well as in Modern South Arabian Languages (MSAL) (Watson and Heselwood, 2016). /tˤ/ has been reported to be produced with a less open glottis than the plain /t/. It has been claimed that /tˤ/ patterns with the plain voiced /d/ in the state of the glottis, compared to the plain voiceless /t/ (Watson and Heselwood, 2016). In terms of the emphatic fricative /sˤ/, it has been reported to be produced with a less open glottis than the plain counterpart /s/ in MSAL (Heselwood et al, 2022). Hence, it has been claimed that /sˤ/ patterns with voiced consonants in the state of the glottis (Heselwood et al, 2022). There is a need to examine /sˤ/ in another Arabic variety to have a clearer view of its behaviour, and this can be acoustically attained by examining the voicing proportion of frication and of the adjacent inter-consonantal interval (ICI), if any. For the purpose of the current thesis, which investigates the gestural overlap of consonant sequences by examining the ICI as the main measure to determine the degree of gestural overlap, the voicing proportion of the ICI will be only examined, and this can reflect to some extent the state of the glottis. Having said that, it can be hypothesised that /sˤ/ will behave differently than /s/ in the degree of gestural overlap of consonant sequences in which they occur, and hence /sˤ/ will behave similarly with /z/, compared to /s/, based on the findings of studies on MSAL. Both /tˤ/ and /sˤ/ are obstruents, and what applies to /tˤ/ could also apply to /sˤ/. In contrast, there is no motivation to hypothesise otherwise. The findings of the current thesis will give a clearer view of the state of the glottis of /sˤ/ in Arabic, by examining the ICI voicing proportion.

Based on the literature reviewed on timing relations (Chapter 2), it has been reported that the state of the glottis plays a role on gestural overlap. When both consonants in a sequence are voiced (sharing the same glottal state), they exhibit a greater degree of gestural overlap than when both consonants differ in voicing (having different glottal states). It is true that the glottis when producing the emphatic coronals is not as closed as when producing the plain voiced consonants,but it is not as widely open as when producing the plain voiceless consonants. Consonants with less open glottis can behave like voiced consonants in the gestural overlap. The gestural overlap of /bd/ and /bt/ sequences, for instance, is investigated in this study, and since both consonants in /bd/ are voiced (sharing the same state of the glottis), /bd/ sequence is expected to exhibit a lower ICI occurrence/count percentage and a shorter ICI than /bt/ sequence since both consonants in /bt/ differ in voicing (voiced/voiceless: having different states of the glottis). Similarly, the gestural overlap of /btˤ/ and /bt/ sequences, for example, is investigated in this study. A /btˤ/ sequence is expected to exhibit a lower ICI count percentage and a shorter ICI, and hence greater degree of gestural overlap, compared to a /bt/ sequence. The role of the state of the glottis during the production of emphatic coronals on gestural overlap was not examined in previous studies. For example, Alsubaie (2014) acoustically examined Najdi Arabic and found that voiced/voiced consonants exhibit a greater degree of gestural overlap than voiced/voiceless consonants; he, however, did not include emphatic consonants in his study. Therefore, the current thesis will fill in this gap in the literature by investigating the impact of the state of the glottis involved when producing emphatic coronals on gestural overlap of consonant sequences. It will contribute to our understanding of the role of state of the glottis in gestural overlap.

Accordingly, the following research question and related hypotheses will be tested:

> ***RQ1,b: Does the state of the glottis involved during the production of emphatic coronals play a role in the degree of gestural overlap in consonant sequences?***
>
> **Hypothesis (c):** voiced/voiced consonant sequences will exhibit a greater degree of gestural overlap than voiced/voiceless consonant sequences.
>
> **Hypothesis (d):** voiced/emphatic /tˤ/ sequences (i.e., /btˤ/ and /tˤb/) will exhibit a greater degree of gestural overlap than voiced/plain /t/ sequences (i.e., /bt/ and /tb/), and accordingly /tˤ/ will behave similarly with the plain voiced counterpart /d/ in the degree of gestural overlap, compared to the plain voiceless counterpart /t/.
>
> **Hypothesis (e):** voiced/emphatic /sˤ/ sequences (i.e., /bsˤ/ and /sˤb/) will exhibit a greater degree of gestural overlap than voiced/plain /s/ sequences (i.e., /bs/ and /sb/), and accordingly /sˤ/ will behave similarly with the plain voiced counterpart /z/ in the degree of gestural overlap, compared to the plain voiceless counterpart /s/.

Another key finding in the literature is the different types of vowel insertion that can occur in a consonant sequence, as discussed in Chapter 4. It has been shown that there are two types of inserted vowels: intrusive and epenthetic (Hall, 2006). As shown in Chapter 4, the types of inserted vowels were found to vary as a function of the sequence position in the word. Plug et al (2019) report that an intrusive vowel occurs in word-initial clusters, two consonant sequences at the word boundary (C#C), whereas epenthetic vowels occur in four consonant sequences at the word boundary (CC#CC) in TLA. Several characteristics can distinguish epenthetic vowels from intrusive vowels, mainly their duration and voicing. Epenthetic vowels were found to be longer in duration than intrusive vowels. An epenthetic vowel has a dedicated articulatory gesture, and it is an independent phonological unit that forms a syllable nucleus. An intrusive vowel, on the other hand, occurs as a result of retiming of existing articulatory gestures, and it is variable in duration and voicing, depending on the surrounding sounds. While epenthetic vowels were found to be mostly voiced even if they occur between two voiceless consonants, intrusive vowels can be voiced if they occur between two voiced consonants, or they can be voiceless if they occur between two voiceless consonants. Most studies in the literature examined the voicing status (in addition to duration) as a diagnostic of the vowel insertion type (e.g., Plug et al,2019); i.e., if it is influenced by the voicing of the adjacent consonants, it is more likely to be intrusive;but if not, it is more likely to be epenthetic. Emphatic coronals were not examined in such studies. It has been shown that emphasis can influence surrounding sounds, as discussed in Chapter 3. This thesis will fill in this gap by investigating the impact of emphasis as a diagnostic of the inserted vowel type. Since intrusive vowels are resulting from retiming of existing consonantal gestures, and they are variable in duration and voicing, they are expected to be influenced by emphasis if an emphatic coronal occurs in the sequence. The duration and voicing of epenthetic vowels, on the other hand, are not expected to be influenced by emphasis since they have a dedicated vocalic gesture and are independent phonological units. It is true that emphasis can affect adjacent lexical vowels by lowering their F2 (e.g., Alarifi, 2010; Almuhaimeed, 2021),but it has not been found that emphasis can affect the duration of the adjacent lexical vowels including Najdi Arabic (Almuhaimeed, 2021), as discussed in Chapter 3. The current thesis will examine ICI duration as a measure of the degree of gestural overlap, along with ICI count percentage and sequence duration in addition to individual intervals. This thesis will also examine ICI voicing proportion. Accordingly, the following research question and related hypotheses will be tested:

RQ2: If yes, is emphasis impact observed in intrusive vowels, epenthetic vowels, or in both?

Hypothesis (f): Intrusive vowels will occur in word-initial sequences (#CC), two-consonant sequences across the word boundary (C#C) and in word-final sequences (CC# that obey the sonority sequencing), whereas epenthetic vowels will occur in four-consonant sequences at the word boundary (CC#CC) and in word-final sequences (CC# that violate the sonority sequencing in Najdi Arabic).

Hypothesis (g): emphasis impact, if any, will be observed in intrusive vowels but not in epenthetic vowels.

As discussed in Chapter 2, order of place of articulation (front-back, back-front), sequence position in the word, and speech rate are influential factors on gestural overlap. It has been reported that back-front sequences such as /tb/ exhibit a lower degree of gestural overlap than front-back sequences such as /bt/, including Najdi Arabic (Alsubaie, 2014). It has also been reported that a lower degree of gestural overlap can be exhibited in word-initial clusters than elsewhere (e.g., Byrd, 1996). Besides, it has been reported that a greater degree of gestural overlap can be exhibited at a fast speech rate than at a normal rate (Byrd, 1996; Shitaw, 2014). Although Alsubaie (2014) investigated the order of place of articulation in NA, he only examined word-initial clusters. Thus, there is a need to investigate the gestural overlap of consonant sequences in different word positions including word-final clusters and sequences across the word boundary in NA. Alsubaie (2014) also did not consider speech rate in his study on NA. Thus, there is a need to consider this crucial factor. Because these are crucial factors that can influence gestural overlap, they are considered and examined in the current thesis to find out whether they will interact with the impact of emphasis, if any. Considering different word positions is also crucial for the second main research question as well, which concerns the types of inserted vowels, as shown above. Accordingly, the following hypotheses will be tested:

> **Hypothesis (h):** word-initial clusters will exhibit a lower degree of gestural overlap than word-final clusters and sequences across the word boundary.
>
> **Hypothesis (i):** back-front consonant sequences will exhibit a lower degree of gestural overlap than front-back consonant sequences.
>
> **Hypothesis (j):** consonant sequences at a fast speech rate will exhibit a greater degree of gestural overlap than sequences at a normal speech rate.

One last main finding in the literature is relevant to gender as an independent variable. Gender is considered in the current thesis based on the findings of previous studies that examined gender. It has been found that emphasis is more exhibited in the speech of males than in the speech of females, including NA (Alfraikh, 2015). Another recent study, however, found different results. Almuhaimeed (2021) found that emphasis is more exhibited in the speech of females than in that of males. Accordingly, gender is considered in the current thesis because it seems to be a potential social factor that can interact with emphasis, based on previous research as discussed in Chapter 3 (Section 3.5), and to have a clearer view of gender behavior in relation to emphasis impact in Najdi Arabic, and also to find out whether the results of the current thesis will be in line with those of Alfraikh (2015) or with those of Almuhaimeed (2021). As discussed in Chapter 3, I cannot formulate a hypothesis to predict whether emphasis impact will be more exhibited in the speech of males or in that of females since there are two studies that reported contradictory results as pointed out above.

Having identified the gaps in the literature and shown how the current thesis will fill in these gaps, now we turn to explain the methodology followed to conduct the current study in the following chapter to answer the main research questions and test the proposed hypotheses.

5 Methods

Following the review of the literature in previous chapters, this chapter is devoted to the methodology used to conduct the production study. It is divided into six main sections. Section 5.1 restates the research questions and related hypotheses; it also introduces the independent and dependent variables that are considered to address those research questions. Section 5.2 is concerned with the participants in this study. The stimuli and procedure followed in conducting this study are explained in Sections 5.3 and 5.4. Section 5.5 shows how the acoustic landmarks were segmented and how durations were extracted. Section 5.6 shows how the statistical analysis was performed and which statistical tests were used. The chapter ends with a general summary.

To reiterate, the main aim of this thesis is to acoustically investigate the impact of emphasis on gestural overlap in Najdi Arabic (NA). The three emphatic coronals /tˤ/, /sˤ/ and /ðˤ/ are examined and compared to their plain counterparts. The current study is aimed at contributing to the study of the phonetics of Arabic through an examination of NA; to our understanding of the timing relations in consonant sequences; and to the study of emphasis in Arabic. The sequence position, the place of articulation, the speech rate and gender are considered. The main research questions and the proposed hypotheses were introduced and motivated throughout Chapters 2, 3 and 4, and they are restated below.

5.1 Research questions, hypotheses and main variables

RQ1: Does emphasis have an impact on the degree of gestural overlap in consonant sequences? In particular,

RQ1,a: Does the secondary articulation of emphatic coronals have an impact on the degree of gestural overlap in consonant sequences?

Hypothesis (a) lingual/lingual consonant sequences will exhibit a lower degree of gestural overlap than labial/lingual consonant sequences.
Hypothesis (b) lingual/lingual consonant sequences in an emphatic context will exhibit a lower degree of gestural overlap than lingual/lingual consonant sequences in the plain counterpart.

RQ 1,b: Does the state of the glottis involved during the production of emphatic coronals play a role in the degree of gestural overlap in consonant sequences?

Hypothesis (c) voiced/voiced consonant sequences will exhibit a greater degree of gestural overlap than voiced/voiceless consonant sequences.
Hypothesis (d): voiced/emphatic /tˤ/ sequences (i.e., /btˤ/ and /tˤb/) will exhibit a greater degree of gestural overlap than voiced/plain /t/ sequences (i.e., /bt/ and /tb/), and accordingly /tˤ/ will behave similarly with the plain voiced counterpart /d/ in the degree of gestural overlap, compared to the plain voiceless counterpart /t/.
Hypothesis (e): voiced/emphatic /sˤ/ sequences (i.e., /bsˤ/ and /sˤb/) will exhibit a greater degree of gestural overlap than voiced/plain /s/ sequences (i.e., /bs/ and /sb/), and accordingly /sˤ/ will behave similarly with the plain voiced counterpart /z/ in the degree of gestural overlap, compared to the plain voiceless counterpart /s/.

RQ2: If yes, is emphasis impact observed in intrusive vowels, epenthetic vowels, or in both?

Hypothesis (f) Intrusive vowels will occur in word-initial sequences (#CC), two-consonant sequences across the word boundary (C#C) and in word-final sequences (CC# that obey the sonority sequencing), whereas epenthetic vowels will occur in four-consonant sequences at the word boundary (CC#CC) and in word-final sequences (CC# that violate the sonority sequencing in Najdi Arabic).
Hypothesis (g) emphasis impact, if any, will be observed in intrusive vowels but not in epenthetic vowels.
Hypothesis (h) word-initial clusters will exhibit a lower degree of gestural overlap than word-final clusters and sequences across the word boundary.

All the above hypotheses will be referred to as specific hypotheses since each will be tested for a specific word set. On the other hand, hypotheses that will be tested across all word positions (#CC, CC#, C#C, CC#CC), as restated below, will be referred to as common hypotheses, since they are tested in all word sets:

Hypothesis (i) back-front consonant sequences will exhibit a lower degree of gestural overlap than front-back consonant sequences.
Hypothesis (j) consonant sequences at a fast speech rate will exhibit a greater degree of gestural overlap than sequences at a normal speech rate.

To test the above hypotheses, the following independent variables are considered:

1. The identity of the articulators (lingual/lingual, lingual/labial)
2. Context (plain, emphatic)[24]
3. Order of place of articulation (front-back, back-front)
4. Word position (##CC, CC##, C#C, CC#CC)
5. Speech rate (normal, fast)
6. Gender (male, female)

The main dependent variables that need to be considered to test the above hypotheses are the inter-consonantal interval (ICI) occurrence/count percentage, ICI duration and sequence duration because these are used as measures to determine the degree of gestural overlap in this thesis. The intervals within the sequence (i.e., the hold phase, frication, VOT) will be considered as well. One more dependent variable to be considered is ICI voicing proportion which acoustically reflects the state of the glottis. The study was designed in light of those variables, as will be shown in Section 5.3.

5.2 Participants

Sixteen participants (8 males and 8 females) took part in this study. According to Buchstaller and Khattab (2013, p.88), traditionally laboratory settings are favored over naturalistic settings in phonetic/phonological research. An acoustic analysis yields a controlled approach. A main aim of phonetic research is to control any potential linguistic confounds as much as possible when analyzing sounds, yielding elicited data. Accordingly, small number of speakers and items can be justified in such kind of research (Buchstaller and Khattab, 2013). Therefore, relevant production studies, that were discussed earlier in the literature chapters, examined the production of a similar number of speakers (e.g., Zsiga, 1994; Plug et al, 2019). Almuhaimeed (2021, p. 80), who examined data collected from five speakers, argues that such production studies generate a large amount of data, and hence the acoustic analysis will be harder as the number of speakers increases. In the current study, various acoustic parameters were examined; i.e., hold phase, VOT, frication, sequence durations, inter-consonantal interval (ICI) duration and voicing proportion. These acoustic intervals take time to be segmented.

[24] Context has three levels in chapter 7: plain voiced, plain voiceless and emphatic.

All speakers who participated in the current study are Saudi nationals and all are native speakers of Najdi Arabic. They were born and lived in Alaflaj governorate in Najd, where the recording took place (see Section 5.4), and they use Najdi Arabic in their daily speech. They were asked to speak in their native dialect as if they were communicating with family members or friends. None reported speech or hearing impairments. Their age ranges between 19 and 35 years old. This age range has been chosen for easy of recruitment. Relevant production studies recruited similar age ranges (e.g., Alsubaie, 2014; Alfaifi, 2019; Almuhaimeed, 2021). The research was conducted in accordance with the ethics regulations of the University of Leeds; the research design was reviewed and approved by the Faculty of Arts, Humanities and Cultures Research Ethics Committee[25].

As stated above, data were collected from eight males and eight females. Gender is considered in the current study because there is evidence that this variable can interact with emphasis, based on the literature, as discussed in Chapter 3 (Section 3.5). Age, on the other hand, is not considered in the current study because it was not considered as much as gender in previous studies, and there is no evidence that age interacts with emphasis. Therefore, there is no motivation to consider age in the current study.

5.3 Word List

Word sets of the current thesis were designed carefully in light of the variables provided in Section 5.1 to answer the proposed research questions. The material was divided into three word sets which are presented in turn with the related research question(s) and hypotheses. Each word set was designed to address a specific research question.

5.3.1 Word set A

Word set A was designed to address Research Question 1a and its associated hypotheses, as restated below:

> ***RQ1,a: Does the secondary articulation of emphatic coronals have an impact on the degree of gestural overlap in consonant sequences?***
>
> **Hypothesis (a)** lingual/lingual consonant sequences will exhibit a lower degree of gestural overlap than labial/lingual consonant sequences.

[25] Ethical review approval, consent form and information sheet are in Appendix A.

Hypothesis (b) lingual/lingual consonant sequences in an emphatic context will exhibit a lower degree of gestural overlap than lingual/lingual consonant sequences in the plain counterpart.

To address RQ1a, lingual/lingual sequences should be compared to lingual/labial (i.e., lingual-labial or labial-lingual) sequences, considering the context (plain or emphatic). Therefore, dorsal/coronal (lingual/lingual) sequences will be compared to labial/coronal (labial/lingual) sequences. The place order (front-back or back-front) was considered as well when designing this word set. This word set consists of 24 sequences across the word boundary (C#C) as in Table 5.1. According to the Najdi Arabic lexicon, dorsal/coronal sequences are not frequently occurring word-initially or word-finally. The pairs to be examined need to be carefully designed to be closely matched as possible. Therefore, these consonant sequences were examined as occurring across a word boundary (C#C). The velar stop /g/ has been used as a constant consonant in coronal-dorsal vs. dorsal-coronal sequences since it is lingual; it involves the tongue dorsum and the emphatic coronal involves the tongue back for the secondary constriction. Najdi Arabic has two velars, /k/ and /g/ (see Table 4.1 in Chapter 4 for the consonant inventory of Najdi Arabic). A voiced velar has been chosen here in order to be consistent when comparing lingual/lingual with labial/lingual sequences because Najdi Arabic has only voiced bilabial /b/, and thus the second member in the lingual sequences is voiced /g/. Word set A consists of monosyllabic words followed by disyllabic words, and they are preceded and followed by the vowel /a:/ for consistency.

Table 5.1 Word set A

Sequence Type	Consonant	Context	Consonant Sequence	Words	Gloss	Sequence Type	Consonant Sequence	Words	Gloss
Labial-Coronal	t	Plain	b#t	ba:b#ta:mir	Tamer's door	**Coronal-Labial**	t#b	ba:t#ba:sim	Basem stayed
	tˤ	Emphatic	b#tˤ	ba:b#tˤa:lib	a student's door		tˤ#b	ba:tˤ#ba:sim	Basem's arm
Dorsal-Coronal	t	Plain	g#t	ba:g#ta:mir	he robbed Tamer	**Coronal-Dorsal**	t#g	ba:t#ga:sim	Gasem stayed
	tˤ	Emphatic	g#tˤ	ba:g#tˤa:lib	he robbed a student		tˤ#g	ba:tˤ#ga:sim	Gasem's arm
Labial-Coronal	s	Plain	b#s	ba:b#sa:lim	Salem's door	**Coronal-Labial**	s#b	ba:s#ba:sem	he greeted Basem
	sˤ	Emphatic	b#sˤ	ba:b#sˤa:liħ	Saleh's door		sˤ#b	ba:sˤ#ba:sim	Basem's bus
Dorsal-Coronal	s	Plain	g#s	ba:g#sa:lim	he robbed Salem	**Coronal-Dorsal**	s#g	ba:s#ga:sim	he greeted Gasem
	sˤ	Emphatic	g#sˤ	ba:g#sˤa:liħ	he robbed Saleh		sˤ#g	ba:sˤ#ga:sim	Gasem's bus
Labial-Coronal	ð	Plain	b#ð	ba:b#ða:bil	a weak door	**Coronal-Labial**	ð#b	ba:ð#ba:sim	he annoyed Basem
	ðˤ	Emphatic	b#ðˤ	ba:b#ðˤa:lim	door of dishonest man		ðˤ#b	ha:ðˤ#ba:sim	Basem got angry
Dorsal-Coronal	ð	Plain	g#ð	sa:g#ða:bil	weak tree trunk	**Coronal-Dorsal**	ð#g	ba:ð#ga:sim	he annoyed Gasem
	ðˤ	Emphatic	g#ðˤ	ba:g#ðˤa:lim	he robbed a dishonest man		ðˤ#g	ha:ðˤ#ga:sim	Gasem got angry

5.3.2 Word set B

Word set B was designed to address Research Question 1b and its associated hypotheses, as restated below:

> ***RQ1,b: Does the state of the glottis involved during the production of emphatic coronals play a role in the degree of gestural overlap in consonant sequences?***
>
> **Hypothesis (c)** voiced/voiced consonant sequences will exhibit a greater degree of gestural overlap than voiced/voiceless consonant sequences.
>
> **Hypothesis (d):** voiced/emphatic /tˤ/ sequences (i.e., /btˤ/ and /tˤb/) will exhibit a greater degree of gestural overlap than voiced/plain /t/ sequences (i.e., /bt/ and /tb/), and accordingly /tˤ/ will behave similarly with the plain voiced counterpart /d/ in the degree of gestural overlap, compared to the plain voiceless counterpart /t/.
>
> **Hypothesis (e):** voiced/emphatic /sˤ/ sequences (i.e., /bsˤ/ and /sˤb/) will exhibit a greater degree of gestural overlap than voiced/plain /s/ sequences (i.e., /bs/ and /sb/), and accordingly /sˤ/ will behave similarly with the plain voiced counterpart /z/ in the degree of gestural overlap, compared to the plain voiceless counterpart /s/.

As pointed out earlier, the emphatic coronal /ðˤ/ was excluded from these hypotheses because both emphatic /ðˤ/ and its plain counterpart /ð/ share the same glottal state, unlike /tˤ ~ t/ and /sˤ ~ s/. Therefore, there is no motivation to hypothesise that /ðˤ/ will behave differently from /ð/ based on their glottal state only.

To address RQ1b, voiced/voiced sequences should be compared to voiced/voiceless sequences, considering the context (plain voiceless, plain voiced or emphatic). For example, /bd/ (voiced/voiced) cluster will be compared to /bt/ (voiced/voiceless) cluster to test Hypothesis (c). To test Hypothesis (d), a cluster such as /btˤ/ (voiced/emphatic) will be compared to /bt/ (voiced/plain voiceless) and to /bd/ (voiced/plain voiced). It will be tested whether sequences that include /tˤ/ as in /btˤ/ will exhibit greater degree of gestural overlap than sequences that include /t/ as in /bt/; it will be tested also whether the emphatic /tˤ/ will behave similarly to the plain voiceless /t/ or to the plain voiced /d/ in the degree of gestural overlap. Same comparison will be carried out for the alveolar fricative (e.g., /bs/ ~ /bsˤ/ ~ /bz/) to test Hypothesis (e).

This word set consists of 24 labial/coronal word-initial and word-final clusters as in Table 5.2. The bilabial stop /b/ has been used as a constant consonant in labial-coronal vs coronal-labial sequences because its constriction is anterior to that of a coronal, so that order of place of articulation (front-back and back-front sequences) is controlled. Najdi Arabic does not have the phoneme /p/. A low vowel has been used in all word sets in this study for consistency, similar to Alsubaie (2014) and Plug et al (2019) who limited the vowel quality to the low vowels /a/ and /a:/ in their data although they had to use /e:/ in a small number of cases, just to have a meaningful item. Word set B was designed to include sequences within words (i.e., word-initial and word-final clusters) for two reasons. First, the findings of most studies (e.g., Hoole et al, 2009; Shitaw, 2013; Alsubaie, 2014), that found that the state of the glottis plays a role on gestural overlap, were based on clusters occurring word-internally, i.e. word-initially or word-finally. Second, according to the NA lexicon, voiced/voiceless consonants are frequently occurring word-initially or word-finally, unlike dorsal/coronal sequences, as pointed out above in word set A.

According to the Najdi Arabic lexicon, most initial clusters containing an emphatic coronal occur before /a:/ and the same clusters in final position always occur after /a/. Therefore, initial clusters were followed by a long low vowel while final clusters were preceded by a short low vowel. Syllables with a long vowel and final CC cluster don't occur in NA (see Table 4.2 for all possible syllable types of NA). Words with initial clusters are disyllabic whereas those with final clusters are monosyllabic. The list contains a small number of nonsense words because the vocabulary of Najdi Arabic does not contain lexical items with the appropriate phoneme sequences such as /sˤb/ in word-initial position, and hence the nonsense word **sˤba:dʒah* is included in order to compare it with the real word *bsˤa:dʒah* 'with an iron'. Because there is a need to carefully design the word set for such production studies, relevant production studies included very few nonsense words to have the appropriate phoneme sequences that were required to test a particular hypothesis (e.g., Byrd, 1996; Byrd and Tan, 1996; Shaw et al, 2009; Almuhaimeed, 2021).

Table 5.2 Word set B

Sequence Type	Emphatic	Labial-Coronal			Coronal-Labial		
		Consonant Sequence	Words	Gloss	Consonant Sequence	Words	Gloss
#CC	tˤ	#btˤ	btˤa:gah	with energy	#tˤb	tˤba:gah	Lid
		#bt	bta:kil	she will eat	#tb	tba:dil	she exchanges
		#bd	bda:bah	he started with it	#db	dba:bah	his bottles
	sˤ	#bsˤ	bsˤa:dʒah	with an iron	#sˤb	sˤba:dʒah	[nonsense]
		#bs	bsa:gah	with his leg	#sb	sba:gah	his race
		#bz	bza:dah	with his food	#zb	zba:lah	Rubbish
CC#	tˤ	btˤ#	rabtˤ	linking	tˤb#	ʃatˤb	Erasing
		bt#	kabt	suppression	tb#	katb	Writing
		bd#	kabd	liver	db#	nadb	Delegation
	sˤ	bsˤ#	gabsˤ	pinch	sˤb#	gasˤb	Butchering
		bs#	kabs	pressing	sb#	kasb	Gain
		bz#	xabz	baking	zb#	xazb	[nonsense]

5.3.3 Word set C

Word set C was designed to address Research Question 2 and its associated hypotheses, as restated below:

> **RQ2: If yes, is emphasis impact observed in intrusive vowels, epenthetic vowels, or in both?**
>
> **Hypothesis (f)** Intrusive vowels will occur in word-initial sequences (#CC), two-consonant sequences across the word boundary (C#C) and in word-final sequences (CC# that obey the sonority sequencing), whereas epenthetic vowels will occur in four-consonant sequences at the word boundary (CC#CC) and in word-final sequences (CC# that violate the sonority sequencing in Najdi Arabic).
>
> **Hypothesis (g)** emphasis impact, if any, will be observed in intrusive vowels but not in epenthetic vowels.
>
> **Hypothesis (h)** word-initial clusters will exhibit a lower degree of gestural overlap than word-final clusters and sequences across the word boundary.

As explained earlier, the types of vowel insertion will be investigated by examining the ICI. It will be investigated whether the ICI exhibits the characteristics of intrusive vowels or epenthetic vowels. To address RQ2, ICI duration and voicing should be examined in various word positions considering the context (emphatic or plain).

Word sets A and B contain various word sequences that are relevant for Hypotheses (f) and (g),but not a full set. Therefore, word set C was designed to include various word positions including four-consonant sequences occurring at the word boundary (CC#CC). This word set consists of a further 32 labial/coronal sequences occurring word-initially, word-finally and across the word boundary as in Table 5.3 to test Hypotheses (f) and (g).

Since dorsal/coronal sequences were already considered in word set A to test the impact of the secondary articulation of emphatic coronals on gestural overlap, as explained above, they were excluded in this word set C, and hence only labial/coronal sequences were included here. Similarly, the plain voiced /d/ and /z/ were already considered in word set B, therefore they were excluded in this word set C, and hence only the emphatic coronals and their plain voiceless counterparts were included here. The focus in the additional four consonant sequences (CC#CC) will be on the two consonants at the word boundary (i.e., C2 and C3 in C1C2#C3C4). These sequences consist of labial/coronal sequences. Accordingly, the exclusions explained above will make the comparison in this word set consistent since all consonant sequences in all word positions in this word set are composed of labial/coronal sequences.

5.3.4 Common hypotheses

As pointed above in Section 5.1, hypotheses that will be tested across all word positions (#CC, CC#, C#C, CC#CC), as restated below, will be referred to as common hypotheses, since they are tested in all word sets:

> **Hypothesis (i)** back-front consonant sequences will exhibit a lower degree of gestural overlap than front-back consonant sequences.
>
> **Hypothesis (j)** consonant sequences at a fast speech rate will exhibit a greater degree of gestural overlap than sequences at a normal speech rate.

Hypothesis (i) has informed the design of all word sets, while Hypothesis (j) has informed the procedure (two speech rates elicited).

Table 5.3 Word set C. The highlighted sequences are the additional sequences in this word set.

Sequence Type	**Labial-Coronal**				**Coronal-Labial**		
	Consonant	**Consonant Sequence**	**Words**	**Gloss**	**Consonant Sequence**	**Words**	**Gloss**
C#C	tˤ	b#tˤ	ba:b#tˤa:lib	a student's door	tˤ#b	ba:tˤ#ba:sim	Basem's arm
		b#t	ba:b#ta:mir	Tamer's door	t#b	ba:t#ba:sim	Basem stayed
	sˤ	b#sˤ	ba:b#sˤa:liħ	Saleh's door	sˤ#b	ba:sˤ#ba:sim	Basem's bus
		b#s	ba:b#sa:lim	Salem's door	s#b	ba:s#ba:sem	he greeted Basem
#CC	tˤ	#btˤ	btˤa:gah	with energy	#tˤb	tˤba:gah	lid
		#bt	bta:kil	she will eat	#tb	tba:dil	she exchanges
	sˤ	#bsˤ	bsˤa:dʒah	with an iron	#sˤb	sˤba:dʒah	[nonsense]
		#bs	bsa:gah	with his leg	#sb	sba:gah	his race
CC#	tˤ	btˤ#	rabtˤ	linking	tˤb#	ʃatˤb	erasing
		bt#	kabt	suppression	tb#	katb	writing
	sˤ	bsˤ#	gabsˤ	pinch	sˤb#	gasˤb	butchering
		bs#	kabs	pressing	sb#	kasb	gain
CC#CC	tˤ	tb#tˤb	katb#tˤba:gah	writing a lid	btˤ#bt	rabtˤ#bta:kil	linking#she will eat
		tb#tb	katb#tba:dil	writing ‘she exchanges’	bt#bt	kabt#bta:kil	suppression#she will eat
	sˤ	sb#sˤb	kasb#sˤba:dʒah	gaining#[nonsense]	bsˤ#bs	gabsˤ#bsa:gah	pinching his leg
		sb#sb	kasb#sba:gah	gaining his race	bs#bs	kabs#bsa:gah	pressing with his leg

5.4 Procedure

The participants produced the target words embedded in the carrier phrase *gilna* ___ *sitt marraat* 'we said ___ six times', resulting in a sentence such as *gilna btaakil sitt marraat* 'we said she will eat six times'. According to Buchstaller and Khattab (2013, p. 88), a carrier phrase can help control neighboring sounds. It helps controlling sounds preceding and following the target word (as markers for segmentation). Besides, using a carrier phrase helps obtain more natural speech, compared to producing the words in isolation (Almuhaimeed, 2021, p. 79). Relevant production studies use a carrier phrase (e.g., Byrd, 1996; Byrd and Tan, 1996; Marin and Pouplier, 2010; Plug et al, 2019). All words were preceded by a vowel which helped to mark the onset of a stop hold phase or onset of frication of a fricative in C1 in an initial cluster. For example, the low vowel /a/, preceding the target word /btaakil/ in the sentence *gilna btaakil sitt marraat*, helped to mark the onset of the bilabial stop /b/ hold phase in the initial cluster /bt/. Because /s/ in '*sitt marraat*' may influence previous clusters containing a fricative in that the frication offset would be difficult to identify, words with final clusters (i.e., with a C2 fricative) were embedded in the carrier phrase *gilna* ___*marriteen* 'we said ___ twice'. For example, it would be difficult to identify the frication offset of the alveolar fricative /s/ in /kabs/ if embedded in the same carrier phrase as in *gilna kabs sitt marraat* because the following consonant is also /s/ in /sitt/. Therefore, a word such as /kabs/ is rather embedded in the carrier phrase *gilna kabs marriteen*, in which /s/ in /kabs/ is followed by the nasal /m/ in '*marriteen*' which helped to mark offset of frication energy of the final /s/. Words that end with a stop, on the other hand, were embedded in the carrier phrase *gilna* ___ *sitt marraat*. A word like *kabt*, for instance, was followed by the fricative /s/ in '*sitt marraat*' as in *gilna kabt sitt marraat*. Only three words end with a fricative, so that they were embedded in the alternative carrier phrase *gilna* ___*marriteen*. The remainder of the target words were embedded in the carrier phrase *gilna*___*sitt marraat*. Each target word or words were embedded in the carrier phrase, yielding 56 sentences. Some relevant studies used two carrier phrases for similar reasons (e.g., Gafos et al, 2010, p. 663). These 56 sentences were produced by 16 speakers at two speech rates (normal and fast) with three repetitions for each speech rate, yielding 5376 tokens to be analysed. Relevant production studies included repetitions (e.g., Zsiga, 1996; Byrd, 1996; Shaw et al, 2011; Plug et al, 2019). Several acoustic intervals need to be segmented and analysed within each token in this study (e.g., hold phase, VOT, frication, ICI), and this takes time. Speech rate manipulation will be explained in detail later in this section.

Due to religious and cultural reasons, a male cannot meet a female who is not his immediate relative. Therefore, a female assistant recorded female speakers. The female assistant was a native speaker of Najdi Arabic and she was instructed by the researcher about the procedures of the recording.

All sentences were typed in Arabic orthography; they were randomized and presented on a sheet of paper. According to Abbuhl et al (2013, p. 127), one method of eliciting data is to ask participants to read words to conduct an acoustic analysis of various features of consonants and vowels. Many researchers chose to elicit scripted speech in relevant production studies (e.g., Alsubaie, 2014; Shitaw, 2014; Plug et al, 2019). Such studies elicit scripted speech over spontaneous speech because the pairs to be examined need to be carefully designed to be closely matched as possible. For example, the place order is considered in this thesis; there is a need to examine the timing relations in /bt/ vs /btˤ/ (in front-back order) and those in /tb/ vs /tˤb/ sequences (in back-front). Therefore, these pairs /bt/ ~ /btˤ/ and /tb/ ~ /tˤb/ were examined in various word positions (#CC, C#C, CC# and CC#CC). This indicates that the pairs to be examined need to be carefully designed to be closely matched as possible. Such considerations cannot be easily obtained in spontaneous speech.

As discussed earlier, the Standard Arabic (SA) is considered the high code and the colloquial variety is considered the low code (see Section 1.3 for more details about the diglossic situation in the Arab world and in Saudi Arabia in particular). Although NA is written in very restricted contexts (i.e., in social media applications, such as WhatsApp, Twitter and Meta), the participants may produce the sentences in SA rather than in NA. In order to avoid any interference of SA when reading the stimuli, the researcher held an informal conversation prior to recording with each participant in Najdi dialect in order for the participant to comfortably shift from using the formal variety to NA, similar to the procedure followed in relevant studies (e.g., Shitaw, 2014). Also, all sentences were typed in Arabic script without diacritics in order to mitigate the influence of SA, similar to Shitaw (2014) and Plug et al (2019). Besides, the sentences include dialectal lexical items that are used in NA but not in SA, such as /baag/ 'he robbed' as opposed to the SA /saraq/ 'he robbed'. This helps the participants produce the sentences in their regional variety rather than the formal variety, SA. Furthermore, the syntactic rules of SA were not followed when writing the sentences that were presented to the participants. For example, the sentences in A in Table 5.4 are written in the colloquial style, and they are in the data set of the current thesis. The sentences in B, however, are written in the formal style (SA), and they are not in the data set of the current thesis.

Table 5.4 The sentences in A are written in the colloquial style (Najdi), whereas the sentences in B are written in the formal style (Standard Arabic).

A			B		
In colloquial Arabic	**Transcription**	**Gloss**	**In Standard Arabic**	**Transcription**	**Gloss**
قلنا باق سالم ست مرات	/gilna baag saalim sitt marraat/	'we said he robbed Salem six times'	قُلْنا سَرَقَ سالِمً سِتَّةُ مَرَّاتٍ	/qulna saraqa saaliman sittatu marraatin/	'we said he robbed Salem six times'
قلنا بتاكل ست مرات	/gilna btaakil sitt marraat/	'we said she will eat six times'	قُلْنا سَتَأكُلُ سِتَّةُ مَرَّاتٍ	/qulna sata?kulu sittatu marraatin/	'we said she will eat six times'

As in Table 5.4, the first word in the carrier phrase includes the velar /g/ as in /gilna/ 'we said'. This velar stop does not occur in SA; it, however, occurs in NA, hence /gilna/ in NA but /qulna/ in SA. Thus, this helped the participant to pronounce it as used in NA. The researcher was monitoring the recordings and all participants pronounced it as /g/, not /q/. Same observation was found in the recordings made by the female assistant.

Similar to Shitaw (2014) and Plug et al (2019), the participants were given the opportunity to practice producing the target words and to annotate them with appropriate diacritics if necessary. Before recording, each participant was given enough time to read the sentences to familiarize himself/herself with their production in their native variety of Arabic, Najdi Arabic. Recording started when he/she felt comfortable to start the recording session. Each participant was recorded individually in one session which lasted around 60-90 minutes including breaks. It was divided into two sub-sessions: one in which speech was elicited at a normal rate and one in which speech was elicited at a fast rate, with a five-minute break after each repetition and a ten-minute break between the two sub-sessions, during which participants were provided with refreshments. They were told that whenever they feel uncomfortable, they could leave any time and we could then arrange another time that will be appropriate for them to complete the recording. None of them had felt uncomfortable during the recording. Most participants needed around 60 minutes including breaks. One male participant, however, needed more time because he needed to go out of room to make a call, and he then came back to complete the recording. Same procedure was followed when he came back; and he then started when he felt comfortable to start the recording. Such recording time is familiar in such production studies (e.g., Byrd, 1996; Byrd and Tan, 1996;

Almuhaimeed, 2021). Almuhaimeed (2021, p. 81), for instance, states that each session in her production study lasted between one and two hours. The researcher and the female assistant kept monitoring all recordings to make sure that each participant produced each target word in Najdi Arabic correctly without the influence of SA.

As stated above, speakers produced all sentences at two speech rates: normal and fast. During the first sub-session, they were asked to read the sentences normally as if they were talking to a friend or a family member. No further instructions were given. They were asked to repeat the whole list three times. Their recordings were coded as Normal in this sub-session. In the second sub-session, they were asked to read the sentences as fast as possible without sacrificing speech accuracy. Again, they produced the sentence list three times. Their recordings were coded as Fast in this sub-session. Such procedure in manipulating speech rate was followed in relevant production studies (e.g., Zsiga, 1994; Shitaw, 2014). The researcher and the female assistant kept monitoring all recordings to make sure they do not misarticulate, and none misarticulated.

Speakers were recorded during fieldwork in Layla, the main city in Alaflaj governorate, which is located about 280 km to the south of Riyadh, the capital city of Saudi Arabia (see Figures 4.1 and 4.2 for the map showing Alafaj). The participants were recorded using a headset microphone (Sony MDR-ZX110AP). This was used in order to be consistent because male speakers were recorded in Alaflaj College, while female speakers were recorded at home. It was done in a quiet room.

Their production was recorded with a sampling frequency of 44100 Hz, 16-bit using *Audacity* software directly onto a laptop. Each repetition was saved in a single WAV file so that each participant had six files, three at normal rate and three at fast rate. Each file was split up into smaller files and each target word was exported to occupy a separate file. Using a Praat script, a matching textgrid was created for each sound file in order to label acoustic landmarks in different interval tiers. More details about the acoustic analysis are provided below.

5.5 Acoustic Analysis

Recorded data were acoustically analysed using *Praat* speech analysis software (Boersma and Weenink, 2016) with reference to both waveforms and spectrograms in order to obtain necessary measurements to answer the research questions proposed above. Various acoustic parameters were examined including the hold phase (HP), frication, Voice Onset Time (VOT), inter-consonantal interval (ICI), the whole sequence durations and the ICI voicing proportion. The acoustic variables in this study were chosen based on earlier research findings on timing relations and on emphasis discussed in the literature chapters 2, 3 and 4. The main landmarks and their segmentation are explained below and illustrated in Figures 5.1, 5.2, 5.3 and 5.4.

1) **Closure Onset of a stop:**

- *If preceded by a vowel*, it is identified by the following criteria:
    - An abrupt decrease in amplitude in the waveform
    - A cessation of formant energy of the preceding vowel, mainly F2, in the spectrogram. Using the offset of the second formant energy to identify closure onset of the following stop is the best criterion because F1 can be confusable with F0 (Turk et al, 2006, p. 6).
    - A cessation of voicing of the previous vowel which is marked by a periodic waveform and a dark bar at the bottom of the spectrogram if it is a voiceless stop. As voicing continues through the first part or all of the hold phase of a voiced stop and sometimes a voiceless stop, only the first two criteria are considered in the case of voiced stops.
- *If preceded by another stop*, it is identified by an abrupt decrease in amplitude in the waveform that coincides with a cessation of noise energy in the spectrogram which marks the release offset of the preceding stop.
- *If preceded by a fricative*, the closure onset is identified by a decrease in amplitude in the waveform that coincides with offset of frication noise that can be visible in the waveform and spectrogram.

2) **Release Onset:** it is identified by an abrupt increase in amplitude after a horizontal line in the waveform that coincides with a vertical line in the spectrogram. If multiple bursts occur (particularly with velars), the first burst is used to mark the release following Turk et al (2006) because “subsequent bursts are produced through the (uncontrolled) Bernoulli effect” (p. 7).

3) **Release Offset:** it is identified by an abrupt decrease in amplitude in the waveform that coincides with a cessation of noise energy in the spectrogram if followed by a stop. If followed by a fricative, it is marked by onset of frication noise that can be visible in the waveform and spectrogram. If followed by a vowel, it is marked by an abrupt increase in amplitude in the waveform, start of formant energy (mainly F2) and by start of voicing in the spectrogram. In this case, it is a VOT (this will be discussed further below).

4) **Frication Onset:** it is identified by onset of frication noise that is visible in the waveform and spectrogram, as a main criterion. If preceded by a vowel, similar criteria used to identify closure onset of a stop as described above are followed. Frication onset is marked by a cessation of the vowel formants, mainly F2, in the spectrogram

and a decrease in amplitude in the waveform. It is also marked by a cessation of voicing bar in the spectrogram, if the fricative is voiceless; if the fricative is voiced and voicing, thus, can continue through the frication noise, only the first criterion and vowel formants are considered.

5) **Frication Offset:** it is identified by offset of frication noise that can be seen in the waveform and spectrogram. If followed by a vowel, it is marked by an abrupt increase in amplitude in the waveform and by onset of vowel formant energy (mainly F2) and by onset of voicing bar in the spectrogram if the fricative is voiceless. If the fricative is voiced, only the first criterion is followed.

The following intervals were then derived:

- **The hold phase (HP):** from closure onset to release onset.
- **Frication:** from frication onset to frication offset.
- **Inter-consonantal interval (ICI):** ICI was derived from release onset of C1 to closure onset if the following consonant is a stop or to frication onset if the following consonant is a fricative; if C1 is a fricative, from frication offset to closure onset of the following stop. Accordingly, any interval occurring between two consonants was labelled as an ICI (including aspiration, if any), similar to relevant studies (e.g., Alsubaie, 2014; Shitaw, 2014; Heselwood et al, 2015; Plug et al, 2019).
- **C2 VOT:** from C2 release onset to onset of voicing of the following vowel if C2 is a voiceless stop (/t/ or /tˤ/), followed by a vowel in VC1#C2V or in ##C1C2V sequences (i.e., in /b#t/, /b#tˤ/, /g#t/, /g#tˤ/, /#bt/ and /#btˤ/ because these sequences are followed by a vowel).
- **ICI voicing proportion:** voicing proportion for the ICI was extracted using a Praat script. Similar to Davidson (2016, 2018) and Plug et al (2019), proportion of voicing was obtained using the "*fraction of locally unvoiced frames"* values that were implemented in "voice reports" in Praat. Following Eager (2015), default pitch floor, ceiling values and time step values were used. Following (Eager, 2015) and (Davidson, 2016), the voice reports settings were Praat's defaults.
- **Sequence duration:** from closure onset if C1 is a stop or from frication onset if it is a fricative to release offset if C2 is a stop or to frication offset if it is a fricative. C2 VOT is included in the sequence duration for consistency since the criterion followed to segment release offset of a stop and frication offset of a fricative when followed by a vowel are similar as explained above; i.e. if followed by a vowel, it is marked by an abrupt increase in amplitude in the waveform and by start of formant energy (mainly

F2). In other words, the same anchor (onset of the following vowel) is used for consistency, therefore VOT is included in the sequence duration. There are cases in which C1 is not released, as in Figure 5.2, and accordingly no ICIs occurred; in these cases, the landmarks to segment the hold phases of C1 and C2 are absent,but VOT of C2 that immediately precedes the vowel is still clear as in Figure 5.2. The landmarks for onset and end of sequence are clear too. Therefore, the number of tokens analysed *in such cases* is equal in ICI, C1 HP and C2 HP, while the number of tokens analysed for sequence and VOT, if C2 is /t/ or /tˤ/, includes all tokens.

Using a Praat script[26], all of the above durations were extracted in milliseconds (ms). As discussed earlier, the degree of gestural overlap was determined by the ICI occurrence/count (percentage) (whether an ICI occurs in the sequence or not), ICI duration and sequence duration in addition to individual intervals as the following criteria:

- The lower the ICI count percentage is, the greater degree of gestural overlap exhibited in the sequence
- The shorter the ICI duration is, the greater degree of gestural overlap exhibited in the sequence
- The shorter the sequence duration and/or an individual interval within the sequence is, the greater degree of gestural overlap exhibited in the sequence.

As explained in chapter 1, if all those measures were met, then we have a very strong evidence to report greater degree of gestural overlap. If, for example, only one or two measures were met, we still have evidence to report greater degree of gestural overlap,but not as very strong as when all were met. It will be made clear which measure(s) were used as evidence, where relevant, in the results as well as in the discussion chapter. The main measures (ICI count, ICI and sequence durations) were considered to examine the impact of place order and the identity of articulators since investigating these effects entails examining more than two or three specific sequences. For example, to investigate the impact of place order on gestural overlap (Hypothesis ***i***) in stop/stop sequences, occurring word-initially or finally (as will be reported in Section 7.2.1 in Chapter 7) more than two sequences that differ in Context, place order and position, were considered, i.e. /#bt/, /#btˤ/, /#bd/, /bt#/, /btˤ#/, /bd#/, /#tb/, /#tˤb/, /#db/, /tb#/, /tˤb#/ and /db#/ sequences. The individual intervals, in addition to the three main measures, were considered when comparing timing relations between two or

[26] Praat scripts are available here: https://github.com/lnplp

three specific consonant sequences to examine the impact of the secondary articulation of emphatics or that of the state of the glottis on gestural overlap. Two or three specific sequences were considered to examine these effects. For example, to investigate the impact of the state of the glottis (Hypotheses ***c*** and ***d***) in stop/stop sequences, occurring word-initially or finally (as will be reported in Section 7.2.3 in Chapter 7) specific sequences were considered, i.e. /#bt/, /#btˤ/, /#bd/ (front-back in #CC as reported in Section 7.2.3.1), /bt#/, /btˤ#/, /bd#/ (front-back in CC# as in Section 7.2.3.2), /#tb/, /#tˤb/, /#db/ (back-front in #CC as in Section 7.2.3.3), and /tb#/, /tˤb#/ and /db#/ sequences (back-front in CC# as in Section 7.2.3.4).

As indicated in Chapters 1 and 4, the types of vowel insertion were investigated by examining the ICI, similar to relevant studies (e.g., Heselwood et al, 2015; Plug et al, 2019). It was investigated whether the ICI exhibits the characteristics of intrusive vowels or epenthetic vowels. To address Research Question 2, ICI duration and voicing proportion were examined in various word positions considering the context (emphatic or plain). These results will be presented in Chapter 8. As also made clear in Chapter 2, the ICI count/occurrence is the only measure that was used to examine the impact of speech rate on the degree of gestural overlap since it is a more reliable measure that can determine the degree of gestural overlap in relation to speech rate effect; i.e., ICIs may disappear at fast speech rate, indicating greater degree of gestural overlap, as explained in Chapter 2.

All these considerations will be made clear, where relevant, in the results chapters.

Figure 5.1 Segmentation of /bt/ sequence in ba:b#ta:mir

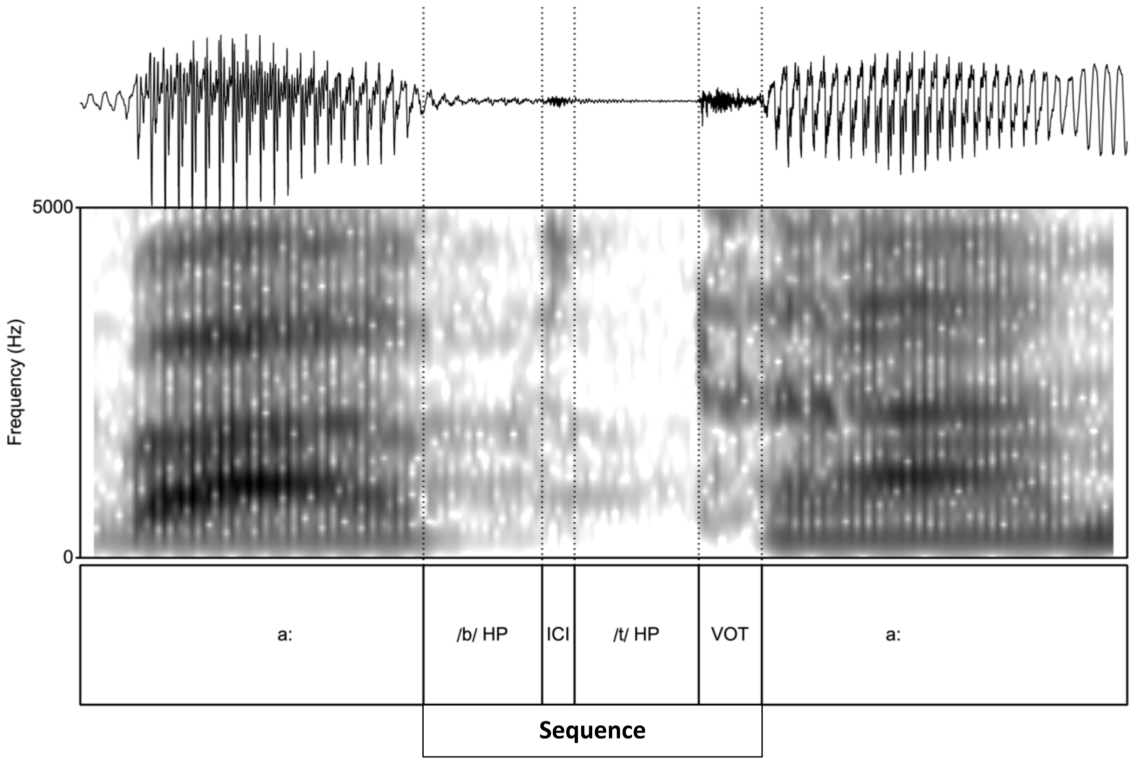


Figure 5.2 Segmentation of /btˤ/ sequence in ba:b#tˤa:lib. It can be noted that C1 (/b/) is not released, and accordingly no ICI occurred.

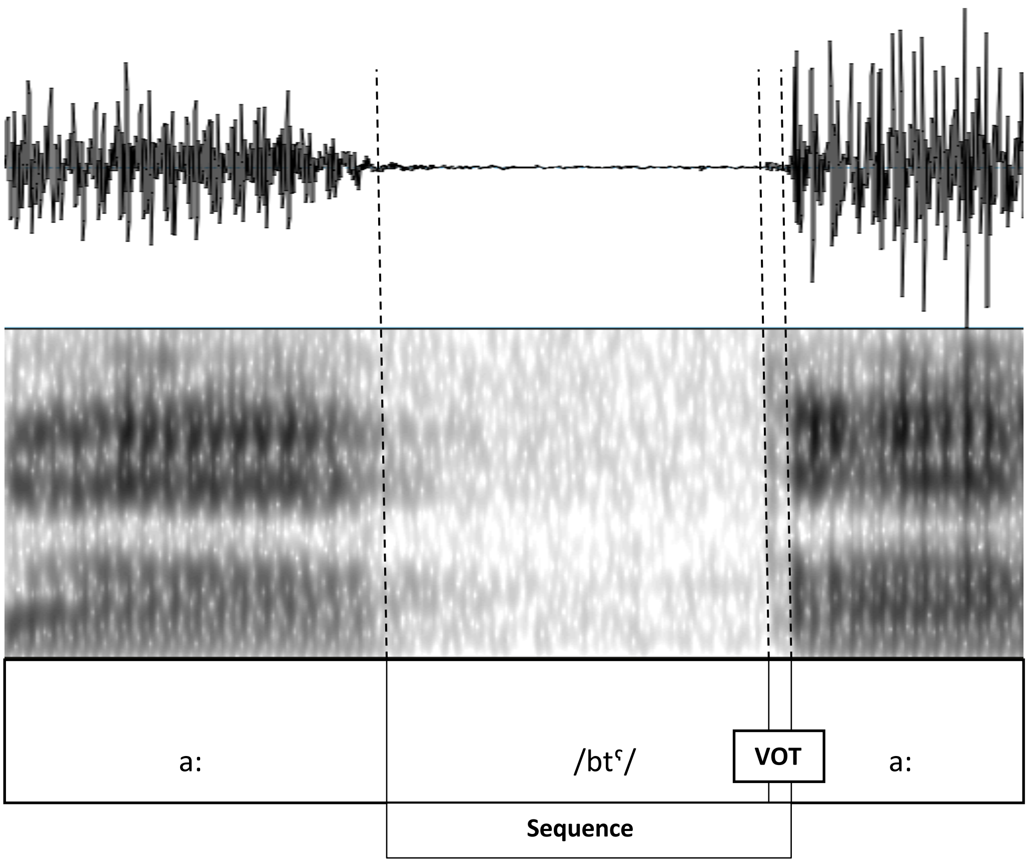


Figure 5.3 Segmentation of /tˤb/ sequence in rabtˤ#bta:kil

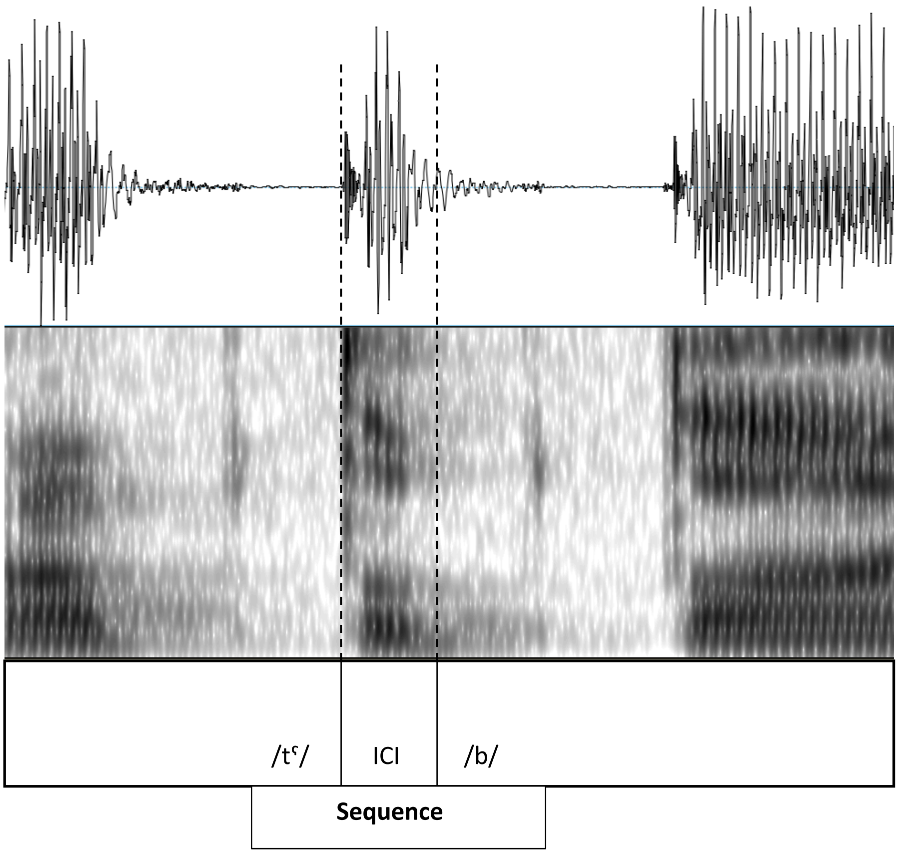
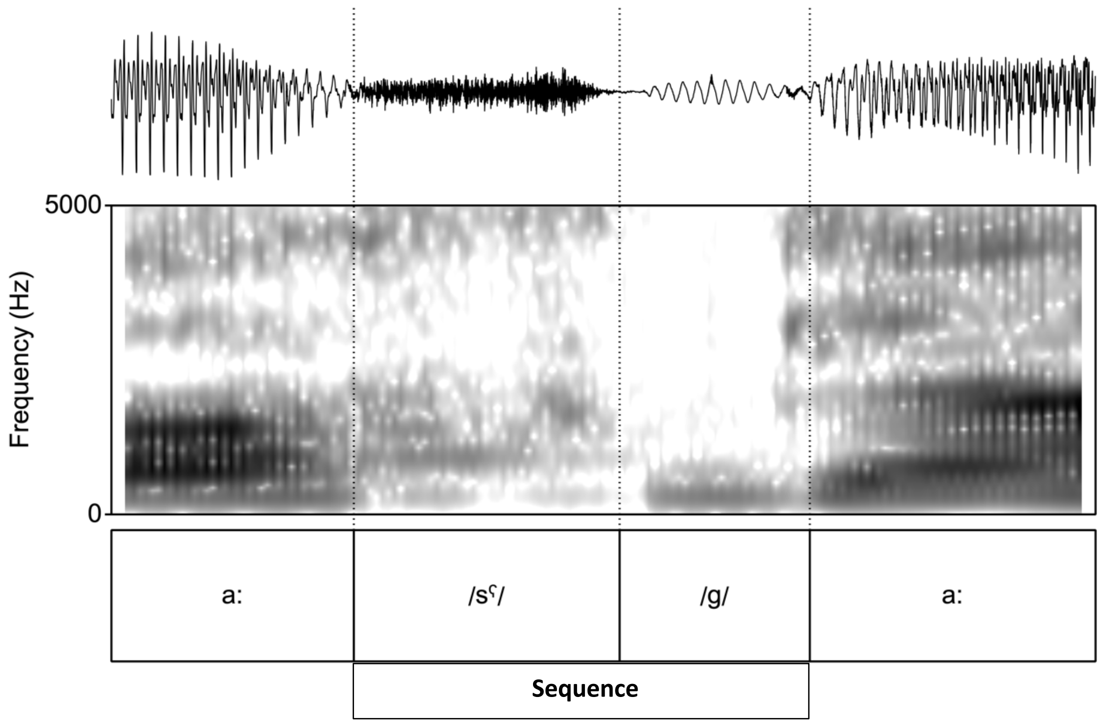


Figure 5.4 Segmentation of /sˤg/ sequence in ba:sˤ#ga:sim



5.6 Statistical Analysis

All statistical analysis was performed using R (R Core Team, 2017). For linear mixed effects modelling, the *lme4* package (Bates, 2015) and *lmerTest* package (Kuznetsova et al, 2017) were used. The *ggplot2* package (Wickham, 2016) was used for visualising data and the *tidyverse* package (Wickham, 2017) was used for obtaining tables including descriptive summaries such as mean values.

Linear mixed-effects models were run with *Speaker* identity as a random intercept and the *Context* (whether plain or emphatic) and its interaction with other independent variables as the crucial fixed factor(s). In sections where the results of the place order effect are presented, linear mixed-effects models were run with *Speaker* identity as a random intercept and the place order (whether front-back or back-front) and its interaction with other independent variables as the crucial fixed factor(s). Likewise, in sections where the results of the identity of the articulators effect are presented, linear mixed-effects models were run with *Speaker* identity as a random intercept and the identity of the articulators (whether lingual/lingual or labial/lingual sequences) and its interaction with other independent variables as the crucial fixed factor(s). These details about the crucial fixed factor(s) will be made clear where relevant in the results chapters. The fixed factors were treatment coded, in which one of the levels is a reference. Similar to Plug et al (2019), all durations were log transformed to minimise the possible effect of outliers. However, the raw values are still presented in descriptive statistics. Table 5.5 lists the variables considered in this study. As explained in Section 5.4, the stimuli were produced at two speech rates, with three repetitions for each rate.

Table 5.5 The list of the variables considered in this study

Dependent variables (all are continuous)	**Independent variables (all are categorical)**
Hold Phase (HP) duration	The identity of the articulators (lingual/lingual, lingual/labial)
Frication duration	Place order (front-back, back-front)
Inter-consonantal interval (ICI) duration	Word positions (##CC, CC##, C#C, CC#CC)
Voice Onset Time (VOT)	Gender (male, female)
ICI count (percentage)	Context (plain, emphatic)[27]
ICI voicing proportion	Rate (normal, fast)
Sequence duration	

[27] In Chapter 7, there are three levels of *Context*: plain voiced, plain voiceless and emphatic.

Not all independent variables are relevant for all analyses. For example, ‘word position’ as an independent variable was only considered in word set C (see Section 5.3.3 for word set C). The variables to be included in the models will be made clear at the beginning of each results chapter.

A stepwise method was used by adding independent variables as main effects one by one. Similar to Plug et al (2019), repetition was added first to the model to see whether it will significantly contribute to the model fit. If not, it was removed and then the predictors were added one by one in a stepwise method. Interaction terms between the crucial fixed factor (e.g., Context, place order or the identity of articulators) and each independent variable were then added in a similar manner. A significant contribution to the model was tested for using ANOVA between models with and without the additional predictor. The effect is considered significant if $P < 0.05$. When a variable did not significantly contribute to the model fit, it was ruled out and then another one was added until we reach the optimal model. At the final stage, after all construction steps, any variables that proved non-significant within the final model summary were removed – so that the models that are presented only contain (robustly) significant variables. This stepwise method was used in relevant studies (e.g., Plug et al, 2019).

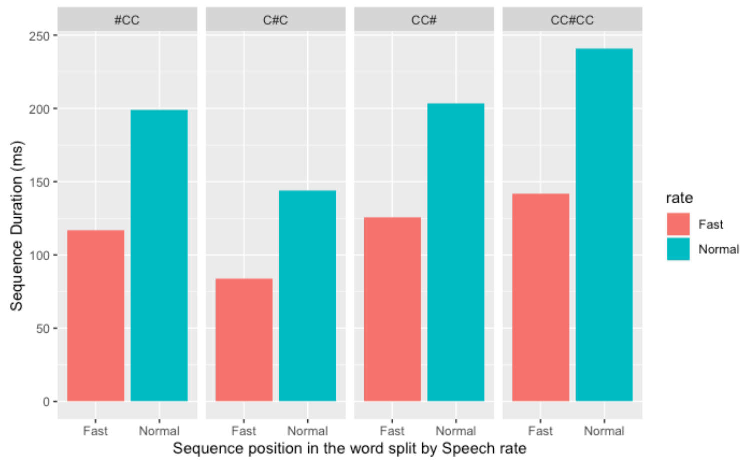
Whenever there was a significant interaction in the optimal model between two predictors, two new subsets were created. For example, if there was a significant interaction between *Context* and *Gender*, a new subset was created that included only male speakers and another that included only female speakers, then further linear mixed-effects models were run to find out which gender shows a significance of context and which does not or to find out which gender exhibits greater effect. It will be made clear where relevant, if such additional models were run. These further models also help verify whether a predictor is statistically significant or just a simple effect. A model may reveal that a particular predictor is significant as a fixed effect while it is in a significant interaction too; this may be a simple effect (Winter, 2019). If, for instance, only male speakers show significance of context, then *Context* is interpreted as a simple effect; if both genders are significant,but one exhibits greater effect than the other, then *Context* is significant as a main effect. This will be made clear where necessary.

As indicated above, ‘Context’ as an independent variable has three levels (plain voiced, plain voiceless and emphatic) in word set B (see Section 5.3.2 for word set B). As pointed out above, in a treatment coded method, one of the levels is a reference, which is automatically picked up alphabetically (Winter, 2019), hence the reference level for this predictor (i.e., Context) is ‘emphatic’. Thus, it is compared to ‘plain voiced’ and ‘plain voiceless’. To make a comparison between 'plain voiced' and 'plain voiceless', the reference was relevelled to be 'plain voiced' using the code: **relevel()**. Then, the model was run with the new reference to have an overall view of the three levels of 'Context' in this word set. This will be made clear where relevant when presenting the results of Chapter 7.

To test Hypothesis (f), concerning the two types of vowel insertion, the ICI was examined whether it would exhibit the characteristics of intrusive or epenthetic vowels, as indicated earlier. Therefore, the distribution of ICI durations in various word positions (#CC, C#C, CC# and CC#CC) were examined to find out whether there are differences in ICI durations, indicating that there are two types of ICIs. The normality of distribution of ICI durations were tested using Shapiro Test. Log transformed values were used for normality tests. Likewise, the normality of distribution of ICI voicing proportion were tested using Shapiro Test. These results will be presented in Chapter 8.

Having discussed the statistical analysis followed in the current study, the following chapters will present the results. Before presenting the results in the following chapters, it is worth ensuring that the speech rate manipulation was successful. Figure 5.5 shows the sequence duration, considering the speech rate (normal and fast) in various word positions. Sequence duration is shorter at fast speech rate than at normal rate in all word positions.

Figure 5.5 Sequence duration with two speech rates (normal and fast) in various word positions



5.7 Summary

This chapter focused on the methodology followed to conduct the current study. The main research questions and associated hypotheses were restated. The word lists, designed to test the proposed hypotheses, were presented. It has been shown that the word lists were designed in light of the variables considered to test the proposed hypotheses and to answer the research questions. The procedure followed to conduct the study, including how the participants were recorded and how the recorded data was processed, was discussed. The acoustic analysis of the recorded data, i.e. segmentation and the extracted durations, was explained. After that, the statistical analysis of the quantitative data was explained.

Now we turn to the results of the current study. The results will be presented over three consecutive chapters. The results of each word set will be presented in a separate chapter because each word set was designed to address a specific research question, as pointed out above. All considerations taken for each word set, as explained above, will be made clear at the beginning of each results chapter.

The results presented in Chapter 6 concerns the impact of the secondary articulation on gestural overlap (word set A). The results presented in Chapter 7 concerns the impact of the state of the glottis on gestural overlap (word set B). The results presented in Chapter 8 concerns the types of vowel insertion and their interaction with emphasis (word set C).

6 Results: the secondary articulation of emphasis and gestural overlap

6.1 Introduction

This chapter presents the results concerning the impact of the secondary articulation of emphasis on gestural overlap in consonant sequences. As discussed in Chapter 5, the material of the current thesis was divided into three word sets, and each word set was designed to address a specific research question and test the associated hypotheses. The relevant word set in this chapter is word set A (see Table 5.1 in Chapter 5 for word set A). As discussed in Chapter 5, word set A was designed to address Research Question 1a and test hypotheses (a) and (b), as restated below:

RQ1,a: Does the secondary articulation of emphatic coronals have an impact on the degree of gestural overlap in consonant sequences?

Hypothesis (a) lingual/lingual consonant sequences will exhibit a lower degree of gestural overlap than labial/lingual consonant sequences.

Hypothesis (b) lingual/lingual consonant sequences in an emphatic context will exhibit a lower degree of gestural overlap than lingual/lingual consonant sequences in the plain counterpart.

As also explained in Chapter 5, Hypotheses (i) and (j), as restated below, are common hypotheses that are tested in all three word sets.

Hypothesis (i) back-front consonant sequences will exhibit a lower degree of gestural overlap than front-back consonant sequences.

Hypothesis (j) consonant sequences at a fast speech rate will exhibit a greater degree of gestural overlap than sequences at a normal speech rate.

As discussed in Chapter 5, to address the above research question and test the above two specific hypotheses (*a* and *b*), word set A was designed to include labial/lingual (e.g., /b#t/, /b#s/, /t#b/, /s#b/) and lingual/lingual (e.g., /g#t/, /g#s/, /t#g/, /s#g/) sequences. This helps to test Hypothesis (a). To test Hypothesis (b), the emphatic coronals /tˤ/, /sˤ/ and /ðˤ/ were included in the list. For example, timing relations in /g#t/ were compared to those in /g#tˤ/, timing relations in /g#s/ were compared to those in /g#sˤ/, and timing relations in /g#ð/ were compared to those in /g#ðˤ/. Same comparison was made for the other place order (i.e., /t#g/ vs /tˤ#g/, /s#g/ vs /sˤ#g/ and /ð#g/ vs /ðˤ#g/). As also made clear in Chapter 5, according to Najdi Arabic lexicon, lingual/lingual sequences do not frequently occur word-initially or word-finally. Because the pairs to be examined need to be carefully designed to be closely matched as possible, these consonant sequences were examined as occurring across a word boundary (C#C). The independent variables that are considered in this chapter are as follows:

1. The identity of the articulators (lingual/lingual, labial/lingual)
2. Context (plain, emphatic)
3. Order of place of articulation (front-back, back-front)
4. Speech rate (normal, fast)
5. Gender (male, female)

There are three sequence types in word set A: stop/stop sequences (e.g., /bt/ and /tb/), stop/alveolar fricative sequences (e.g., /bs/ and /sb/) and stop/dental fricative sequences (e.g., /bð/ and /ðb/). The results of each sequence type will be presented separately in three consecutive sections, and accordingly the hypotheses will be tested for each sequence type; and the results of these sections will be summarised in Section 6.5, where it will be made clear whether the hypotheses are supported or not for all sequence types.

Each section will start with reporting the results of the common hypotheses (i) and (j), and the remainder of each section will be devoted to the results of the specific hypotheses (i.e., Hypothesis (a) and Hypothesis (b)). Accordingly, this chapter consists of five sections. Section 6.1 is an introductory section. Section 6.2 presents the results of stop/stop sequences. Section 6.3 presents the results of stop/alveolar fricative sequences. Section 6.4 presents the results of stop/dental fricative sequences. The chapter ends with an interim discussion in Section 6.5 in which the results of the chapter are summarised, and it will be made clear whether the specific hypotheses (a) and (b) and the common hypotheses (i) and (j) are supported or not.

A further point that is worth reiterating before reporting the results concerns the measures that were used to determine the degree of gestural overlap in this thesis. As made clear in Chapters 1, 2 and 5, ICI occurrence/count (whether an ICI occurs in the sequence or not), ICI duration if it occurs, sequence duration, in addition to the individual intervals (e.g., the hold phase, frication durations) within the sequence, were used as measures to determine the degree of gestural overlap in consonant sequences. The degree of gestural overlap is determined as follows:

The lower the ICI count[28] (percentage), the greater the degree of gestural overlap.

The shorter the ICI duration, the greater the degree of gestural overlap.

[28] As made clear in Chapters 1, ICI occurrence (whether an ICI occurs in the sequence or not) will be called ICI count in the results chapters.

The shorter the sequence duration and/or an individual interval within the sequence (e.g., the hold phase, frication), the greater the degree of gestural overlap.

6.2 Stop/stop sequences

6.2.1 The results of the place order effect[29] (common Hypothesis (i))

As pointed out in Chapter 5, linear mixed-effects models were run to test Hypothesis (i) with the place order and its interaction with other independent variables as the crucial fixed factor(s). The independent variables that were included in these models are the identity of the articulators, Context (plain, emphatic), order of place of articulation, speech rate and gender.

Table 6.1 ICI count. Yes (count and percentage of occurring ICIs), Not (count and percentage of non-occurring ICIs)

Place Order	**Total *n***	**Not**		**Yes**	
		n	**Percentage**	***n***	**Percentage**
back-front	384	136	35.42	248	64.58
front-back	384	181	47.14	203	52.86
Total	768	317	41.28	451	58.72

The ICI count, ICI duration and sequence duration in back-front were compared to those in front-back stop/stop sequences, occurring at the word boundary (C#C). Sequences in a back-front place order include /tb/, /tˤb/, /gt/ and /gtˤ/, and sequences in a front-back order include /bt/, /btˤ/, /tg/ and /tˤg/ sequences.

As in Table 6.1 the ICI occurs more often in back-front than in front-back place order (64% and 52% respectively). When considering other independent variables, however, it turns out that the place order effect on ICI count (i.e., ICIs occur more often in back-front than front-back sequences) is only exhibited in labial/lingual sequences (35% in back-front vs 11% in front-back), compared to lingual/lingual sequences (95% in back-front vs 94% in front-back). The ICI and sequence durations are presented in Table 6.2.

Table 6.2 Acoustic measurements for stop/stop sequences (mean_values)

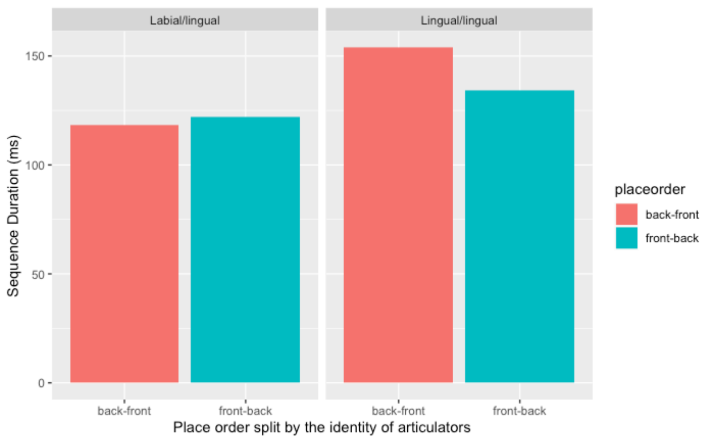
Place Order	**ICI_duration**	**Sequence_duration**
back-front	22.43	136.11
front-back	25.29	128.20

[29] As made clear in chapter 2, place order effect refers to the observation that back-front sequences exhibit lower degree of gestural overlap than front-back sequences. This is referred to as the place order effect throughout the thesis.

Regarding the ICI duration, which is the second main measure to determine the degree of gestural overlap, the results reveal that there is no a significant difference between the two place orders (i.e., back-front and front-back) in the ICI duration as in the optimal model in Table 6.3. Similarly, the results reveal that the place order as a main effect is not statistically significant in sequence duration, which is the third main measure to determine the degree of gestural overlap as in Table 6.4; the place order, however, significantly interacts with the identity of the articulators (n= 768, β=-0.078553, SE=0.008048, t-value=-9.761, p<0.001) as in the optimal model in Table 6.4, and as visualised in Figure 6.1. The results of further models[30] reveal that sequence duration in back-front place order is significantly longer than in front-back order only in lingual/lingual sequences (n= 384, β=-0.06267, SE=0.002764, t-value=-22.68, p<0.001),but no significant differences were found between the two orders in labial/lingual sequences, as in the optimal models in Tables 6.5 and 6.6.

In general, the ICI occurs more often in a back-front than in front-back place order only in labial/lingual sequences. While no differences were found between the two orders in ICI duration, sequence duration was significantly longer in a back-front than in front-back place order only in lingual/lingual sequences. Accordingly, there is *no strong evidence* to conclude that the place order effect is exhibited in stop/stop sequences, occurring at the word boundary (C#C) in Najdi Arabic.

Figure 6.1 Sequence_duration in stop/stop sequences in both place orders, split by the identities of articulators



[30] As made clear in Chapter 5, whenever the optimal model reveals that there is a significant interaction between two independent variables, two new subsets (one for each level) were created. In this significant interaction (place order and the identity of articulators), a new subset was created that included only lingual/lingual sequences and another that included only labial/lingual sequences, then further models were run to find out which identity of articulators shows a significance of place order effect, or to find out which identity exhibits a greater effect.

*Table 6.3 The optimal model of ICI_duration in stop/stop sequences. Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1*

```
Formula: icilog ~rate + gender + Context + articulators + (1 | speaker)
   Data: At
Fixed effects:
                            Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)                  0.95532   0.02258 446.00000 42.311  <2e-16***
rateNormal                   0.13498   0.01481 446.00000  9.116  <2e-16***
genderMale                   0.02951   0.01452 446.00000  2.033 0.042667*
ContextPlain                -0.05147   0.01464 446.00000 -3.517 0.000481***
articulatorsLingual/lingual  0.38453   0.01842 446.00000 20.876  <2e-16***
```

*Table 6.4 The optimal model of sequence_duration in stop/stop sequences. Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1*

```
Formula: wslog ~ rate + Context + placeorder + articulators + placeorder:articulators +
(1 | speaker)
   Data: At
Fixed effects:
                                                  Estimate Std.Error         df tvalue
Pr(>|t|)
(Intercept)                                       1.974824   0.004928 762.000000
400.728  <2e-16***
rateNormal                                        0.152683   0.004024 762.000000
37.945  <2e-16***
ContextPlain                                      0.020343   0.004024 762.000000
5.056 5.37e-07***
placeorderfront-back                              -0.015875   0.008869 762.000000   -
1.790  0.07385.
articulatorsLingual/lingual                       0.117906   0.005690 762.000000
20.720  <2e-16***
placeorderfront-back:articulatorsLingual/lingual -0.078553   0.008048 762.000000  -
9.761  <2e-16***
```

<u>FURTHER</u>

Table 6.5 The optimal model of sequence_duration in stop/stop sequences (in labial/ingual sequence)

```
Formula: wslog ~ rate + Context + (1 | speaker)
   Data: At_LAB
Fixed effects:
              Estimate Std.Error        df  tvalue Pr(>|t|)
(Intercept)  1.937e+00 4.404e-03 3.800e+02 439.927  <2e-16***
rateNormal   1.435e-01 4.404e-03 3.800e+02  32.593  <2e-16***
ContextPlain 1.043e-01 4.404e-03 3.800e+02  23.687  <2e-16***
```

Table 6.6 The optimal model of sequence_duration in stop/stop sequences (in lingual/ingual sequence)

```
Formula: wslog ~ rate + Context + placeorder + (1 | speaker)
   Data: At_DOR
Fixed effects:
                      Estimate Std.Error         df tvalue Pr(>|t|)
(Intercept)           2.130143  0.003136  79.761167 679.33  <2e-16***
rateNormal            0.161829  0.002764 365.000000  58.55  <2e-16***
ContextPlain         -0.063629  0.002764 365.000000 -23.02  <2e-16***
placeorderfront-back -0.062677  0.002764 365.000000 -22.68  <2e-16***
```

6.2.2 The results of the speech rate effect[31] (Hypothesis (j))

As made clear in Chapter 2, the main measure to determine whether there is an effect of speech rate on gestural overlap is the ICI count/occurrence (whether an ICI occurs in the sequence or not). Therefore, the ICI count is the only dependent variable considered here.

Table 6.7 ICI count. Yes (count and percentage of occurring ICIs), Not (count and percentage of non-occurring ICIs)

Speech Rate	**Total *n***	**Not**		**Yes**	
		n	**Percentage**	***n***	**Percentage**
Fast	384	198	51.56	186	48.44
Normal	384	119	30.99	265	69.01
Total	768	317	41.27	451	58.72

As in Table 6.7, the ICIs occur less often in fast speech rate than in normal rate by around 21%. The other independent variables (i.e., gender, Context, place order and the identity of articulators) did not play any role in the speech rate effect. Accordingly, it can be concluded that stop/stop sequences (C#C) at fast speech rate exhibit greater degree of gestural overlap than in normal speech rate in Najdi Arabic.

Having presented the results of the common hypotheses (i) and (j) that are relevant to the place order effect and speech rate effect, now we turn to present the results of the specific hypothesis (a) which concerns the effect of the identity of the articulators.

6.2.3 The results of the impact of the identity of the articulators[32] (Hypothesis (a))

As pointed out in Chapter 5, linear mixed-effects models were run to test Hypothesis (a) with the identity of the articulators and its interaction with other independent variables as the crucial fixed factor(s). The independent variables that were included in these models are the identity of the articulators, Context (plain, emphatic), order of place of articulation, speech rate and gender.

The ICI count, ICI duration and sequence duration in lingual/lingual sequences were compared to those in labial/lingual sequences, occurring at the word boundary (C#C).

[31] As made clear in Chapter 2, speech rate effect refers to the observation that sequences at fast rate exhibit greater degree of gestural overlap than sequences at normal rate. This is referred to as the speech rate effect throughout the thesis.

[32] As made clear in chapter 2, the identity of the articulators effect refers to the observation that lingual/lingual sequences exhibit lower degree of gestural overlap than labial/lingual sequences. This is referred to as the identity of the articulators effect throughout the thesis.

Lingual/lingual sequences include /tg/, /tˤg/, /gt/ and /gtˤ/, and labial/lingual sequences include /bt/, /btˤ/, /tb/ and /tˤb/.

Table 6.8 ICI count. Yes (count and percentage of occurring ICIs), Not (count and percentage of non-occurring ICIs)

Articulators	**Total *n***	**Not**		**Yes**	
		n	**Percentage**	***n***	**Percentage**
Labial/lingual	384	293	76.30	91	23.70
Lingual/lingual	384	24	6.25	360	93.75
Total	768	317	41.28	451	58.72

Table 6.9 Acoustic measurements for stop/stop sequences (mean_values)

Articulators	**ICI_duration_(ms)**	**Sequence_duration_(ms)**
Labial/lingual	12.61	120.29
Lingual/lingual	26.52	144.02

As in Table 6.8, the ICI occurs more often in lingual/lingual sequences than in labial/lingual sequences (93% and 23% respectively). The ICI and sequence durations are presented in Table 6.9. The ICI is significantly longer in duration in lingual/lingual sequences than in labial/lingual sequences (n= 451, β=0.759986, SE=0.017484, t-value=43.467, p<0.001) as in Table 6.10. The results also reveal that there is a significant interaction between the identity of articulators and Context in ICI duration (n= 451, β=-0.625982, SE=0.022476, t-value=-27.851, p<0.001) as visualised in Figure 6.2. The results of further models[33] reveal that the ICI duration is significantly longer in lingual/lingual sequences than in labial/lingual sequences across Context, but the effect is greater in an emphatic context than in the plain counterpart, as in the optimal models in Tables 6.11 and 6.12. Similarly, sequence duration is significantly longer in lingual/lingual sequences than in labial/lingual sequences (n=768,β=0.192732, SE= 0.005233, t-value=36.833,p<0.001) as in Table 6.13, but this can be a simple effect because the results also reveal that there is a significant interaction between the identity of articulators and Context in sequence duration (n=768,β=-0.167945, SE=0.005233, t-value=-32.096,p<0.001) as visualised in Figure 6.3. The results of further models[34] reveal that sequence duration is significantly longer in lingual/lingual sequences than in labial/lingual sequences only in an emphatic context,but not in the plain counterpart, as in the optimal models in Tables 6.14 and 6.15. This indicates that the identity of the articulators effect on sequence duration, as a main effect, is a simple effect. Besides, the results reveal that the identity of articulators significantly interacts

[33] A new subset was created that included only emphatic context and another that included only plain context, then further models were run to find out which context exhibits a greater effect.
[34]A new subset was created that included only emphatic context and another that included only plain context, then further models were run to find out which Context exhibits greater effect.

with speech rate (n=768,β=0.018291,SE=0.005233,t-value=3.496,p<0.001), as visualised in Figure 6.4, and with place order (n=768,β=-0.078553, SE=0.005233, t-value=-15.012,p<0.001), as visualised in Figure 6.5, in sequence duration. The results of further models[35] reveal that sequence duration is significantly longer in lingual/lingual sequences than in labial/lingual sequences across speech rate, but the effect is greater at normal rate than at fast rate, as in the optimal models in Tables 6.16 and 6.17. Likewise, sequence duration is significantly longer in lingual/lingual sequences than in labial/lingual sequences across place order, but the effect is greater in back-front than in front-back order, as in the optimal models in Tables 6.18 and 6.19.

Figure 6.2 ICI_duration in stop/stop sequences in both identities of articulators, split by Context

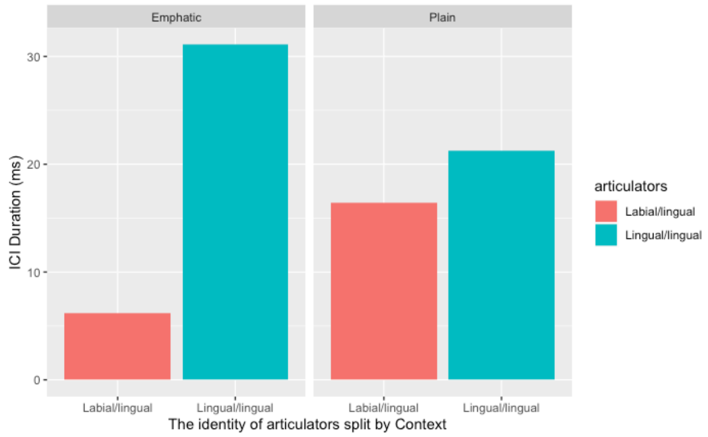
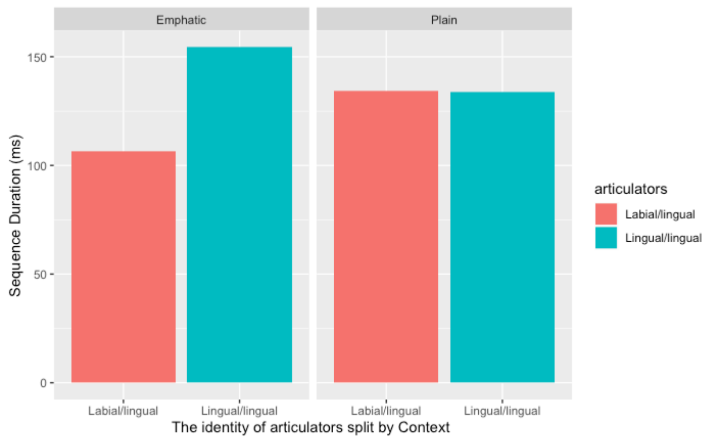


Figure 6.3 Sequence_duration in stop/stop sequences in both identities of articulators, split by Context



[35]A new subset was created that included only normal speech rate and another that included only fast speech rate, then further models were run to find out which speech rate exhibits greater effect.

Figure 6.4 Sequence_duration in stop/stop sequences in both identities of articulators, split by speech rate

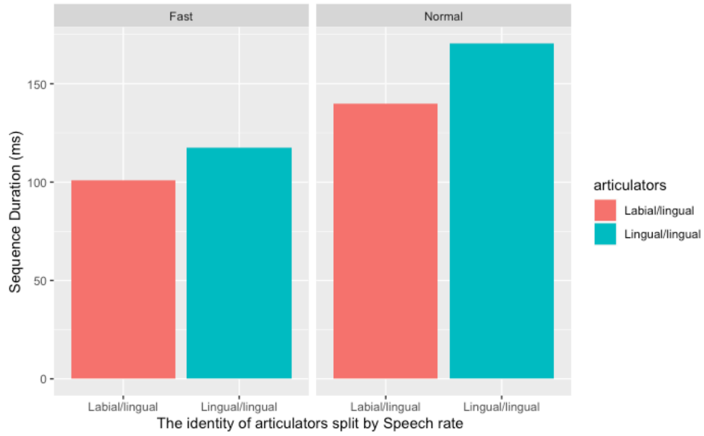
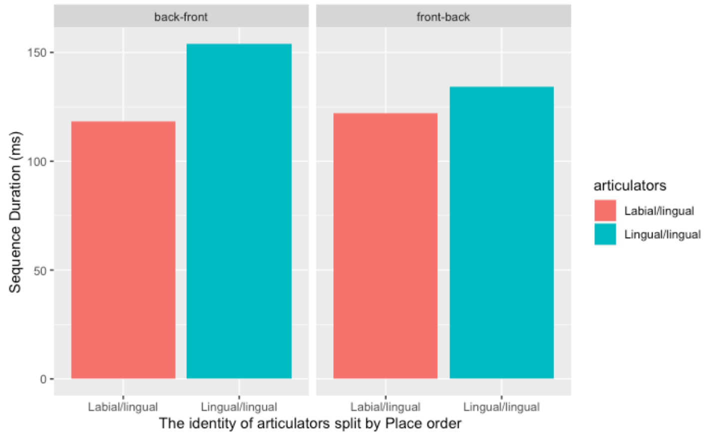


Figure 6.5 Sequence_duration in stop/stop sequences in both identities of articulators, split by place order



In general, the ICI occurs more often in lingual/lingual sequences than in labial/lingual sequences. The ICI duration is significantly longer in lingual/lingual sequences than in labial/lingual sequences. Sequence duration is significantly longer in lingual/lingual sequences than in labial/lingual sequences only in an emphatic context. Accordingly, it can be concluded that lingual/lingual sequences exhibit lower degree of gestural overlap than labial/lingual sequences in stop/stop sequences, occurring at the word boundary (C#C) in Najdi Arabic, *based on ICI count and ICI duration*.

Based on the above results, it can be concluded that Hypothesis (a) is supported for stop-stop sequences. This hypothesis will be discussed further in Section 6.5.

Table 6.10 The optimal model of ICI_duration in stop/stop sequences

```
Formula: icilog ~ rate + gender + Context + articulators + articulators:Context + (1 |
speaker)
   Data: At
Fixed effects:
                                          Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)                               0.628296   0.018004 445.000000  34.898  <2e-
16***
rateNormal                                0.148933   0.008965 445.000000  16.613  <2e-
16***
genderMale                                0.030558   0.008776 445.000000   3.482
0.000547***
ContextPlain                             -0.453817   0.020185 445.000000  -22.483  <2e-
16***
articulatorsLingual/lingual               0.759986   0.017484 445.000000  43.467  <2e-
16***
ContextPlain:articulatorsLingual/lingual  -0.625982   0.022476 445.000000 -27.851  <2e-
16***
```

FURTHER

Table 6.11 The optimal model of ICI_duration in stop/stop sequences (in an emphatic Context)

```
Formula: icilog ~ rate + gender + articulators + (1 | speaker)
   Data: At_E
Fixed effects:
                             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)                   0.60655    0.02027 222.00000  29.921  <2e-16***
rateNormal                    0.14854    0.01297 222.00000  11.450  <2e-16***
genderMale                    0.07221    0.01270 222.00000   5.686 4.08e-08***
articulatorsLingual/lingual   0.76111    0.01809 222.00000  42.074  <2e-16***
```

Table 6.12 The optimal model of ICI_duration in stop/stop sequences (in a plain Context)

```
Formula: icilog ~ rate + articulators + (1 | speaker)
   Data: At_P
Fixed effects:
                             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)                   1.09915    0.01395 222.00000   78.81   <2e-16***
rateNormal                    0.14833    0.01174 222.00000   12.63   <2e-16***
articulatorsLingual/lingual   0.13332    0.01327 222.00000   10.04   <2e-16***
```

Table 6.13 The optimal model of sequence_duration in stop/stop sequences

```
Formula: wslog ~ rate + Context + articulators + articulators:Context +
    articulators:rate + articulators:placeorder + (1 | speaker)
   Data: At
Fixed effects:
                                                  Estimate Std.Error        df tvalue
Pr(>|t|)
(Intercept)                                       1.937411   0.003700 760.000000
523.619  <2e-16***
rateNormal                                        0.143538   0.003700 760.000000
38.794  <2e-16***
ContextPlain                                      0.104316   0.003700 760.000000
28.193  <2e-16***
articulatorsLingual/lingual                       0.192732   0.005233 760.000000
36.833  <2e-16***
ContextPlain:articulatorsLingual/lingual         -0.167945   0.005233 760.000000 -
32.096  <2e-16***
rateNormal:articulatorsLingual/lingual            0.018291   0.005233 760.000000
3.496    5e-04***
articulatorsLabial/lingual:placeorderfront-back   0.015875   0.003700 760.000000
4.291 2.01e-05***
articulatorsLingual/lingual:placeorderfront-back -0.062677   0.003700 760.000000 -
16.940  <2e-16***
```

FURTHER

Table 6.14 The optimal model of sequence_duration in stop/stop sequences (in an emphatic Context)

```
Formula: wslog ~ rate + articulators + articulators:placeorder + (1 | speaker)
   Data: At_E
Fixed effects:
                                                    Estimate Std.Error        df tvalue
Pr(>|t|)
(Intercept)                                         1.933023   0.004496 379.000000
429.927  <2e-16***
rateNormal                                          0.158653   0.004021 379.000000
39.451  <2e-16***
articulatorsLingual/lingual                         0.190504   0.005687 379.000000
33.497  <2e-16***
articulatorsLabial/lingual:placeorderfront-back     0.009536   0.005687 379.000000
1.677   0.0944 .
articulatorsLingual/lingual:placeorderfront-back   -0.046269   0.005687 379.000000  -
8.136 5.93e-15***
```

Table 6.15 The optimal model of sequence_duration in stop/stop sequences (in a plain Context)

```
Formula: wslog ~ rate + articulators + articulators:placeorder + (1 | speaker)
   Data: At_P
Fixed effects:
                                                    Estimate Std.Error        df tvalue
Pr(>|t|)
(Intercept)                                         2.036969   0.003660 379.000000
556.525  <2e-16***
rateNormal                                          0.146714   0.003274 379.000000
44.815  <2e-16***
articulatorsLingual/lingual                         0.045307   0.004630 379.000000
9.786  <2e-16***
articulatorsLabial/lingual:placeorderfront-back     0.022214   0.004630 379.000000
4.798 2.31e-06***
articulatorsLingual/lingual:placeorderfront-back   -0.079086   0.004630 379.000000 -
17.082  <2e-16***
```

Table 6.16 The optimal model of sequence_duration in stop/stop sequences (at normal rate)

```
Formula: wslog ~ Context + articulators + articulators:Context + articulators:placeorder
+ (1 | speaker)
   Data: At_Normal
Fixed effects:
                                                    Estimate Std.Error        df tvalue
Pr(>|t|)
(Intercept)                                         2.095307   0.004110 190.943461
509.820   <2e-16***
ContextPlain                                        0.093169   0.004553 363.000000
20.462   <2e-16***
articulatorsLingual/lingual                         0.191837   0.005577 363.000000
34.401   <2e-16***
ContextPlain:articulatorsLingual/lingual           -0.157590   0.006439 363.000000 -
24.474   <2e-16***
articulatorsLabial/lingual:placeorderfront-back    -0.001693   0.004553 363.000000  -
0.372     0.71
articulatorsLingual/lingual:placeorderfront-back   -0.052228   0.004553 363.000000 -
11.471   <2e-16***
```

Table 6.17 The optimal model of sequence_duration in stop/stop sequences (at fast rate)

```
Formula: wslog ~ Context + articulators + articulators:Context + articulators:placeorder
+  (1 | speaker)
   Data: At_Fast
Fixed effects:
                                                   Estimate Std.Error        df tvalue
Pr(>|t|)
(Intercept)                                        1.923053   0.004824 378.000000
398.684  <2e-16***
ContextPlain                                       0.115463   0.005570 378.000000
20.731  <2e-16***
articulatorsLingual/lingual                        0.211919   0.006821 378.000000
31.066  <2e-16***
ContextPlain:articulatorsLingual/lingual          -0.178300   0.007877 378.000000 -
22.636  <2e-16***
articulatorsLabial/lingual:placeorderfront-back    0.033444   0.005570 378.000000
6.005  4.5e-09***
articulatorsLingual/lingual:placeorderfront-back  -0.073126   0.005570 378.000000 -
13.129  <2e-16***
```

Table 6.18 The optimal model of sequence_duration in stop/stop sequences (in front-back place order)

```
Formula: wslog ~ rate + Context + articulators + articulators:Context +
    articulators:rate + (1 | speaker)
   Data: At_FB
Fixed effects:
                                           Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)                                1.958901   0.004429 197.892112 442.335  <2e-
16***
rateNormal                                 0.125969   0.004928 363.000000  25.559  <2e-
16***
ContextPlain                               0.110655   0.004928 363.000000  22.452  <2e-
16***
articulatorsLingual/lingual                0.111545   0.006036 363.000000  18.479  <2e-
16***
ContextPlain:articulatorsLingual/lingual  -0.190692   0.006970 363.000000 -27.359  <2e-
16***
rateNormal:articulatorsLingual/lingual     0.046309   0.006970 363.000000   6.644 1.12e-
10***
```

Table 6.19 The optimal model of sequence_duration in stop/stop sequences (in back-front place order)

```
Formula: wslog ~ rate + Context + articulators + articulators:Context + (1 | speaker)
   Data: At_BF
Fixed effects:
                                           Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)                                1.934228   0.004072 379.000000  475.05   <2e-
16***
rateNormal                                 0.156243   0.003642 379.000000   42.90   <2e-
16***
ContextPlain                               0.097977   0.005150 379.000000   19.02   <2e-
16***
articulatorsLingual/lingual                0.190504   0.005150 379.000000   36.99   <2e-
16***
ContextPlain:articulatorsLingual/lingual  -0.145197   0.007284 379.000000  -19.93   <2e-
16***
```

Having presented the results of the impact of the identity of the articulators (Hypothesis (a)), now we present the results of the specific hypothesis (b) which concerns the impact of the secondary articulation of emphatic coronals.

6.2.4 The results of the impact of the secondary articulation of emphatic coronals (Hypothesis (b))

As pointed out in Chapter 5, linear mixed-effects models were run to test Hypothesis (b) with Context (emphatic or plain) and its interaction with other independent variables as the crucial fixed factor(s). The independent variables that were included in these models are Context, order of place of articulation, speech rate and gender.

Table 6.20 ICI count in lingual/lingual sequences. Yes (count and percentage of occurring ICIs), Not (count and percentage of non-occurring ICIs)

Context	**Total n**	**Not**		**Yes**	
		n	**Percentage**	***n***	**Percentage**
Emphatic	192	0	0	192	100
Plain	192	24	12.5	168	87.5
Total	384	24	6.25	360	93.75

Table 6.21 Acoustic measurements for stop/stop sequences (mean_values)

Context	**ICI_duration**	**Sequence_duration**
Emphatic	31.10	154.39
Plain	21.29	133.65

To test Hypothesis (b), emphatic coronals were considered, as explained above. As in Table 6.20, the ICI occurs more often in an emphatic context than in the plain counterpart in lingual/lingual sequences (100 % and 87.5 % respectively), indicating that the consonantal gestures tend to be less overlapped in an emphatic context than in the plain counterpart. In those instances where ICIs occur, the average duration of the ICI is 31ms in an emphatic context and 21ms in the plain counterpart, as in Table 6.21. The results reveal that this difference in ICI duration is statistically significant (n=360,β=-0.120859, SE=0.012172, t-value=-9.930,p<0.001) as in Table 6.22. The results also reveal that there is a significant interaction between Context and gender in ICI duration (n=360,β=-0.100067, SE=0.016977, t-value=-5.894,p<0.001) as visualised in Figure 6.6. The results of further models[36] reveal that the ICI duration is longer in an emphatic context than in the plain counterpart across gender, and the effect is greater in male speech as in Tables 6.23 and 6.24. Likewise, sequence duration is significantly longer in an emphatic context than in the plain counterpart in lingual/lingual sequences (n=384, β=-0.037494, SE=0.004476, t-value=-8.376,p<0.001) as in Table 6.25. The results also reveal that Context significantly interacts with gender (n=384,β=-0.019453,

[36] A new subset was created that included only male speakers and another that included only female speakers, then further models were run to examine which gender exhibits greater effect.

SE=0.005169, t-value=-3.764,p<0.001) as visualised in Figure 6.7, and with the place order (n=384,β=-0.046269, SE=0.003655, t-value=-12.659 ,p<0.001) in sequence duration as visualised in Figure 6.8. The results of further models[37] reveal that the sequence duration is longer in an emphatic context than in the plain counterpart across gender, but the effect is greater in male speech as in Tables 6.26 and 6.27. The results of further models[38] also reveal that the sequence duration is longer in an emphatic context than in the plain counterpart across place order, but the effect is greater in back-front place order as in Tables 6.28 and 6.29.

Figure 6.6 ICI_duration in stop/stop sequences in both Contexts, split by gender

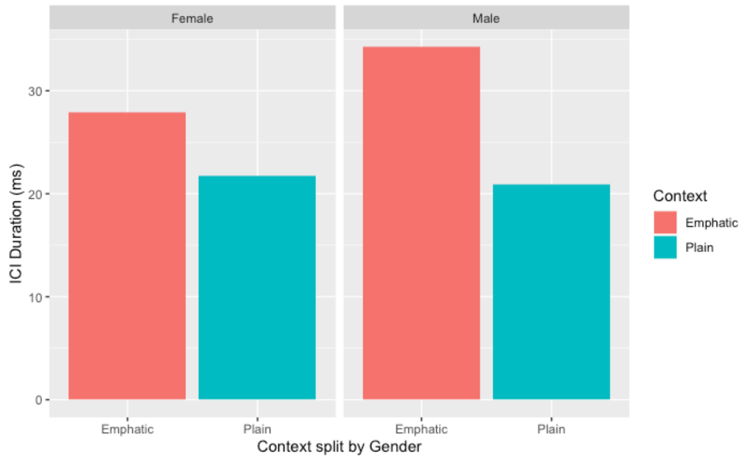
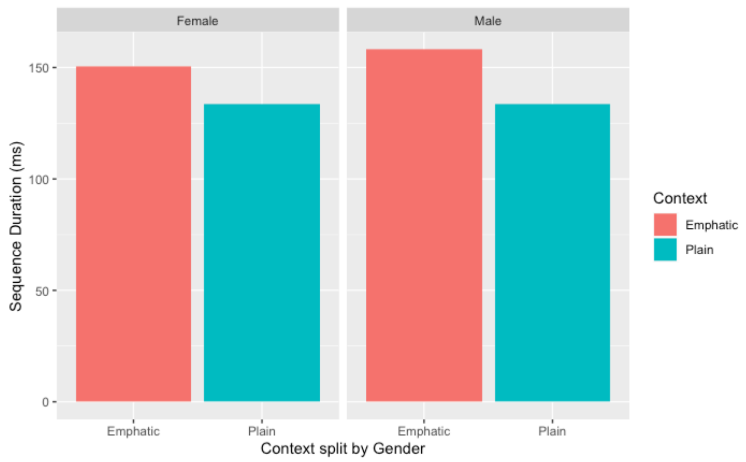
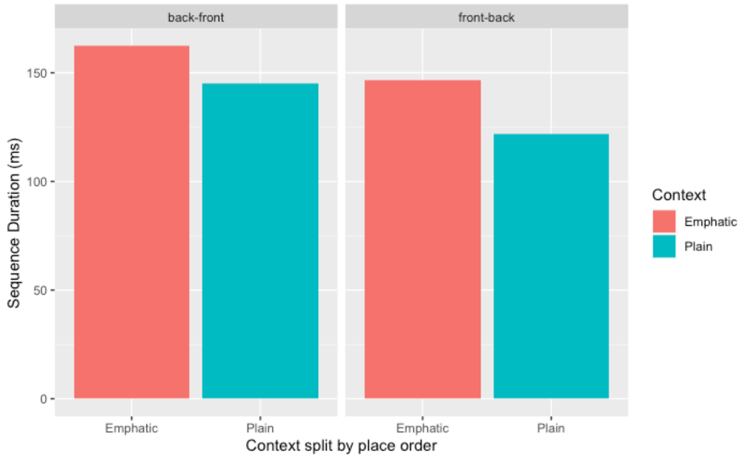


Figure 6.7 Sequence_duration in stop/stop sequences in both Contexts, split by gender



[37] A new subset was created that included only male speakers and another that included only female speakers, then further models were run to examine which gender exhibits greater effect.
[38] A new subset was created that included only back-front sequences and another that included only front-back sequences, then further models were run to examine which place order exhibits greater effect.

Figure 6.8 Sequence_duration in stop/stop sequences in both Contexts, split by place order



Based on these results, it can be concluded that lingual/lingual sequences exhibit lower degree of gestural overlap in an emphatic context than in the plain counterpart in stop/stop sequences in Najdi Arabic (NA). This hypothesis (b) will be discussed further in Section 6.5.

Table 6.22 The optimal model of ICI_duration in stop/stop sequences (in lingual/lingual sequences)

Formula: icilog ~ rate + gender + Context + Context:gender + (1 | speaker)
Data: At_DOR
Fixed effects

	Estimate	Std.Error	df	tvalue	Pr(>|t|)
(Intercept)	1.361699	0.009230	355.000000	147.532	<2e-16***
rateNormal	0.144577	0.008493	355.000000	17.022	<2e-16***
genderMale	0.088079	0.011589	355.000000	7.600	2.66e-13***
ContextPlain	-0.120859	0.012172	355.000000	-9.930	<2e-16***
genderMale:ContextPlain	-0.100067	0.016977	355.000000	-5.894	8.76e-09***

Further

Table 6.23 The optimal model of ICI_duration in stop/stop sequences in lingual/lingual sequences (only male speakers). n=184

Formula: icilog ~ rate + Context + (1 | speaker)
Data: At_DORmale
Fixed effects:

	Estimate	Std.Error	df	tvalue	Pr(>|t|)
(Intercept)	1.44919	0.01042	38.35138	139.09	<2e-16***
rateNormal	0.14575	0.01164	174.06626	12.53	<2e-16***
ContextPlain	-0.22093	0.01164	174.06626	-18.99	<2e-16***

Table 6.24 The optimal model of ICI_duration in stop/stop sequences in lingual/lingual sequences (only female speakers). n=176

```
Formula: icilog ~ rate + Context + (1 | speaker)
   Data: At_DORfemale
Fixed effects:
              Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)    1.36234   0.01038 173.00000 131.287   <2e-16***
rateNormal     0.14329   0.01237 173.00000  11.584   <2e-16***
ContextPlain  -0.12076   0.01239 173.00000  -9.744   <2e-16***
```

Table 6.25 The optimal model of sequence_duration in stop/stop sequences in lingual/lingual sequences

```
Formula: wslog ~ rate + gender + Context + Context:gender + Context:placeorder + (1 |
speaker)
   Data: At_DOR
Fixed effects:
                                      Estimate Std.Error         df tvalue Pr(>|t|)
(Intercept)                           2.111889   0.003647  91.097949 579.139  <2e-16***
rateNormal                            0.161829   0.002584 363.000000  62.616  <2e-16***
genderMale                            0.020100   0.004071  38.596490   4.937 1.56e-
05***
ContextPlain                         -0.037494   0.004476 363.000000  -8.376 1.21e-
15***
genderMale:ContextPlain              -0.019453   0.005169 363.000000  -3.764
0.000195***
ContextEmphatic:placeorderfront-back -0.046269   0.003655 363.000000 -12.659  <2e-16***
ContextPlain:placeorderfront-back    -0.079086   0.003655 363.000000 -21.638  <2e-16***
```

FURTHER:

Table 6.26 The optimal model of sequence_duration in stop/stop sequences in lingual/lingual sequences (only male speakers). n=192

```
Formula: wslog ~ rate + Context + Context:placeorder + (1 | speaker)
   Data: At_DORmale
Fixed effects:
                                      Estimate Std.Error         df tvalue Pr(>|t|)
(Intercept)                           2.126904   0.004882  44.729471  435.62  <2e-16***
rateNormal                            0.164022   0.003857 180.000000   42.53  <2e-16***
ContextPlain                         -0.052911   0.005455 180.000000   -9.70  <2e-16***
ContextEmphatic:placeorderfront-back -0.038291   0.005455 180.000000   -7.02 4.37e-
11***
ContextPlain:placeorderfront-back    -0.079181   0.005455 180.000000  -14.52  <2e-16***
```

Table 6.27 The optimal model of sequence_duration in stop/stop sequences in lingual/lingual sequences (only female speakers). n=192

```
Formula: wslog ~ rate + Context + Context:placeorder + (1 | speaker)
   Data: At_DORfemale
Fixed effects:
                                      Estimate Std.Error         df tvalue Pr(>|t|)
(Intercept)                           2.116974   0.003768 187.000000 561.762  <2e-16***
rateNormal                            0.159636   0.003371 187.000000  47.361  <2e-16***
ContextPlain                         -0.041530   0.004767 187.000000  -8.712 1.57e-
15***
ContextEmphatic:placeorderfront-back -0.054246   0.004767 187.000000 -11.380  <2e-16***
ContextPlain:placeorderfront-back    -0.078991   0.004767 187.000000 -16.571  <2e-16***
```

Table 6.28 The optimal model of sequence_duration in stop/stop sequences in lingual/lingual sequences (only front-back place order) n=192

```
Formula: wslog ~ rate + gender + Context + Context:gender + (1 | speaker)
   Data: At_DOR_FB
Fixed effects:
                         Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)              2.056407  0.005024  42.467909 409.278  <2e-16***
rateNormal               0.172278  0.003847 173.000000  44.785  <2e-16***
genderMale               0.028077  0.006564  31.770652   4.277 0.000162***
ContextPlain            -0.066275  0.005440 173.000000 -12.182  <2e-16***
genderMale:ContextPlain -0.027526  0.007694 173.000000  -3.578 0.000450***
```

Table 6.29 The optimal model of sequence_duration in stop/stop sequences in lingual/lingual sequences (only back-front place order). n=192

```
Formula: wslog ~ rate + gender + Context + Context:gender + (1 | speaker)
   Data: At_DOR_BF
Fixed effects:
                         Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)              2.121102  0.003553 187.000000 597.037  <2e-16***
rateNormal               0.151380  0.003178 187.000000  47.639  <2e-16***
genderMale               0.012123  0.004494 187.000000   2.698  0.00762**
ContextPlain            -0.041530  0.004494 187.000000  -9.241  <2e-16***
genderMale:ContextPlain -0.011381  0.006355 187.000000  -1.791  0.07494 .
```

As explained in Chapters 1 and 5 and reiterated above, the sequence duration and the individual intervals within the sequence are used as measures to determine the degree of gestural overlap in this thesis in addition to the ICI occurrence (count) and ICI duration. Therefore, the remainder of this section will be devoted to the timing relations in stop/stop sequences. The timing relations in /btˤ/ were compared to those in /bt/. The timing relations in /tˤb/ were compared to those in /tb/. Similar comparisons were then made in lingual/lingual sequences (/gtˤ/ vs /gt/ and /tˤg/ vs /tg/). Due to these specific comparisons, the identity of the articulators and the order of place of articulation were not included in the models that were run in these subsections. For instance, the timing relations in /gtˤ/ were compared to those in /gt/, and both sequences consist of lingual/lingual consonants and both are in back-front place order. Therefore, the two independent variables (i.e., the identity of the articulators and the order of place of articulation) were excluded in the relevant models. Models were run with Context (emphatic or plain) and its interaction with other independent variables as the crucial fixed factor(s).

6.2.4.1 b#t vs b#tˤ

The timing relations in /btˤ/ in *ba:b#tˤa:lib* were compared to those in /bt/ in *ba:b#ta:mir*. As in Table 6.30, The ICI occurs less often in /btˤ/ than in /bt/. The acoustic measurements are presented in Table 6.31. As made clear in Chapter 5, C2 VOT was segmented in these two sequences since C2 is /tˤ/ or /t/, followed by a vowel. The summary of optimal models of all dependent variables (including VOT of C2) is presented in Table 6.32.

Table 6.30 ICI count. Yes (count and percentage of occurring ICIs), Not (count and percentage of non-occurring ICIs)

Consonant Sequence	**Total *n***	**Not**		**Yes**	
		n	**Percentage**	***n***	**Percentage**
b#t	96	80	83.33	16	16.67
b#tˤ	96	90	93.75	6	6.25
Total	192	170	88.54	22	11.46

Table 6.31 Acoustic measurements for b#tˤ and b#t (mean_ values)

Consonant Sequence	**C1_HP**	**ICI**	**C2_HP**	**VOT**	**Sequence**	**ICI_Voicing Proportion**
b#t	64.48	18.2	45.46	38.22	137.62	0.62
b#tˤ	46.13	5.95	53.21	22.96	106.74	0.81

*Table 6.32 The summary of optimal models of all dependent variables. Full optimal models are presented in Appendix B (Section 11.2.1.1.1). Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05. IVs=Independent Variables. DVs=Dependent Variables*

IVs / **DVs**	Rate	Gender	Context	Context * Rate	Context * Gender
C1 HP	***		***		
ICI	***		***		
C2 HP	***		***		
VOT	***		***		
Sequence	***		***		
ICI Voicing Proportion			***		

As in Table 6.31, the average duration of /btˤ/ sequence is shorter than /bt/ sequence (106ms and 137ms, respectively). As shown in Table 6.32, the results of linear mixed effects models show that this difference is statistically significant ($n=192, \beta=1.107e-01, SE=5.634e-03, t\text{-value}=19.64, p<0.001$). /b/ HP duration is significantly shorter in an emphatic context than in the plain counterpart ($n=22$[39]$, \beta=0.16691, SE=0.01530, t\text{-value}=10.910, p<0.001$). /tˤ/ HP

[39] As pointed out in Chapter 5 (Section 5.5), it can be noted that the number of tokens in C1 HP, ICI and C2 HP are the same: 22. This is due to ICI count; the ICI occurred in 22 tokens as shown in Table 6.30. In

duration is significantly longer than /t/ HP duration (n=22,β=-0.04627, SE=0.02175, t-value=-2.127,p<0.001). In those instances where ICI occurred, the ICI duration is significantly shorter in /btˤ/ than in /bt/ (n=22,β=0.53678, SE=0.06302, t-value=8.518,p<0.001). VOT is also significantly shorter in /btˤ/ than in /bt/ (n=192,β=2.240e-01, SE=5.598e-03, t-value=40.02,p<0.001).

In general, the ICI occurs less often in an emphatic than in the plain counterpart. The ICI duration is significantly shorter in an emphatic context than in the plain counterpart, indicating that the consonantal gestures are further apart in the plain context than in the emphatic context. Apart from C2 HP, all individual intervals along with sequence duration are significantly shorter in an emphatic than in the plain counterpart. Accordingly, it can be concluded that /btˤ/ exhibits greater degree of gestural overlap than /bt/, when occurring at the word boundary in two consonant sequences (C#C). This could be attributed to the role of the state of the glottis, which is less open in /tˤ/ than in /t/, on gestural overlap. The ICI voicing proportion is significantly higher in /btˤ/ than in /bt/ sequence (n=22,β=-0.19102, SE=0.03118, t-value=-6.126,p<0.001), supporting this conclusion.

6.2.4.2 t#b vs tˤ#b

The timing relations in /tˤb/ in *ba:tˤ#ba:sim* were compared to those in /tb/ in *ba:t#ba:sim*. As in Table 6.33, the ICI occurs less often in /tˤb/ than in /tb/. The acoustic measurements are presented in Table 6.34. The summary of optimal models of all dependent variables is presented in Table 6.35.

Table 6.33 ICI count.

Consonant Sequence	**Total *n***	**Not**		**Yes**	
		n	**Percentage**	***n***	**Percentage**
t#b	96	55	57.29	41	42.71
tˤ#b	96	68	70.83	28	29.17
Total	192	123	64.06	69	35.94

cases where an ICI did not occur, the landmark that can help identify the offset of C1 HP and onset of C2 HP were absent accordingly. Therefore, C1 and C2 HPs were not segmented, but C2 VOT, which was present in all tokens, and sequence duration were segmented and measured. Thus, the number of tokens analysed in VOT and sequence durations is bigger than that of the tokens analysed in C1 HP, ICI and C2 HP durations (See Section 5.5. in Chapter 5, and Figure 5.2).

Table 6.34 Acoustic measurements for tˤ#b and t#b (mean_values)

Consonant Sequence	C1_HP	ICI	C2_HP	Sequence	ICI_Voicing Proportion
t#b	51.63	15.77	68.87	130.92	0.44
tˤ#b	57.77	6.22	61.26	105.87	0.67

Table 6.35 The summary of optimal models of all dependent variables. Full optimal models are presented in Appendix B (Section 11.2.1.1.2).

IVs / DVs	Rate	Gender	Context	Context * Rate	Context * Gender
C1 HP	***				
ICI	***		***		
C2 HP	***				
Sequence	***		***		
ICI Voicing Proportion			***		

As in Table 6.34, the average duration of the ICI is shorter in /tˤb/ than in /tb/. This difference is statistically significant (n=69,β=0.43425,SE=0.02790,t-value=15.56,p<0.001). Sequence duration is also significantly shorter in /tˤb/ than /tb/ (n=192,β=9.798e-02,SE=6.517e-03,t-value=15.03,p<0.001). No significant differences were found in the other intervals between an emphatic context and the plain counterpart.

In general, ICI occurs less often in /tˤb/ than in /tb/. The ICI duration is significantly shorter in /tˤb/ than /tb/, indicating that the consonantal gestures are further apart in the plain context than in the emphatic context. Sequence duration is significantly shorter in /tˤb/ than /tb/. Accordingly, it can be concluded that /tˤb/ sequence exhibits greater degree of gestural overlap than /tb/ sequence, when occurring at the word boundary in two consonant sequences (C#C). This could be attributed to the role of the state of the glottis, which is less open in /tˤ/ than in /t/, on gestural overlap. The ICI voicing proportion is significantly higher in /tˤb/ than in /tb/ sequence (n=69,β=-0.226919,SE=0.010297,t-value=-22.04,p<0.001), supporting this conclusion.

Having presented the results of labial/lingual sequences in word set A, now we present the results of lingual/lingual sequences in word set A.

6.2.4.3 g#t vs g#tˤ

The timing relations in /gtˤ/ in *ba:g#tˤa:lib* were compared to those in /gt/ in *ba:g#ta:mir*. As in Table 6.36, the ICI occurs more often in /gtˤ/ than in /gt/. The acoustic measurements are presented in Table 6.37. As made clear in Chapter 5, C2 VOT was segmented in these two sequences since C2 is /tˤ/ or /t/, followed by a vowel. The summary of optimal models of all dependent variables (including VOT of C2) is presented in Table 6.38.

Table 6.36 ICI count

Consonant Sequence	**Total *n***	**Not**		**Yes**	
		n	**Percentage**	***n***	**Percentage**
g#t	96	12	12.5	84	87.5
g#tˤ	96	0	0	96	100
Total	192	12	6.25	180	93.75

Table 6.37 Acoustic measurements for g#tˤ and g#t (mean_values)

Consonant Sequence	**C1_HP**	**ICI**	**C2_HP**	**VOT**	**Sequence**	**ICI_Voicing Proportion**
g#t	50.53	20.9	42.38	36.38	145.34	0.47
g#tˤ	55.61	31.32	53.72	21.66	162.3	0.56

Table 6.38 The summary of optimal models of all dependent variables. Full optimal models are presented in Appendix B (Section 11.2.1.1.3).

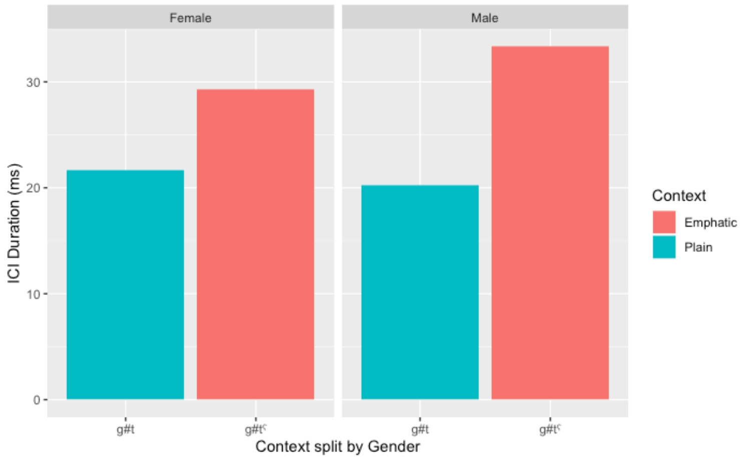
IVs / DVs	Rate	Gender	Context	Context * Rate	Context * Gender
C1 HP	***				
ICI	***		***		***
C2 HP	***		***		
VOT	***		***		
Sequence	***		***		
ICI Voicing Proportion					

As in Table 6.37, the ICI is longer in duration in /gtˤ/ than in /gt/. This difference is statistically significant (n=180,β=-0.14913,SE=0.01720,t-value=-8.671,p<0.001). The results also reveal that there is a significant interaction between Context and gender (n=180,β=-0.07255,SE=0.02376,t-value=-3.054,p<0.01), as visualised in Figure 6.9. The results of further models[40] reveal that the ICI is significantly longer in /gtˤ/ than in /gt/ across gender,but the effect is greater in the speech of males, compared to that of females (as pointed out above, all optimal models are presented in Appendix B, see Section 11.2.1.1.3). C2 HP duration is also longer in /gtˤ/ than in /gt/ (n=180,β=-0.116134,SE=0.005693,t-value=-20.40,p<0.001).

[40] A new subset was created that included only male speakers and another that included only female speakers, then further models were run to examine which gender exhibits greater effect.

Similarly, sequence duration is longer in /gtˤ/ than in /gt/ (n=192,β=-0.047220,SE=0.003222,t-value=-14.66,p<0.001). VOT, however, is shorter in /gtˤ/ than in /gt/ (n=192,β=2.388e-01,SE=8.134e-03,t-value=29.35,p<0.001). No significant differences were found in the ICI voicing proportion between the two sequences.

Figure 6.9 ICI_duration in ba:g#tˤa:lib and ba:g#ta:mir in both genders



In general, the ICI occurs more often in an emphatic context than in the plain counterpart. The ICI duration is significantly longer in an emphatic context than in the plain counterpart, indicating that the consonantal gestures are further apart in the plain context than in the emphatic context. Sequence duration is significantly longer in an emphatic context than in the plain counterpart. In addition, C1 HP duration is significantly longer in an emphatic context than in the plain counterpart. Accordingly, it can be concluded that /gtˤ/ sequence exhibits lower degree of gestural overlap than /gt/ sequence, when occurring at the word boundary in two consonant sequences. This could be attributed to the secondary articulation of the emphatic coronal /tˤ/. It can be noted that /gtˤ/ exhibits lower degree of gestural overlap than /gt/ sequence, while /bt/ exhibits greater degree of gestural overlap than /bt/ sequence, as reported in Section 6.2.4.1. The lower degree of gestural overlap in /gtˤ/ than in /gt/ could be attributed to the secondary articulation of the emphatic coronal /tˤ/. The greater degree of gestural overlap in /btˤ/ than in /bt/ could be attributed to the state of the glottis involved during the production of the emphatic coronal /tˤ/. These two findings indicate that the impact of the secondary articulation of emphasis is stronger and more effective than the impact of the state of the glottis. Whenever the impact of the secondary articulation is operative, the impact of the state of the glottis is not. This will be discussed further in Section 6.5.

6.2.4.4 t#g vs tˤ#g

The timing relations in /tˤg/ in *ba:tˤ#ga:sim* were compared to those in /tg/ in *ba:t#ga:sim*. As in Table 6.39, the ICI occurs more often in /tˤg/ than in /tg/. The acoustic measurements are presented in Table 6.40. The summary of optimal models of all dependent variables is presented in Table 6.41.

Table 6.39 ICI count.

Consonant Sequence	Total *n*	Not		Yes	
		n	Percentage	*n*	Percentage
t#g	96	11	11.46	85	88.54
tˤ#g	96	0	0	96	100
Total	192	11	5.73	181	94.27

Table 6.40 Acoustic measurements for tˤ#g and t#g (mean_values)

Consonant Sequence	C1_HP	ICI	C2_HP	Sequence	ICI_Voicing Proportion
t#g	52.68	21.68	48.38	121.96	0.69
tˤ#g	56.61	30.87	59	146.47	0.73

Table 6.41 The summary of optimal models of all dependent variables. Full optimal models are presented in Appendix B (Section 11.2.1.1.4).

IVs / DVs	Rate	Gender	Context	Context * Rate	Context * Gender
C1 HP	***				
ICI	***		***		***
C2 HP	***		***		
Sequence	***		***		***
ICI Voicing Proportion					

As in Table 6.40, the average duration of the ICI in /tˤg/ is longer than that in /tg/. This difference is statistically significant (n=181,β=-0.09326,SE=0.01701,t-value=-5.482,p<0.001). The results also reveal that there is a significant interaction between Context and gender in the ICI duration (n=181,β=-0.12660,SE= 0.02395,t-value=-5.285,p<0.001), as visualised in Figure 6.10. The results of further models[41] show that the ICI duration is significantly longer in an emphatic context than in the plain counterpart across gender,but the effect is greater in the speech of males (see Appendix B, Section 11.2.1.1.4 for full optimal models). C2 HP duration is

[41] A new subset was created that included only male speakers and another that included only female speakers, then further models were run to examine which gender exhibits greater effect.

also significantly longer in /tˤg/ than in /tg/ (n=181,β=-0.104722,SE=0.006432,t-value=-16.28,p<0.001). Similarly, the sequence duration is significantly longer in /tˤg/ than in /tg/ (n=192,β=-0.066275,SE=0.005440,t-value=-12.182,p<0.001). The results also reveal that Context significantly interacts with gender in sequence duration (n=192,β=-0.027526,SE=0.007694,t-value=-3.578,p<0.001), as visualised in Figure 6.11. The results of further models[42] show that the effect is greater in the speech of males (see Appendix B, Section 11.2.1.1.4). No differences were found between the two sequences in C1 HP duration and ICI voicing proportion.

Figure 6.10 ICI_duration in ba:tˤ#ga:sim and ba:t#ga:sim in both genders

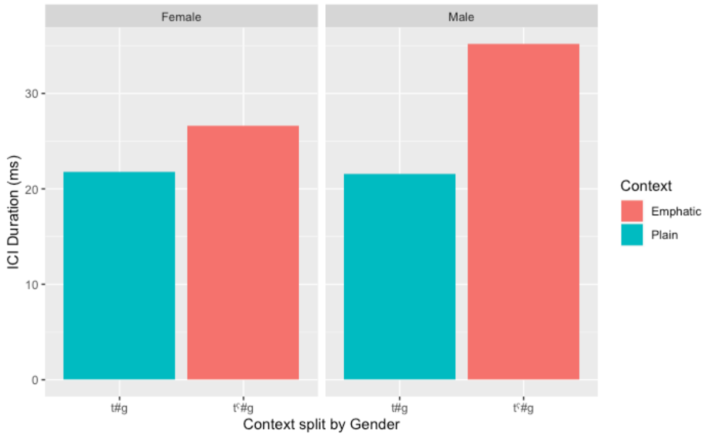
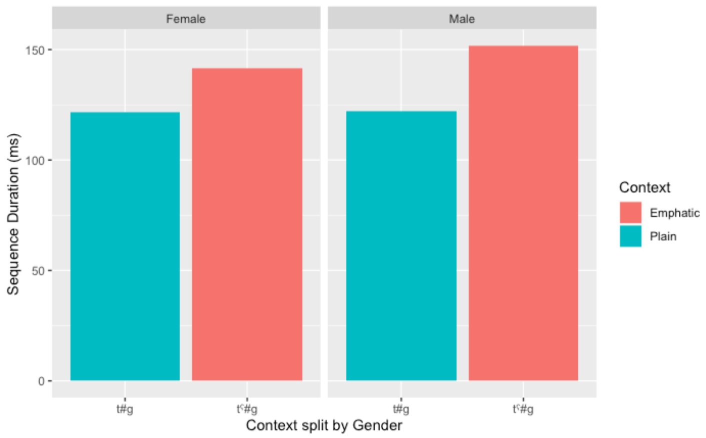


Figure 6.11 Sequence_duration in ba:tˤ#ga:sim and ba:t#ga:sim in both genders



In general, the ICI occurs more often in an emphatic context than in the plain counterpart. The ICI duration is significantly longer in an emphatic context than in the plain counterpart, indicating that the consonantal gestures are further apart in the plain context than in the emphatic context. C2 HP, in addition to, sequence durations is significantly longer in an emphatic context than in the plain counterpart. Accordingly, it can be concluded that /tˤg/

[42] A new subset was created that included only male speakers and another that included only female speakers, then further models were run to examine which gender exhibits greater effect.

sequence exhibits lower degree of gestural overlap than /tg/ sequence, when occurring at the word boundary in two consonant sequences (C#C). This could be attributed to the secondary articulation of the emphatic coronal /tˤ/. It can be noted that /tˤg/ exhibits lower degree of gestural overlap than /tg/ sequence, while /tˤb/ exhibits greater degree of gestural overlap than /tb/ sequence, as reported in Section 6.2.4.2. The lower degree of gestural overlap in /tˤg/ than in /tg/ could be attributed to the secondary articulation of the emphatic coronal /tˤ/. The greater degree of gestural overlap in /tˤb/ than in /tb/ could be attributed to the state of the glottis involved during the production of the emphatic coronal /tˤ/. These two findings indicate that the impact of the secondary articulation of emphasis is stronger and more effective than the impact of the state of the glottis. Whenever the impact of the secondary articulation is operative, the impact of the state of the glottis is not. This will be discussed further in Section 6.5.

6.3 Stop/alveolar fricative sequences

6.3.1 The results of the place order effect (Hypothesis (i))

As pointed out in Chapter 5, linear mixed-effects models were run to test Hypothesis (i) with the place order and its interaction with other independent variables as the crucial fixed factor(s). The independent variables that were included in these models are the identity of the articulators, Context (plain, emphatic), order of place of articulation, speech rate and gender.

Table 6.42 ICI count. Yes (count and percentage of occurring ICIs), Not (count and percentage of non-occurring ICIs)

Place Order	Total *n*	Not		Yes	
		n	Percentage	*n*	Percentage
back-front	384	230	59.9	154	40.1
front-back	384	360	93.75	24	6.25
Total	768	590	76.82	178	23.18

Table 6.43 Acoustic measurements for stop/alveolar fricative sequences (mean_values)

Place Order	ICI_duration	Sequence_duration
back-front	23.82	145.84
front-back	9.69	139.25

The ICI count, ICI duration and sequence duration in back-front were compared to those in front-back stop/alveolar fricative sequences, occurring at the word boundary (C#C). Sequences in a back-front place order include /sb/, /sˤb/, /gs/ and /gsˤ/, and sequences in a front-back order include /bs/, /bsˤ/, /sg/ and /sˤg/ sequences.

As in Table 6.42, the ICI occurs more often in back-front than in front-back place order (40% and 6% respectively). When considering other independent variables, however, it turns out that the place order effect on ICI count is only exhibited in lingual/lingual sequences (80% in back-front vs 0% in front-back), compared to labial/lingual sequences (0% in back-front vs 12% in front-back). The fact that the ICI count in front-back place order (i.e., /bs/, /bsˤ/) scores 12% higher than in back-front order (i.e., /sb/, /sˤb/) in labial/lingual sequences could be due to C1 identity. C1 in /bs/ and /bsˤ/ is the bilabial stop /b/, and ICIs are prone to occur if C1 is a stop in the sequence because there is a release in stops, unlike C1 in /sb/ and /sˤb/ in two consonant sequences which is a fricative, and ICIs occur less often because there is no a release after a fricative.

The place order effect on the ICI count is more exhibited in an emphatic context (45% in back-front vs 6% in front-back) than in the plain counterpart (34% in back-front vs 6% in front-back).

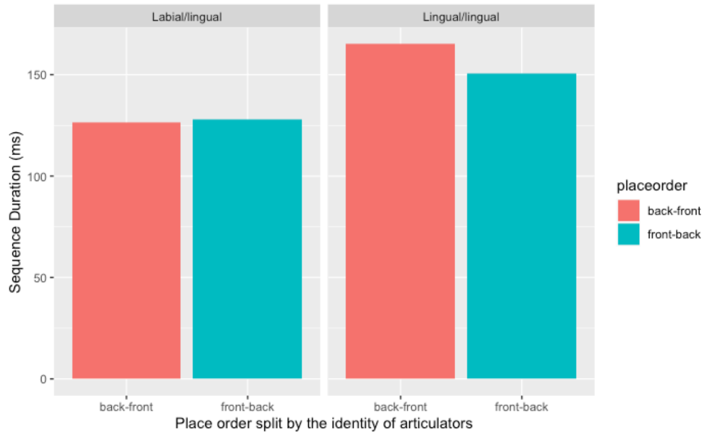
As in Table 6.43, the ICI duration is 23ms in a back-front place order and 9ms in front-back order. When running linear mixed-effects models for ICI duration (considering speech rate, gender, Context, the place order and the identity of the articulators), the model gives a warning note (i.e., `fixed-effect model matrix is rank deficient so dropping 1 column`). In these models, when adding the identity of articulators to the model, it significantly contributes to the model fit. In the summary of the optimal model, however, this predictor (the identity of articulators) did not appear in the list of the fixed effects. This could be due to the fact that ICIs occur in front-back sequences only in labial/lingual sequences, and ICIs occur in back-front sequences only in lingual/lingual sequences, as indicated above. Accordingly, the comparison between both place orders in ICI duration could not be valid. Therefore, a comparison between the two place orders in sequence duration is more valid.

As in Table 6.44, sequence duration is not significantly different between back-front and front-back place orders; the place order, however, significantly interacts with the identity of the articulators in sequence duration ($n=768, \beta=-0.040289, SE=0.004251, t\text{-value}=-9.478, p<0.001$) as visualised in Figure 6.12. The results of further models[43] reveal that sequence duration in back-front place order is significantly longer than in front-back order only

[43] A new subset was created that included only lingual/lingual consonant sequences and another that included only labial/lingual consonant sequences, then further models were run.

in lingual/lingual sequences (n=384,β=-0.040289,SE= 0.003228,t-value=-12.48,p<0.001), but not in labial/lingual sequences, as in the optimal models in Tables 6.45 and 6.46.

Figure 6.12 Sequence_duration in stop/alveolar fricative sequences in both place orders, split by the identities of articulators



In general, the ICI occurs more often in a back-front than in front-back place order only in lingual/lingual sequences. Similarly, sequence duration is significantly longer in a back-front than in front-back place order only in lingual/lingual sequences. Accordingly, the place order effect is ***only exhibited*** in lingual/lingual sequences in stop/alveolar fricative sequences occurring at the word boundary (C#C) in Najdi Arabic, *based on ICI count and sequence duration.*

Table 6.44 The optimal model of sequence_duration in stop/alveolar fricative sequences

```
Formula: wslog ~ rate + Context + articulators + placeorder:articulators + (1 | speaker)
   Data: As
Fixed effects:
                                                    Estimate Std.Error         df tvalue
Pr(>|t|)
(Intercept)                                         2.059052   0.003681 762.000000
559.341   <2e-16***
rateNormal                                          0.128966   0.003006 762.000000
42.907   <2e-16***
ContextPlain                                       -0.054091   0.003006 762.000000 -
17.996   <2e-16***
articulatorsLingual/lingual                         0.113650   0.004251 762.000000
26.737   <2e-16***
articulatorsLabial/lingual:placeorderfront-back     0.001821   0.004251 762.000000
0.428    0.668
articulatorsLingual/lingual:placeorderfront-back   -0.040289   0.004251 762.000000  -
9.478   <2e-16***
```

FURTHER:

Table 6.45 The optimal model of sequence_duration in stop/alveolar fricative sequences (in labial/lingual sequences). n=384

```
Formula: wslog ~ rate + gender + (1 | speaker)
   Data: As_LAB
Fixed effects:
              Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)   2.031171  0.003106 381.000000 653.983  <2e-16***
rateNormal    0.141838  0.003586 381.000000  39.550  <2e-16***
genderMale   -0.009379  0.003586 381.000000  -2.615  0.00927**
```

Table 6.46 The optimal model of sequence_duration in stop/alveolar fricative sequences (in lingual/lingual sequences). n=384

```
Formula: wslog ~ rate + Context + placeorder + (1 | speaker)
   Data: As_DOR
Fixed effects:
                      Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)           2.202943  0.003228 380.000000 682.38   <2e-16***
rateNormal            0.116094  0.003228 380.000000  35.96   <2e-16***
ContextPlain         -0.101701  0.003228 380.000000 -31.50   <2e-16***
placeorderfront-back -0.040289  0.003228 380.000000 -12.48   <2e-16***
```

6.3.2 The results of the speech rate effect (Hypothesis (j))

As made clear in Chapter 2, the main measure to determine whether there is an effect of speech rate on gestural overlap is the ICI count/occurrence. Therefore, the ICI count is the only dependent variable considered here.

Table 6.47 ICI count. Yes (count and percentage of occurring ICIs), Not (count and percentage of non-occurring ICIs)

Speech Rate	Total *n*	Not		Yes	
		n	**Percentage**	***n***	**Percentage**
Fast	384	333	86.72	51	13.28
Normal	384	257	66.93	127	33.07
Total	768	590	76.82	178	23.18

As in Table 6.47, the ICIs occur less often in fast speech rate than in normal rate by around 20%. The other independent variables (i.e., gender, Context, place order and the identity of articulators) did not play any role in the speech rate effect. Accordingly, it can be concluded that stop/alveolar fricative sequences (C#C) at fast speech rate exhibit greater degree of gestural overlap than in normal speech rate in Najdi Arabic. It should be noted that no ICIs occurred in sequences where C1 is a fricative (/s#b/, /sˤ#b/, /s#g/ and /sˤ#g/), as will be shown later in this chapter. Thus, the speech rate effect, based on ICI count, is exhibited in sequences where C1 is a stop (/b#s/, /b#sˤ/, /g#s/ and /g#sˤ/).

6.3.3 The results of the impact of the identity of the articulators (Hypothesis (a))

As pointed out in Chapter 5, linear mixed-effects models were run to test Hypothesis (a) with the identity of the articulators and its interaction with other independent variables as the crucial fixed factor(s). The independent variables that were included in these models are the identity of the articulators, Context (plain, emphatic), order of place of articulation, speech rate and gender.

The ICI count, ICI duration and sequence duration in lingual/lingual were compared to those in labial/lingual sequences, occurring at the word boundary (C#C). Lingual/lingual sequences include /sg/, /sˤg/, /gs/ and /gsˤ/, and labial/lingual sequences include /bs/, /bsˤ/, /sb/ and /sˤb/.

Table 6.48 ICI count. Yes (count and percentage of occurring ICIs), Not (count and percentage of non-occurring ICIs)

Articulators	**Total *n***	**Not**		**Yes**	
		n	**Percentage**	***n***	**Percentage**
Labial/lingual	384	360	93.75	24	6.25
Lingual/lingual	384	230	59.9	154	40.1
Total	768	590	76.82	178	23.18

Table 6.49 Acoustic measurements for stop/alveolar fricative sequences (mean_values)

Articulators	**ICI_duration**	**Sequence_duration**
Labial/lingual	9.69	127.22
Lingual/lingual	23.82	157.87

As in Table 6.48, the ICI occurs more often in lingual/lingual sequences than in labial/lingual sequences (40% and 6% respectively). When considering other independent variables, however, it turns out that the identity of articulators effect on ICI count is only exhibited in sequences in back-front order (80% in lingual/lingual vs 0% in labial/lingual sequences), compared to sequences in front-back order (0% in lingual/lingual vs 12% in labial/lingual sequences). The fact that the ICI count in labial/lingual sequences (i.e., /bs/, /bsˤ/) scores 12% higher than in lingual/lingual sequences (i.e., /sg/, /sˤg/) in front-back order could be due to C1 identity. C1 in /bs/ and /bsˤ/ is the bilabial stop /b/, and ICIs are prone to occur if C1 is a stop in the sequence because there is a release in stops, unlike C1 in /sg/ and /sˤg/ in two consonant sequences which is a fricative, and ICIs occur less often because there is no a release after a fricative.

The effect of the identity of articulators on the ICI count is more exhibited in an emphatic context (45% in lingual/lingual vs 6% in labial/lingual sequences) than in the plain counterpart (34% in lingual/lingual vs 6% in labial/lingual sequences).

As in Table 6.49, the ICI duration is 23ms in lingual/lingual sequences and 9ms in labial/lingual sequences. When running linear mixed-effects models for ICI duration (considering speech rate, gender, Context, the place order and the identity of the articulators), the model gives a warning note (i.e., `fixed-effect model matrix is rank deficient so dropping 1 column`). In these models, when adding the identity of articulators to the model, it significantly contributes to the model fit. In the summary of the optimal model, however, this predictor (the identity of articulators) did not appear in the list of the fixed effects. This could be due to the fact that ICIs occur in labial/lingual sequences only in front-back, and ICIs occur in lingual/lingual sequences only in back-front sequences, as indicated above. Accordingly, the comparison between both identities of the articulators in ICI duration could not be valid. Therefore, a comparison between the two identities in sequence duration is more valid.

Sequence duration is significantly longer in lingual/lingual sequences than in labial/lingual sequences ($n=768, \beta=0.161261, SE=0.004266, t\text{-value}=37.798, p<0.001$) as in Table 6.50. The results also reveal that there is a significant interaction between the identity of articulators and Context in sequence duration ($n=768, \beta=-0.095221, SE=0.004926, t\text{-value}=-19.329, p<0.001$) as visualised in Figure 6.14. The results of further models[44] reveal that sequence duration is significantly longer in lingual/lingual sequences than in labial/lingual sequences across Context, but the effect is greater in an emphatic context than in the plain counterpart, as in the optimal models in Tables 6.51 and 6.52. The results also reveal that the identity of articulators significantly interacts with place order ($n=768, \beta=-0.040289, SE=0.003484, t\text{-value}=-11.566, p<0.001$) in sequence duration, as visualised in Figure 6.13. The results of further models[45] reveal that sequence duration is significantly longer in lingual/lingual sequences than in labial/lingual sequences across place order,but the effect is greater in back-front than in front-back order, as in the optimal models in Tables 6.53 and 6.54.

[44] A new subset was created that included only emphatic context and another that included only plain context, then further models were run for each.

[45] A new subset was created that included only front-back place order and another that included only back-front order, then further models were run for each.

Figure 6.13 Sequence_duration in stop/alveolar fricative sequences in both identities of articulators, split by place order

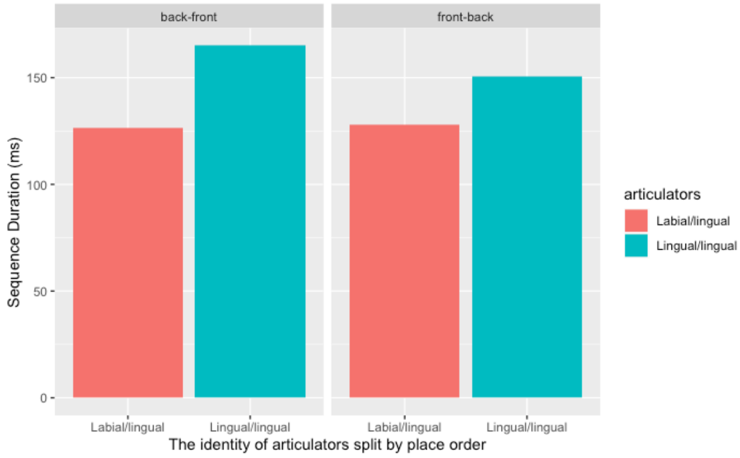
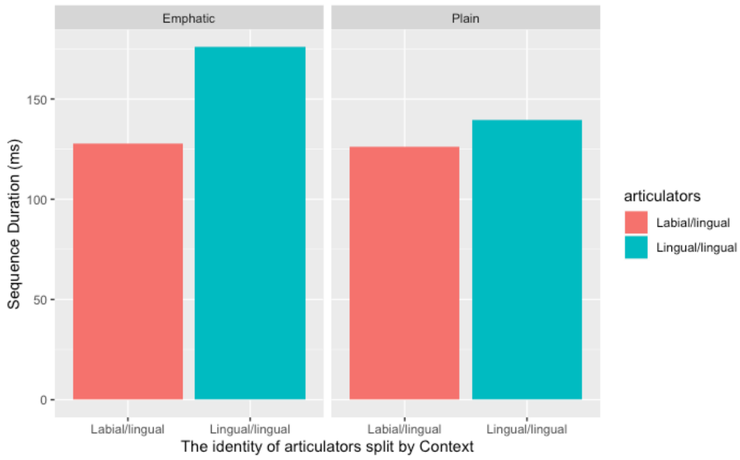


Figure 6.14 Sequence_duration in stop/alveolar fricative sequences in both identities of articulators, split by Context



In general, the ICI occurs more often in lingual/lingual sequences than in labial/lingual sequences only in back-front order. Sequence duration is significantly longer in lingual/lingual sequences than in labial/lingual sequences across place order. Accordingly, it can be concluded that lingual/lingual sequences exhibit lower degree of gestural overlap than labial/lingual sequences in stop/alveolar fricative sequences, occurring at the word boundary (C#C) in Najdi Arabic, *based on sequence duration*.

Table 6.50 The optimal model of sequence_duration in stop/alveolar fricative sequences

```
Formula: wslog ~ rate + Context + articulators + articulators:Context +
    articulators:placeorder + (1 | speaker)
   Data: As
Fixed effects:
                                                   Estimate Std.Error         df tvalue
Pr(>|t|)
(Intercept)                                        2.035247   0.003259 761.000000
624.590   <2e-16***
rateNormal                                         0.128966   0.002463 761.000000
52.357   <2e-16***
ContextPlain                                      -0.006481   0.003484 761.000000  -
1.860   0.0632 .
articulatorsLingual/lingual                        0.161261   0.004266 761.000000
37.798   <2e-16***
ContextPlain:articulatorsLingual/lingual          -0.095221   0.004926 761.000000 -
19.329   <2e-16***
articulatorsLabial/lingual:placeorderfront-back    0.001821   0.003484 761.000000
0.523   0.6012
articulatorsLingual/lingual:placeorderfront-back  -0.040289   0.003484 761.000000 -
11.566   <2e-16***
```

FURTHER:

Table 6.51 The optimal model of sequence_duration in stop/alveolar fricative sequences (in an emphatic Context). n=384

```
Formula: wslog ~ rate + articulators + articulators:placeorder + (1 | speaker)
   Data: As_E
Fixed effects:
                                                   Estimate Std.Error         df tvalue
Pr(>|t|)
(Intercept)                                        2.028317   0.003411 195.097916
594.635  <2e-16***
rateNormal                                         0.124176   0.002995 363.999984
41.456  <2e-16***
articulatorsLingual/lingual                        0.162892   0.004236 363.999984
38.453  <2e-16***
articulatorsLabial/lingual:placeorderfront-back    0.020472   0.004236 363.999984
4.833 1.99e-06***
articulatorsLingual/lingual:placeorderfront-back  -0.024902   0.004236 363.999984  -
5.878 9.37e-09***
```

Table 6.52 The optimal model of sequence_duration in stop/alveolar fricative sequences (in a plain Context). n=384

```
Formula: wslog ~ rate + articulators + articulators:placeorder + (1 | speaker)
   Data: As_P
Fixed effects:
                                                   Estimate Std.Error         df tvalue
Pr(>|t|)
(Intercept)                                        2.035696   0.004133 379.000000
492.579   <2e-16***
rateNormal                                         0.133756   0.003696 379.000000
36.185   <2e-16***
articulatorsLingual/lingual                        0.064408   0.005228 379.000000
12.321   <2e-16***
articulatorsLabial/lingual:placeorderfront-back   -0.016829   0.005228 379.000000  -
3.219   0.0014**
articulatorsLingual/lingual:placeorderfront-back  -0.055676   0.005228 379.000000 -
10.651   <2e-16***
```

Table 6.53 The optimal model of sequence_duration in stop/alveolar fricative sequences (in front-back place order). n=384

```
Formula: wslog ~ rate + gender + Context + articulators + articulators:Context + (1 |
speaker)
   Data: As_FB
Fixed effects:
                                          Estimate Std.Error         df tvalue Pr(>|t|)
(Intercept)                               2.051479   0.004669 378.000000 439.379  <2e-
16***
rateNormal                                0.127980   0.003812 378.000000  33.571  <2e-
16***
genderMale                               -0.009185   0.003812 378.000000  -2.409
0.0165*
ContextPlain                             -0.025131   0.005391 378.000000  -4.661 4.36e-
06***
articulatorsLingual/lingual               0.117519   0.005391 378.000000  21.798  <2e-
16***
ContextPlain:articulatorsLingual/lingual -0.091957   0.007625 378.000000 -12.061  <2e-
16***
```

Table 6.54 The optimal model of sequence_duration in stop/alveolar fricative sequences (in back-front place order). n=384

```
Formula: wslog ~ rate + Context + articulators + articulators:Context + (1 | speaker)
   Data: As_BF
Fixed effects:
                                          Estimate Std.Error         df tvalue Pr(>|t|)
(Intercept)                               2.025429   0.003182 379.000000 636.507  <2e-
16***
rateNormal                                0.129951   0.002846 379.000000  45.659  <2e-
16***
ContextPlain                             -0.012170   0.004025 379.000000   -3.024
0.00267**
articulatorsLingual/lingual               0.162892   0.004025 379.000000  40.469  <2e-
16***
ContextPlain:articulatorsLingual/lingual -0.098484   0.005692 379.000000 -17.301  <2e-
16***
```

6.3.4 The results of the impact of the secondary articulation of emphatic coronals (Hypothesis (b))

As pointed out in Chapter 5, linear mixed-effects models were run to test Hypothesis (b) with Context (emphatic or plain) and its interaction with other independent variables as the crucial fixed factor(s). The independent variables that were included in these models are Context, order of place of articulation, speech rate and gender.

Table 6.55 ICI count in lingual/lingual sequences.

Context	Total *n*	Not		Yes	
		n	**Percentage**	***n***	**Percentage**
Emphatic	192	105	54.69	87	45.31
Plain	192	125	65.10	67	34.90
Total	384	230	59.90	154	40.10

Table 6.56 Acoustic measurements for stop/alveolar fricative sequences (mean_values)

Context	ICI_duration	Sequence_duration
Emphatic	27.76	175.91
Plain	18.70	139.83

To test Hypothesis (b), emphatic coronals were considered, as explained earlier. As in Table 6.55, the ICI occurs more often in an emphatic context than in the plain counterpart in lingual/lingual sequences (45 % and 34.5 % respectively). In those instances where ICIs occur, the average duration of the ICI is 27ms in an emphatic context and 18ms in the plain counterpart, as in Table 6.56. The results reveal that this difference in ICI duration is statistically significant (n=154,β=-0.18499,SE=0.01078,t-value=-17.16,p<0.001) as in Table 6.57. Similarly, sequence duration is significantly longer in an emphatic context than in the plain counterpart in lingual/lingual sequences (n=384,β=-0.101701,SE=0.003828,t-value=-26.57,p<0.001) as in Table 6.58.

Table 6.57 The optimal model of ICI_duration in stop/alveolar fricative sequences (in lingual/lingual sequences)

```
Formula: icilog ~ rate + Context + (1 | speaker)
   Data: As_DOR
Fixed effects:
              Estimate Std. Error        df t value Pr(>|t|)
(Intercept)    1.36737    0.00927 151.00000  147.51   <2e-16***
rateNormal     0.12744    0.01080 151.00000   11.80   <2e-16***
ContextPlain  -0.18499    0.01078 151.00000  -17.16   <2e-16***
```

Table 6.58 The optimal model of sequence_duration in stop/alveolar fricative sequences (in lingual/lingual sequences)

```
Formula: wslog ~ rate + Context + placeorder + (1 | speaker)
   Data: As_DOR
Fixed effects:
                     Estimate Std. Error         df t value Pr(>|t|)
(Intercept)          2.202943   0.003228 380.000000  682.38   <2e-16***
rateNormal           0.116094   0.003228 380.000000   35.96   <2e-16***
ContextPlain        -0.101701   0.003228 380.000000  -31.50   <2e-16***
placeorderfront-back -0.040289  0.003228 380.000000  -12.48   <2e-16***
```

Based on these results, it can be concluded that lingual/lingual sequences exhibit lower degree of gestural overlap in an emphatic context than in the plain counterpart in stop/alveolar fricative sequences in Najdi Arabic. This hypothesis (b) will be discussed further in Section 6.5.

The sequence duration and the individual intervals within the sequence are used as measures to determine the degree of gestural overlap in this thesis in addition to the ICI count and ICI duration. Therefore, the remainder of this section will be devoted to the timing relations in stop/alveolar fricative sequences. The timing relations in /bsˤ/ will be compared to those in /bs/. The timing relations in /sˤb/ will be compared to those in /sb/. Similar comparisons will be then made in lingual/lingual sequences (/gsˤ/ vs /gs/ and /sˤg/ vs /sg/). Due to these specific comparisons, the identity of the articulators and the order of place of articulation are not included in the models that were run in these subsections. For instance, the timing relations in /gsˤ/ will be compared to those in /gs/, and both sequences consist of lingual/lingual consonants and both are in back-front place order. Therefore, the two independent variables (i.e., the identity of the articulators and the order of place of articulation) were excluded in the relevant models. Models were run with Context (emphatic or plain) and its interaction with other independent variables as the crucial fixed factor(s).

6.3.4.1 b#s vs b#sˤ

The timing relations in /bsˤ/ in *ba:b#sˤa:liħ* were compared to those in /bs/ in *ba:b#sa:lim*. As in Table 6.59, the ICI count the same in both /bsˤ/ and /bs/. The acoustic measurements are presented in Table 6.60. The summary of optimal models of all dependent variables is presented in Table 6.61.

Table 6.59 ICI count. Yes (count and percentage of occurring ICIs), Not (count and percentage of non-occurring ICIs)

Consonant Sequence	**Total *n***	**Not**		**Yes**	
		n	**Percentage**	***n***	**Percentage**
b#s	96	84	87.5	12	12.5
b#sˤ	96	84	87.5	12	12.5
Total	192	168	87.5	24	12.5

Table 6.60 Acoustic measurements for b#sˤ and b#s (mean_values)

Consonant Sequence	**C1_HP**	**ICI**	**C2_Frication**	**Sequence**	**ICI_Voicing Proportion**
b#s	54.9	9.03	71.48	124.43	0.69
b#sˤ	51	10.35	72.12	131.22	0.66

Table 6.61 The summary of optimal models of all dependent variables. Full optimal models are presented in Appendix B (Section 11.2.1.2.1).

IVs / DVs	Rate	Gender	Context	Context * Rate	Context * Gender
C1 HP	***				
ICI	***				
C2 Frication	***				
Sequence	***				
ICI Voicing Proportion					

As in Table 6.60, the individual intervals are similar between an emphatic context and the plain counterpart. Sequence duration tends to be longer in /bsˤ/ than in /bs/, but this difference is not statistically significant. The ICI duration is almost the same between /bsˤ/ and /bs/ sequences (10ms and 9ms respectively), which is not statistically significant. This indicates that the consonantal gestures are apart to a similar degree in both /bsˤ/ and /bs/ sequences. Accordingly, there is no evidence to conclude that /bsˤ/ and /bs/ differ in the degree of gestural overlap, unlike /btˤ/ and /bt/ as reported in Section 6.2.4.1, indicating that the state of the glottis is the same in both /sˤ/ and /s/; no differences were found between the two sequences in the ICI voicing proportion, supporting this conclusion.

6.3.4.2 s#b vs sˤ#b

The timing relations in /sˤb/ in *ba:sˤ#ba:sim* were compared to those in /sb/ in *ba:s#ba:sim*.

Table 6.62 ICI count

Consonant Sequence	Total *n*	Not		Yes	
		n	**Percentage**	***n***	**Percentage**
s#b	96	96	100	0	0
sˤ#b	96	96	100	0	0
Total	192	192	100	0	0

Table 6.63 Acoustic measurements for sˤ#b and s#b (mean_values). NA=No ICIs occurred.

Consonant Sequence	C1_Frication	ICI	C2_HP	Sequence	ICI_Voicing Proportion
s#b	70.99	NA	57.41	128.4	NA
sˤ#b	70.82	NA	53.99	124.81	NA

Table 6.64 The summary of optimal models of all dependent variables. Full optimal models are presented in Appendix B (Section 11.2.1.2.2).

IVs / DVs	Rate	Gender	Context	Context * Rate	Context * Gender
C1 Frication	***				
ICI	NA	NA	NA	NA	NA
C2 HP	***				
Sequence	***				
ICI Voicing Proportion	NA	NA	NA	NA	NA

No ICIs occurred in these two sequences as in Table 6.62. The fact that no ICIs occur in /sb/ and /sˤb/ sequences,but occur in /bs/ and /bsˤ/ sequences, as reported in Section 6.3.4.1, could be due to C1 identity. C1 in /bs/ and /bsˤ/ is the bilabial stop /b/, and ICIs are prone to occur if C1 is a stop in the sequence because there is a release in stops, unlike C1 in /sb/ and /sˤb/ in two consonant sequences which is a fricative, and ICIs occur less often because there is no release after a fricative. This is, however, not operative in marked sequences where epenthetic vowels are likely to occur such as /sb#/ (since it violates the sonority sequencing in Najdi Arabic); /sb#/ ~ /sˤb#/ sequences will be discussed in Chapter 7. The acoustic measurements are presented in Table 6.63. The summary of optimal models of all dependent variables is presented in Table 6.64.

As in Table 6.63, the individual intervals and sequence durations are similar between the two sequences. The results reveal that there are no significant differences between an emphatic context and the plain counterpart in those intervals. Accordingly, there is no evidence to conclude that /sˤb/ and /sb/ differ in the degree of gestural overlap, indicating that the state of the glottis is the same in both /sˤ/ and /s/.

6.3.4.3 g#s vs g#sˤ

The timing relations in /gsˤ/ in *ba:g#sˤa:liħ* were compared to those in /gs/ in *ba:g#sa:lim* As in Table 6.65, the ICI occurs more often in /gsˤ/ than in /gs/. The acoustic measurements are presented in Table 6.66. The summary of optimal models of all dependent variables is presented in Table 6.67.

Table 6.65 ICI count

Consonant Sequence	Total *n*	Not		Yes	
		n	Percentage	*n*	Percentage
g#s	96	29	30.21	67	69.79
g#sˤ	96	9	9.38	87	90.63
Total	192	38	19.79	154	80.21

Table 6.66 Acoustic measurements for g#sˤ and g#s (mean_values)

Consonant Sequence	C1_HP	ICI	C2_Frication	Sequence	ICI_Voicing Proportion
g#s	50.46	18.7	78.33	149	0.56
g#sˤ	60.96	27.76	95.54	181.14	0.62

Table 6.67 The summary of optimal models of all dependent variables. Full optimal models are presented in Appendix B (Section 11.2.1.2.3).

IVs / DVs	Rate	Gender	Context	Context * Rate	Context * Gender
C1 HP	***		***		
ICI	***		***		
C2 Frication	***		***		
Sequence	***		***		
ICI Voicing Proportion					

As in Table 6.66, the average duration of /gsˤ/ sequence is 181ms and that of /gs/ sequence is 149ms. This difference is statistically significant (n=192,β=-0.086314,SE=0.003286,t-value=-26.27,p<0.001). The ICI is significantly longer in /gsˤ/ than /gs/ (n=154,β=-0.18499,SE=0.01078,t-value=-17.16,p<0.001). Similarly, /g/ HP is significantly longer in duration in /gsˤ/ than in /gs/ (n=192,β=-0.097510,SE=0.005609,t-value=-17.39,p<0.001), and /sˤ/ frication is also significantly longer than that of /s/ (n=192,β=-0.093869,SE=0.003825,t-value=-24.54,p<0.001). No differences were found between the two sequences in the ICI voicing proportion.

In general, the ICI occurs more often in an emphatic context than in the plain counterpart. The ICI duration is significantly longer in an emphatic context than in the plain counterpart, indicating that the consonantal gestures are further apart in the plain context than in the emphatic context. All individual intervals, along with sequence durations, are significantly longer in an emphatic context than in the plain counterpart. Accordingly, it can be concluded that /gsˤ/ sequence exhibits lower degree of gestural overlap than /gs/ sequence, when occurring at the word boundary in two consonant sequences. This could be attributed to the secondary articulation of the emphatic coronal /sˤ/, similar to the behaviour of /gtˤ/ and /gt/ as reported in Section 6.2.4.3.

6.3.4.4 s#g vs sˤ#g

The timing relations in /sˤg/ in *ba:sˤ#ga:sim* were compared to those in /sg/ in ba:s#ga:sim.

Table 6.68 ICI count

Consonant Sequence	Total *n*	Not		Yes	
		n	**Percentage**	***n***	**Percentage**
s#g	96	96	100	0	0
sˤ#g	96	96	100	0	0
Total	192	192	100	0	0

Table 6.69 Acoustic measurements for sˤ#g and s#g (mean_values)

Consonant Sequence	C1_Frication	ICI	C2_HP	Sequence	ICI_Voicing Proportion
s#g	81.12	NA	49.55	130.67	NA
sˤ#g	107.14	NA	63.54	170.68	NA

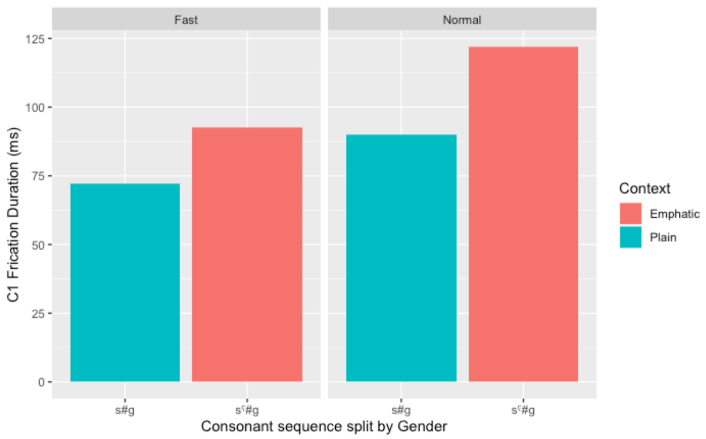
Table 6.70 The summary of optimal models of all dependent variables. Full optimal models are presented in Appendix B (Section 11.2.1.2.4).

IVs / DVs	Rate	Gender	Context	Context * Rate	Context * Gender
C1 Frication	***		***	*	
ICI	NA	NA	NA	NA	NA
C2 HP	***		***		
Sequence	***		***		
ICI Voicing Proportion	NA	NA	NA	NA	NA

No ICIs occurred in these two sequences as in Table 6.68. The fact that no ICIs occur in /sg/ and /sˤg/ sequences, but occur in /gs/, /gsˤ/ sequences, as reported in Section 6.3.4.3, could be due to C1 identity. C1 in /gs/ and /gsˤ/ is the stop /g/, and ICIs are prone to occur if C1 is a stop in the sequence because there is a release in stops, unlike C1 in /sg/ and /sˤg/ in two consonant sequences which is a fricative, and ICIs occur less often because there is no release after a fricative. This is, however, not operative in marked sequences where epenthetic vowels are likely to occur such as /sb#/, as pointed out in Section 6.3.4.2. The acoustic measurements are presented in Table 6.69. The summary of optimal models of all dependent variables is presented in Table 6.70.

As in Table 6.69, the duration of /sˤg/ sequence is longer than that of /sg/ sequence. This difference is statistically significant (n=192,β=-0.117089,SE=0.005128,t-value=-22.83,p<0.001). /sˤ/ frication also significantly longer in duration than /s/ frication (n=192,β=-0.108475,SE=0.007743,t-value=-14.009,p<0.001). The results also reveal that there is a significant interaction between Context and speech rate in the C1 frication duration (n=192,β=-0.024064,SE=0.010950,t-value=-2.198,p<0.001), as visualised in Figure 6.15. The results of further models[46] show that the effect is greater when produced at normal speech rate (see Appendix B, Section 11.2.1.2.4). Likewise, C2 HP duration is significantly longer in /sˤg/ than in /sg/ (n=192,β=-0.113235,SE=0.008814,t-value=-12.85,p<0.001).

Figure 6.15 C1_frication duration in ba:sˤ#ga:sim and ba:s#ga:sim in both speech rates



In general, both C1 frication and C2 HP, along with sequence durations, are longer in an emphatic context than in the plain counterpart. Accordingly, it can be concluded that /sˤg/ sequence exhibits lower degree of gestural overlap than /sg/ sequence, when occurring at the word boundary in two consonant sequences, similar to the patter of gestural overlap observed in /gs/ ~ /gsˤ/ as reported in Section 6.3.4.3, indicating that the secondary articulation of the emphatic coronal /sˤ/ has an impact on gestural overlap.

[46] A new subset was created that included only normal speech rate and another that included only fast speech rate, then further models were run for each.

6.4 Stop/dental fricative sequences

6.4.1 The results of the place order effect (Hypothesis (i))

As pointed out in Chapter 5, linear mixed-effects models were run to test Hypothesis (i) with the place order and its interaction with other independent variables as the crucial fixed factor(s). The independent variables that were included in these models are the identity of the articulators, Context (plain, emphatic), order of place of articulation, speech rate and gender.

Table 6.71 ICI count. Yes (count and percentage of occurring ICIs), Not (count and percentage of non-occurring ICIs)

Place Order	**Total *n***	**Not**		**Yes**	
		n	**Percentage**	***n***	**Percentage**
back-front	384	217	56.51	167	43.49
front-back	384	359	93.49	25	6.51
Total	768	576	75.00	192	25.00

Table 6.72 Acoustic measurements for stop/dental fricative sequences (mean_values)

Place Order	**ICI_duration**	**Sequence_duration**
back-front	25.71	124.91
front-back	11.55	124.48

The ICI count, ICI duration and sequence duration in back-front were compared to those in front-back stop/dental fricative sequences, occurring at the word boundary (C#C). Sequences in a back-front place order include /ðb/, /ðˤb/, /gð/ and /gðˤ/, and sequences in a front-back order include /bð/, /bðˤ/, /ðg/ and /ðˤg/ sequences.

As in Table 6.71, the ICI occurs more often in back-front than in front-back place order (43% and 6% respectively). When considering other independent variables, however, it turns out that the place order effect on ICI count is only exhibited in lingual/lingual sequences (86% in back-front vs 0% in front-back), compared to labial/lingual sequences (0% in back-front vs 13% in front-back). The fact that the ICI count in front-back place order (i.e., /bð/, /bðˤ/) scores 13% higher than in back-front order (i.e., /ðb/, /ðˤb/) in labial/lingual sequences could be due to C1 identity. C1 in /bð/ and /bðˤ/ is the bilabial stop /b/, and ICIs are prone to occur if C1 is a stop in the sequence because there is a release in stops, unlike C1 in /ðb/ and /ðˤb/ in two consonant sequences which is a fricative, and ICIs occur less often because there is no a release after a fricative.

As in Table 6.72, the ICI duration is 25ms in a back-front order and 11ms in front-back order. When running linear mixed-effects models for ICI duration (considering speech rate, gender, Context, the place order and the identity of the articulators), the model gives a warning note (i.e., `fixed-effect model matrix is rank deficient so dropping 1 column`). In these models, when adding the identity of articulators to the model, it significantly contributes to the model fit. In the summary of the optimal model, however, this predictor (the identity of articulators) did not appear in the list of the fixed effects. This could be due to the fact that ICIs occur in front-back sequences only in labial/lingual sequences, and ICIs occur in back-front sequences only in lingual/lingual sequences, as indicated above. Accordingly, the comparison between both place orders in ICI duration could not be valid. Therefore, a comparison between the two place orders in sequence duration is more valid.

No significant differences were found between the two orders in sequence duration as in Table 6.73. In general, the ICI occurs more often in a back-front than in front-back place order only in lingual/lingual sequences, but not in labial/lingual sequences. No significant differences were found between the two orders in sequence duration. Accordingly, the place order effect is ***only exhibited*** in lingual/lingual sequences in stop/dental fricative sequences, occurring at the word boundary (C#C) in Najdi Arabic, *based on ICI count*.

Table 6.73 The optimal model of sequence_duration in stop/dental fricative sequences

```
Formula: wslog ~ rate + Context + articulators + (1 | speaker)
   Data: AD
Fixed effects:
                            Estimate Std.Error         df tvalue Pr(>|t|)
(Intercept)                 1.986569   0.003367 126.992206  590.04   <2e-16***
rateNormal                  0.130943   0.003181 749.000000   41.16   <2e-16***
ContextPlain               -0.048274   0.003181 749.000000  -15.17   <2e-16***
articulatorsLingual/lingual 0.112237   0.003181 749.000000   35.28   <2e-16***
```

6.4.2 The results of the speech rate effect (Hypothesis (j))

As made clear in Chapter 2, the main measure to determine whether there is an effect of speech rate on gestural overlap is the ICI count. Therefore, the ICI count is the only dependent variable considered here.

Table 6.74 ICI count. Yes (count and percentage of occurring ICIs), Not (count and percentage of non-occurring ICIs)

Speech Rate	**Total *n***	**Not**		**Yes**	
		n	**Percentage**	***n***	**Percentage**
Fast	384	329	85.68	55	14.32
Normal	384	247	64.32	137	35.68
Total	768	576	75.00	192	25.00

As in Table 6.74, the ICIs occur less often in fast speech rate than in normal rate by around 21%. The other independent variables (i.e. gender, Context, place order and the identity of articulators) did not play any role in the speech rate effect. Accordingly, it can be concluded that stop/dental fricative sequences (C#C) at fast speech rate exhibit greater degree of gestural overlap than in normal speech rate. It should be noted that no ICIs occurred in sequences where C1 is a fricative (/ð#b/, /ðˤ#b/, /ð#g/ and /ðˤ#g/), as will be shown later in this chapter. Thus, the speech rate effect, based on ICI count, is exhibited in sequences where C1 is a stop (/b#ð/, /b#ðˤ/, /g#ð/ and /g#ðˤ/).

6.4.3 The results of the impact of the identity of the articulators (Hypothesis (a))

As pointed out in Chapter 5, linear mixed-effects models were run to test Hypothesis (a) with the identity of the articulators and its interaction with other independent variables as the crucial fixed factor(s). The independent variables that were included in these models are the identity of the articulators, Context (plain, emphatic), order of place of articulation, speech rate and gender.

The ICI count, ICI duration and sequence duration in lingual/lingual were compared to those in labial/lingual sequences, occurring at the word boundary (C#C). Lingual/lingual sequences include /ðg/, /ðˤg/, /gð/ and /gðˤ/, and labial/lingual sequences include /bð/, /bðˤ/, /ðb/ and /ðˤb/.

Table 6.75 ICI count. Yes (count and percentage of occurring ICIs), Not (count and percentage of non-occurring ICIs)

Articulators	**Total *n***	**Not**		**Yes**	
		n	**Percentage**	***n***	**Percentage**
Labial/lingual	384	359	93.49	25	6.51
Lingual/lingual	384	217	56.51	167	43.49
Total	768	576	75.00	192	25.00

Table 6.76 Acoustic measurements for stop/dental fricative sequences (mean_values)

Articulators	**ICI_duration**	**Sequence_duration**
Labial/lingual	11.55	108.73
Lingual/lingual	25.71	140.66

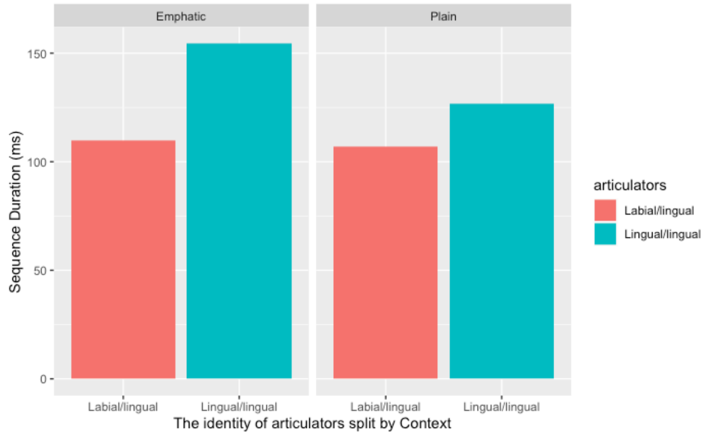
As in Table 6.75, the ICI occurs more often in lingual/lingual sequences than in labial/lingual sequences (43% and 6% respectively). When considering other independent variables, however, it turns out that the identity of articulators effect on ICI count is only exhibited in sequences in back-front order (86% in lingual/lingual vs 0% in labial/lingual sequences), compared to sequences in front-back order (0% in lingual/lingual vs 13% in labial/lingual sequences). The fact that the ICI count in labial/lingual sequences (i.e., /bð/, /bðˤ/) scores 13% higher than in lingual/lingual sequences (i.e., /ðg/, /ðˤg/) in front-back order could be due to C1 identity. C1 in /bð/ and /bðˤ/ is the bilabial stop /b/, and ICIs are prone to occur if C1 is a stop in the sequence because there is a release in stops, unlike C1 in /ðg/ and /ðˤg/ in two consonant sequences which is a fricative, and ICIs occur less often because there is no a release after a fricative.

As in Table 6.76, the ICI duration is 25ms in lingual/lingual sequences and 11ms in labial/lingual sequences. When running linear mixed-effects models for ICI duration (considering speech rate, gender, Context, the place order and the identity of the articulators), the model gives a warning note (i.e., `fixed-effect model matrix is rank deficient so dropping 1 column`). In these models, when adding the identity of articulators to the model, it significantly contributes to the model fit. In the summary of the optimal model, however, this predictor (the identity of articulators) did not appear in the list of the fixed effects. This could be due to the fact that ICIs occur in labial/lingual sequences only in front-back, and ICIs occur in lingual/lingual sequences only in back-front sequences, as indicated above. Accordingly, the comparison between both identities of the articulators in ICI duration could not be valid. Therefore, a comparison between the two identities in sequence duration is more valid.

Sequence duration is significantly longer in lingual/lingual sequences than in labial/lingual sequences ($n=768, \beta=0.149879, SE=0.004060, t\text{-value}=36.920, p<0.001$) as in Table 6.77. The results also reveal that there is a significant interaction between the identity of articulators and Context in sequence duration ($n=768, \beta=-0.075285, SE=0.005741, t\text{-value}=-13.113, p<0.001$) as visualised in Figure 6.16. The results of further models[47] reveal that sequence duration is significantly longer in lingual/lingual sequences than in labial/lingual sequences across Context, but the effect is greater in an emphatic context than in the plain counterpart, as in the optimal models in Tables 6.78 and 6.79.

[47] A new subset was created that included only emphatic context and another that included only plain context, then further models were run for each.

Figure 6.16 Sequence_duration in stop/dental fricative sequences in both identities of articulators, split by Context



In general, the ICI occurs more often in lingual/lingual sequences than in labial/lingual sequences only in back-front order, but not in front-back order. Sequence duration is significantly longer in lingual/lingual sequences than in labial/lingual sequences across place order. Accordingly, it can be concluded that lingual/lingual sequences exhibit lower degree of gestural overlap than labial/lingual sequences in stop/dental fricative sequences, occurring at the word boundary (C#C) in Najdi Arabic, *based on sequence duration*, similar to stop/alveolar fricative sequences as reported in Section 6.3.3.

Table 6.77 The optimal model of sequence_duration in stop/dental fricative sequences

```
Formula: wslog ~ rate + Context + articulators + articulators:Context + (1 | speaker)
   Data: AD
Fixed effects:
                                         Estimate Std.Error          df tvalue Pr(>|t|)
(Intercept)                              1.967748   0.003462 140.043467 568.399   <2e-
16***
rateNormal                               0.130943   0.002871 748.000002  45.616   <2e-
16***
ContextPlain                            -0.010631   0.004060 748.000002  -2.619
0.009**
articulatorsLingual/lingual              0.149879   0.004060 748.000002  36.920   <2e-
16***
ContextPlain:articulatorsLingual/lingual -0.075285   0.005741 748.000002 -13.113   <2e-
16***
```

<u>FURTHER:</u>

Table 6.78 The optimal model of sequence_duration in stop/dental fricative sequences (in an emphatic Context)

```
Formula: wslog ~ rate + articulators + (1 | speaker)
   Data: AD_E
Fixed effects:
                          Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)              1.968e+00 3.664e-03 6.207e+01 537.17  <2e-16***
rateNormal               1.305e-01 3.735e-03 3.660e+02  34.93  <2e-16***
articulatorsLingual/lingual 1.499e-01 3.735e-03 3.660e+02 40.12  <2e-16***
```

Table 6.79 The optimal model of sequence_duration in stop/dental fricative sequences (in a plain Context)

```
Formula: wslog ~ rate + articulators + (1 | speaker)
   Data: AD_P
Fixed effects:
                              Estimate Std.Error       df tvalue Pr(>|t|)
(Intercept)                  1.957e+00  3.786e-03 3.810e+02  516.85   <2e-16***
rateNormal                   1.314e-01  4.372e-03 3.810e+02   30.06   <2e-16***
articulatorsLingual/lingual  7.459e-02  4.372e-03 3.810e+02   17.06   <2e-16***
```

6.4.4 The results of the impact of the secondary articulation of emphatic coronals (Hypothesis (b))

As pointed out in Chapter 5, linear mixed-effects models were run to test Hypothesis (b) with Context (emphatic or plain) and its interaction with other independent variables as the crucial fixed factor(s). The independent variables that were included in these models are Context, order of place of articulation, speech rate and gender.

Table 6.80 ICI count in lingual/lingual sequences

Context	**Total *n***	**Not**		**Yes**	
		n	**Percentage**	***n***	**Percentage**
Emphatic	192	102	53.13	90	46.88
Plain	192	115	59.90	77	40.10
Total	384	217	56.51	167	43.49

Table 6.81 Acoustic measurements for stop/dental fricative sequences (mean_values)

Context	**ICI_duration**	**Sequence_duration**
Emphatic	31.07	154.40
Plain	19.45	126.93

To test Hypothesis (b), emphatic coronals were considered, as explained earlier. As in Table 6.80, the ICI tends to occur more often in an emphatic context than in the plain counterpart in lingual/lingual sequences (46 % and 40.5 % respectively). In those instances where ICIs occur, the average duration of the ICI is 31ms in an emphatic context and 19ms in the plain counterpart, as in Table 6.81. The results reveal that this difference in ICI duration is statistically significant ($n=167, \beta=-0.21981, SE=0.01337, t\text{-value}=-16.442, p<0.001$) as in Table 6.82. Similarly, sequence duration is significantly longer in an emphatic context than in the plain counterpart in lingual/lingual sequences ($n=384, \beta=-0.085916, SE=0.004107$, t-value=-20.92, $p<0.001$) as in Table 6.83.

Table 6.82 The optimal model of ICI_duration in stop/dental fricative sequences (in lingual/lingual sequences)

```
Formula: icilog ~ rate + gender + Context + (1 | speaker)
   Data: AD_DOR
Fixed effects:
              Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)    1.39561   0.01370 163.00000 101.871  <2e-16***
rateNormal     0.12517   0.01344 163.00000   9.311  <2e-16***
genderMale     0.04113   0.01333 163.00000   3.086  0.00239**
ContextPlain  -0.21981   0.01337 163.00000 -16.442  <2e-16***
```

Table 6.83 The optimal model of sequence_duration in stop/dental fricative sequences (in lingual/lingual sequences)

```
Formula: wslog ~ rate + Context + (1 | speaker)
   Data: AD_DOR
Fixed effects:
              Estimate Std. Error         df t value Pr(>|t|)
(Intercept)   2.123346   0.004058  60.322283  523.30   <2e-16***
rateNormal    0.119505   0.004107 366.000000   29.10   <2e-16***
ContextPlain -0.085916   0.004107 366.000000  -20.92   <2e-16***
```

Based on these results, it can be concluded that lingual/lingual sequences exhibit lower degree of gestural overlap in an emphatic context than in the plain counterpart in stop/dental fricative sequences in Najdi Arabic. This hypothesis (b) will be discussed further in Section 6.5.

The sequence duration and the individual intervals within the sequence are used as measures to determine the degree of gestural overlap in this thesis in addition to the ICI count and ICI duration. Therefore, the remainder of this section will be devoted to the timing relations in stop/dental fricative sequences. The timing relations in /bðˤ/ will be compared to those in /bð/. The timing relations in /ðˤb/ will be compared to those in /tb/. Similar comparisons will be then made in lingual/lingual sequences (/gðˤ/ vs /gð/ and /ðˤg/ vs /ðg/). Due to these specific comparisons, the identity of the articulators and the order of place of articulation are not included in the models that were run in these subsections. For instance, the timing relations in /gðˤ/ will be compared to those in /gð/, and both sequences consist of lingual/lingual consonants and both are in back-front place order. Therefore, the two independent variables (i.e., the identity of the articulators and the order of place of articulation) were excluded in the relevant models. Models were run with Context (emphatic or plain) and its interaction with other independent variables as the crucial fixed factor(s).

6.4.4.1 b#ð vs b#ðˤ

The timing relations in /bðˤ/ in *ba:b#ðˤa:lim* were compared to those in /bð/ in *ba:b#ða:bil*. As in Table 6.84, the ICI count is almost the same in both sequences. The acoustic measurements are presented in Table 6.85. The summary of optimal models of all dependent variables is presented in Table 6.86.

Table 6.84 ICI count

Consonant Sequence	Total *n*	Not		Yes	
		n	Percentage	*n*	Percentage
b#ð	96	84	87.5	12	12.5
b#ðˤ	96	83	86.46	13	13.54
Total	192	167	86.98	25	13.02

Table 6.85 Acoustic measurements for b#ðˤ and b#ð (mean_values)

Consonant Sequence	C1_HP	ICI	C2_Frication	Sequence	ICI_Voicing Proportion
b#ð	47.7	10.08	55.77	106.74	0.95
b#ðˤ	52.66	12.91	56.52	109.23	0.94

Table 6.86 The summary of optimal models of all dependent variables. Full optimal models are presented in Appendix B (Section 11.2.1.3.1).

IVs / DVs	Rate	Gender	Context	Context * Rate	Context * Gender
C1 HP	***				
ICI	***				
C2 Frication	***				
Sequence	***				
ICI Voicing Proportion					

As in Table 6.85, the individual intervals and sequence durations are similar between the two sequences. The results reveal that these intervals are not significantly different between an emphatic context and the plain counterpart. C1 HP duration tends to be longer in /bðˤ/ than in /bð/, but this is not statistically significant. Accordingly, there is no evidence to conclude that /bðˤ/ and /bð/ differ in the degree of gestural overlap, confirming that the state of the glottis is the same in both /ðˤ/ and /ð/; no differences were found between the two sequences in the ICI voicing proportion, supporting this conclusion. This finding provides evidence that the state of the glottis plays a role in gestural overlap. We have seen that /btˤ/ and /tˤb/ sequences exhibit greater degree of gestural overlap than /bt/ and /tb/ sequences, respectively, as reported in Sections 6.2.4.1 and 6.2.4.2, because the state of the glottis for /tˤ/ is different from that for /t/ which is less open in the former than in the latter. Because the state of the glottis is the same in /ðˤ/ and /ð/, no differences were found between the two in the degree of gestural overlap.

6.4.4.2 ð#b vs ðˤ#b

The timing relations in /ðˤb/ in *ha:ðˤ#ba:sim* were compared to those in /ðb/ in *ba:ð#ba:sim*.

Table 6.87 ICI count

Consonant Sequence	Total *n*	Not		Yes	
		n	Percentage	*n*	Percentage
ð#b	96	96	100	0	0
ðˤ#b	96	96	100	0	0
Total	192	192	100	0	0

Table 6.88 Acoustic measurements for ðˤ#b and ð#b (mean_values)

Consonant Sequence	C1_Frication	ICI	C2_HP	Sequence	ICI_Voicing Proportion
ð#b	54.19	NA	53.45	107.64	NA
ðˤ#b	57.46	NA	52.84	110.3	NA

Table 6.89 The summary of optimal models of all dependent variables. Full optimal models are presented in Appendix B (Section 11.2.1.3.2).

IVs / DVs	Rate	Gender	Context	Context * Rate	Context * Gender
C1 Frication	***				
ICI	NA	NA	NA	NA	NA
C2 HP	***				
Sequence	***				
ICI Voicing Proportion	NA	NA	NA	NA	NA

No ICIs occurred in these two sequences as in Table 6.87. The fact that no ICIs occur in /ðb/ and /ðˤb/ sequences, but occur in /bð/ and /bðˤ/ sequences, as reported in Section 6.4.4.1, could be due to C1 identity. C1 in /bð/ and /bðˤ/ is the bilabial stop /b/, and ICIs are prone to occur if C1 is a stop in the sequence because there is a release in stops, unlike C1 in /ðb/ and /ðˤb/ in two consonant sequences which is a fricative, and ICIs occur less often because there is no release after a fricative. This is, however, not operative in marked sequences where epenthetic vowels are likely to occur such as /sb#/, as pointed out in Sections 6.3.4.2 and 6.3.4.4. The acoustic measurements are presented in Table 6.88. The summary of optimal models of all dependent variables is presented in Table 6.89.

As in Table 6.88, the individual intervals and sequence durations are similar between the two sequences. The results reveal that there are no significant differences between an emphatic context and the plain counterpart in those intervals. Accordingly, there is no evidence to conclude that /ðˤb/ and /ðb/ differ in the degree of gestural overlap, confirming that the state of the glottis is the same in both /ðˤ/ and /ð/.

6.4.4.3 g#ð vs g#ðˤ

The timing relations in /gðˤ/ in *ba:g#ðˤa:lim* were compared to those in /gð/ in *sa:g#ða:bil*. As in Table 6.90, the ICI occurs more often in /gðˤ/ than in /gð/. The acoustic measurements are presented in Table 6.91. The summary of optimal models of all dependent variables is presented in Table 6.92.

Table 6.90 ICI count

Consonant Sequence	**Total *n***	**Not**		**Yes**	
		n	**Percentage**	***n***	**Percentage**
g#ð	96	19	19.79	77	80.21
g#ðˤ	96	6	6.25	90	93.75
Total	192	25	13.02	167	86.98

Table 6.91 Acoustic measurements for g#ðˤ and g#ð (mean_values)

Consonant Sequence	**C1_HP**	**ICI**	**C2_Frication**	**Sequence**	**ICI_Voicing Proportion**
g#ð	45.59	19.45	61.54	129.93	0.95
g#ðˤ	59.79	31.07	61.29	150.76	0.97

Table 6.92 The summary of optimal models of all dependent variables. Full optimal models are presented in Appendix B (Section 11.2.1.3.3).

IVs / DVs	Rate	Gender	Context	Context * Rate	Context * Gender
C1 HP	***		***		
ICI	***		***		
C2 Frication	***				
Sequence	***		***		
ICI Voicing Proportion					

As in Table 6.91, the average duration of /gðˤ/ sequence is 150ms and that of /gð/ sequence is 129ms. This difference is statistically significant (n=192,β=-0.066151,SE=0.005324,t-value=-12.42,p<0.001). The ICI is significantly longer in /gðˤ/ than /gð/ (n=167,β=-0.22012,SE=0.01354,t-value=-16.255,p<0.001). Similarly, /g/ HP is significantly longer in duration in /gðˤ/ than in /gð/ (n=186,β=-0.144148,SE=0.007735,t-value=-18.64,p<0.001). No differences were found between the two sequences in C2 frication and the ICI voicing proportion.

In general, the ICI occurs more often in an emphatic context than in the plain counterpart. The ICI duration is significantly longer in an emphatic context than in the plain counterpart, indicating that the consonantal gestures are further apart in the plain context than in the emphatic context. C1 HP duration, along with sequence durations, are significantly longer in an emphatic context than in the plain counterpart. Accordingly, it can be concluded that /gðˤ/ sequence exhibits lower degree of gestural overlap than /gð/ sequence, when occurring at the word boundary in two consonant sequences, indicating that the secondary articulation of the emphatic coronal /ðˤ/ has an impact on gestural overlap, similar to the behaviour of /gtˤ/ vs /gt/ and /gsˤ/ vs /gs/ as reported in Sections 6.2.4.3 and 6.3.4.3.

6.4.4.4 ð#g vs ðˤ#g

The timing relations in /ðˤg/ in *ha:ðˤ#ga:sim* were compared to those in /ðg/ in *ba:ð#ga:sim*.

Table 6.93 ICI count

Consonant Sequence	Total *n*	Not		Yes	
		n	**Percentage**	***n***	**Percentage**
ð#g	96	96	100	0	0
ðˤ#g	96	96	100	0	0
Total	192	192	100	0	0

Table 6.94 Acoustic measurements for ðˤ#g and ð#g (mean_values)

Consonant Sequence	C1_Frication	C2_HP	Sequence
ð#g	67.07	56.85	123.92
ðˤ#g	96.82	61.21	158.04

Table 6.95 The summary of optimal models of all dependent variables. Full optimal models are presented in Appendix B (Section 11.2.1.3.4).

IVs / DVs	Rate	Gender	Context	Context * Rate	Context * Gender
C1 Frication	***		***		
ICI	NA	NA	NA	NA	NA
C2 HP	***				
Sequence	***		***		
ICI Voicing Proportion	NA	NA	NA	NA	NA

No ICIs occurred in these two sequences as in Table 6.93. The fact that no ICIs occur in /ðg/ and /ðˤg/ sequences, but occur in /gð/, /gðˤ/ sequences, as reported in Section 6.4.4.3, could be due to C1 identity. C1 in /gð/ and /gðˤ/ is the stop /g/, and ICIs are prone to occur if C1 is a stop in the sequence because there is a release in stops, unlike C1 in /ðg/ and /ðˤg/ in two consonant sequences which is a fricative, and ICIs occur less often because there is no release after a fricative. This is, however, not operative in marked sequences where epenthetic vowels are likely to occur as pointed out earlier. The acoustic measurements are presented in Table 6.94. The summary of optimal models of all dependent variables is presented in Table 6.95.

As in Table 6.94, the intervals are longer in an emphatic context than in the plain counterpart. The results reveal that /ðˤ/ frication is significantly longer than /ð/ frication ($n=192, \beta=-0.160014, SE=0.006380, t\text{-value}=-25.08, p<0.001$). Likewise, sequence duration is significantly longer in an emphatic context than in the plain counterpart ($n=192, \beta=-0.105682, SE=0.004770, t\text{-value}=-22.16, p<0.001$). No significant differences were found between the two sequences in C2 HP duration.

Accordingly, it can be concluded that /ðˤg/ sequence exhibits lower degree of gestural overlap than /ðg/ sequence, when occurring at the word boundary in two consonant sequences, similar to the pattern of gestural overlap observed in /gð/ ~ /gðˤ/ sequences as reported in Setion 6.4.4.3, indicating that the secondary articulation of the emphatic coronal /ðˤ/ has an impact on gestural overlap.

6.5 Interim discussion

This chapter presented the results concerning the secondary articulation of emphasis and gestural overlap: Research Question 1a and the associated specific hypotheses (a) and (b). The results of each sequence type (stop/stop, stop/alveolar fricative or stop/dental fricative) were provided separately. The results of the common hypotheses (i) and (j) were presented first, followed by the results of the specific hypotheses (a) and (b).

Table 6.96 Summary of the impact of place order, by sequence type.(√) indicates that the impact is exhibited

	Stop/stop	Stop/alveolar fricative	Stop/dental fricative
C#C	(inconsistent)[48]	√ (only in lingual/lingual)	√ (only in lingual/lingual)

Table 6.97 Summary of the impact of speech rate, by sequence type.(√) indicates that the impact is exhibited. NA=no ICIs occurred

	Stop/stop	Stop/alveolar fricative		Stop/dental fricative	
		C1 is a stop (/b/ or /g/)	C1 is a fricative (/s/ or /sˤ/)	C1 is a stop (/b/ or /g/)	C1 is a fricative (/ð/ or /ðˤ/)
C#C	√	√	X	√	X

Table 6.98 Summary of the impact of the identity of articulators, by sequence type.(√) indicates that the impact is exhibited

	Stop/stop	Stop/alveolar fricative	Stop/dental fricative
The identity of articulators effect	√	√	√

Table 6.99 Summary of the impact of the secondary articulation of emphasis, by sequence type. √) indicates that the impact is exhibited

	Stop/stop	Stop/alveolar fricative	Stop/dental fricative
The impact of the secondary articulation of emphasis	√	√	√

As in Table, 6.96, in stop/stop sequences, the impact of the place order on ICI count was exhibited only in labial/lingual, while the place order impact on sequence duration was only exhibited in lingual/lingual sequences. These results seem inconsistent although both measures suggest that back-front exhibit lower degree of gestural overlap than front-back

[48] Some measures reveal that the place order effect is exhibited in labial/lingual only, and other measures reveal that it is exhibited in lingual/lingual sequences only.

sequences. In both stop/fricative sequences, the place order effect was only exhibited in lingual/lingual sequences. Lingual/lingual in back-front place order exhibit lower degree of gestural overlap than those in front-back order in these two sequence types. This effect is generally characterised by higher ICI count percentage, longer ICI and/or sequence durations in back-front than in front-back sequences. Accordingly, Hypothesis (i) is ***partially*** supported. The place order effect can be attributed to perceptual recoverability. The finding that the place order effect was only exhibited in lingual/lingual sequences could be attributed to the identity of articulators. Greater degree of gestural overlap was exhibited in labial/lingual than in lingual/lingual sequences in general since the articulators are independent in the former, and hence do not influence each other, while the articulators are connected in the latter and hence they constrain the movement of each other. Besides, ICIs do not occur in sequences where C1 is a fricative. Hence, ICIs do not occur in /s#b/, /sˤ#b/, /ð#b/ and /ðˤ#b/ back-front sequences, whereas ICIs occur in /b#s/, /b#sˤ/, /b#ð/ and /b#ðˤ/ front-back sequences; this may explain why the place order effect was not exhibited in labial/lingual sequences *in both stop/fricative* sequences. On the other hand, ICIs do not occur in /s#g/, /sˤ#g/, /ð#g/ and /ðˤ#g/ front-back sequences, whereas ICIs occur in /g#s/, /g#sˤ/, /g#ð/ and /g#ðˤ/ back-front sequences; this may explain why the place order effect was only exhibited in lingual/lingual sequences *in both stop/fricative* sequences; also sequence duration was longer in /g#s/ and /g#sˤ/ (back-front) than in /s#g/ and /sˤ#g/ (front-back) sequences. The finding that no ICIs occurred in those sequences has been attributed to C1 identity. C1 in /bs/ and /gs/, for example, is the stop /b/ or /g/, and ICIs are prone to occur if C1 is a stop in the sequence because there is a release in stops, unlike C1 in /sb/ and /sg/, for instance, in two consonant sequences which is a fricative, and ICIs occur less often because there is no release after a fricative. This interpretation is, however, not operative in marked sequences where epenthetic vowels are likely to occur such as /sb#/ (since it violates the sonority sequencing in Najdi Arabic); /sb#/ ~ /sˤb#/ sequences will be discussed in Chapter 7. The impact of the place order and Hypothesis (i) will be discussed further in Chapter 9.

As in Table, 6.97, apart from sequences in which C1 is a fricative /s/, /sˤ/, /ð/ or /ðˤ/, the impact of the speech rate effect was exhibited in all three sequence types. Sequences at fast rate exhibit greater degree of gestural overlap than those at normal rate. This effect is characterised by lower ICI count percentage at fast rate than at the normal rate. Accordingly, Hypothesis (j) is ***supported***. It should be noted that ICIs do not occur in sequences where C1 is a fricative as indicated above. The speech rate effect and Hypothesis (j) will be discussed in detail in Chapter 9.

As in Table, 6.98, the impact of the identity of articulators was exhibited in all three sequence types. Lingual/lingual sequences exhibit lower degree of gestural overlap than labial/lingual sequences. This impact is generally characterised by higher ICI count percentage, longer ICI and/or sequence durations in lingual/lingual than in labial/lingual sequences. Accordingly, Hypothesis (a) is ***supported***. This could be attributed to the identity of articulators which are connected in lingual/lingual, and hence constrain the movement of each other, whereas the articulators in labial/lingual sequences are independent from each other and hence each can move freely to reach its target without the influence of the other. The impact of the identity of articulators and Hypothesis (a) will be discussed further in Chapter 9.

As in Table, 6.99, the impact of the secondary articulation of the emphatic coronals was exhibited in all three sequence types. Lingual/lingual sequences in an emphatic context exhibit lower degree of gestural overlap than those in the plain counterpart. This impact is generally characterised by higher ICI count percentage, longer ICI, sequence durations and/or longer individual intervals in lingual/lingual sequences in an emphatic context than in those in the plain counterpart. Accordingly, Hypothesis (b) is ***supported***. This could be attributed to motor constraints; i.e., the secondary articulation in addition to the primary one. The articulators in lingual/lingual sequences in an emphatic context constrain the movement of each other more than lingual/lingual in the plain counterpart since there is an additional secondary articulation involving the back of the tongue in emphatic context but not in the plain counterpart. The impact of the secondary articulation of emphasis and Hypothesis (b) will be discussed further in Chapter 9.

Having presented the results of the secondary articulation and gestural overlap in Chapter 6, the results of the state of the glottis and gestural overlap will be presented in the following chapter: 7, followed by the results of the types of vowel insertion and emphasis in Chapter 8.

7 Results: the state of the glottis and gestural overlap

7.1 Introduction

This chapter presents the results concerning the impact of the state of the glottis on gestural overlap in consonant sequences. The relevant word set in this chapter is word set B (see Table 5.2 in Chapter 5 for word set B). As discussed in Chapter 5, word set B was designed to address RQb and test hypotheses (c), (d) and (e), as restated below:

RQ 1,b: Does the state of the glottis involved during the production of emphatic coronals play a role in the degree of gestural overlap in consonant sequences?

Hypothesis (c) voiced/voiced consonant sequences will exhibit a greater degree of gestural overlap than voiced/voiceless consonant sequences.

Hypothesis (d) voiced/emphatic /tˤ/ sequences (i.e., /btˤ/ and /tˤb/) will exhibit a greater degree of gestural overlap than voiced/plain /t/ sequences (i.e., /bt/ and /tb/), and accordingly /tˤ/ will behave similarly with the plain voiced counterpart /d/ in the degree of gestural overlap, compared to the plain voiceless counterpart /t/.

Hypothesis (e) voiced/emphatic /sˤ/ sequences (i.e., /bsˤ/ and /sˤb/) will exhibit a greater degree of gestural overlap than voiced/plain /s/ sequences (i.e., /bs/ and /sb/), and accordingly /sˤ/ will behave similarly with the plain voiced counterpart /z/ in the degree of gestural overlap, compared to the plain voiceless counterpart /s/.

As also explained in Chapter 5, Hypotheses (i) and (j), as restated below, are common hypotheses that are tested in all three-word sets.

Hypothesis (i) back-front consonant sequences will exhibit a lower degree of gestural overlap than front-back consonant sequences.

Hypothesis (j) consonant sequences at a fast speech rate will exhibit a greater degree of gestural overlap than sequences at a normal speech rate.

As discussed in Chapter 5, to address the above research question and test the above three specific hypotheses (c, d and e), word set B was designed to include voiced/voiced sequences and voiced/voiceless sequences. This helps to test Hypothesis (c). For example, the timing relations in /bd/ (voiced/voiced) sequence were compared to those in both /bt/ (voiced/plain voiceless) and /btˁ/ (voiced/voiceless emphatic) sequences. Similar comparison was carried out for sequences including fricatives. For example, the timing relations in /bz/ (voiced/voiced) sequence were compared to those in both /bs/ (voiced/plain voiceless) and /bsˁ/ (voiced/voiceless emphatic) sequences. To test Hypothesis (d), the emphatic coronal /tˁ/ was included in the list, considering Context (plain voiceless /t/, plain voiced /d/ or emphatic /tˁ/). For example, the timing relations in /btˁ/ (voiced/emphatic) sequence were compared to those in /bt/ (voiced/plain voiceless) sequence and to those in /bd/ (voiced/plain voiced) sequence. To test Hypothesis (e), the emphatic coronal /sˁ/ was included in the list, considering Context (plain voiceless /s/, plain voiced /z/ or emphatic /sˁ/). For example, the timing relations in /bsˁ/ (voiced/emphatic) sequence were compared to those in /bs/ (voiced/plain voiceless) sequence and to those in /bz/ (voiced/plain voiced) sequence. As made clear in Chapter 5, the coronals /ðˁ/ and /ð/ were excluded in this word set because the state of the glottis is the same in both which are voiced. Therefore, based on the literature, there is no motivation to examine sequences including /ðˁ/ or /ð/ to investigate the role of the state of the glottis in the degree of gestural overlap.

As also made clear in Chapter 5, word set B was designed to include sequences occurring word-internally (i.e., word-initial and word-final clusters) because, first, the findings of most studies (e.g., Hoole et al, 2009; Shitaw, 2013; Alsubaie, 2014), that found that the state of the glottis plays a role on gestural overlap, were based on sequences occurring within words, i.e. word-initially or word-finally. Besides, voiced/voiceless consonants frequently occur word-initially or word-finally according to the Najdi Arabic lexicon, unlike dorsal/coronal sequences (e.g., /gt/, /tg/), as pointed out in word set A in Chapters 5 and 6. The independent variables that are considered in this chapter are as follows:

1. Word position (word-initial #CC, word-final CC#)
2. Context (plain voiced, plain voiceless, emphatic)
3. Order of place of articulation (front-back, back-front)
4. Speech rate (normal, fast)
5. Gender (male, female)

There are two sequence types in word set B: stop/stop sequences (e.g., /bt/, /tb/) and stop/alveolar fricative sequences (e.g., /bs/, /sb/). The results of each sequence type will be presented separately in two consecutive sections, and accordingly Hypothesis (c) will be tested for each sequence type; and the results of these sections will be summarised in Section 7.4, where it will be made clear whether the hypotheses are supported or not for all sequence types.

Each section will start with reporting the results of the common hypotheses (i) and (j), and the remainder of each section will be devoted to the results of the specific hypotheses (i.e. Hypothesis (c), Hypothesis (*d*, for stop/stop sequences) and Hypothesis (*e*, for stop/alveolar fricative sequences)). Accordingly, this chapter consists of four sections. Section 7.1 is an introductory section. Section 7.2 presents the results of stop/stop sequences. Section 7.3 presents the results of stop/alveolar fricative sequences. The chapter ends with an interim discussion in Section 7.4 in which the results of the chapter are summarised, and it will be made clear whether the specific hypotheses (c), (d) and (e) and the common hypotheses (i) and (j) are supported.

7.2 Stop/stop sequences

7.2.1 The results of the place order effect (Hypothesis (i))

Linear mixed-effects models were run to test Hypothesis (i) with the place order and its interaction with other independent variables as the crucial fixed factor(s). The independent variables that were included in these models are Context (plain voiced, plain voiceless, emphatic), order of place of articulation, word position, speech rate and gender.

The ICI count, ICI duration and sequence duration in back-front were compared to those in front-back stop/stop sequences, occurring word-initially or finally (#CC and CC#). Sequences in a back-front place order include /tb/, /tˤb/ and /db/, and sequences in a front-back order include /bt/, /btˤ/ and /bd/ sequences.

Table 7.1 ICI count. Yes (count and percentage of occurring ICIs), Not (count and percentage of non-occurring ICIs)

Place Order	**Total *n***	**Not**		**Yes**	
		n	**Percentage**	***n***	**Percentage**
back-front	576	74	12.85	502	87.15
front-back	576	341	59.20	235	40.80
Total	1152	415	36.02	737	63.98

Table 7.2 Acoustic measurements for stop/stop sequences (mean_values)

Place order	**ICI_duration**	**Sequence_duration**
back-front	49.39	163.54
front-back	23.92	132.16

As in Table 7.1, the ICI occurs more often in back-front than in front-back place order (87% and 40% respectively). When considering other independent variables, however, it turns out that the difference in ICI count in relation to the place order effect is bigger in sequences including the plain voiced /d/ (69% in back-front vs 14% in front-back), followed by sequences including the emphatic /tˤ/ (92% in back-front vs 27% in front-back), and then followed by sequences including the plain voiceless /t/ (66% in back-front vs 53% in front-back). Besides, the difference in ICI count in relation to the place order effect is bigger in a word-final position (99% in back-front vs 33% in front-back), followed by a word-initial position (75% in back-front vs 48% in front-back). In addition, the difference in ICI count in relation to the place order effect is more exhibited in fast speech rate (82% in back-front vs 30% in front-back), followed by normal speech rate (91% in back-front vs 51% in front-back).

As in Table 7.2, the ICI is longer in a back-front place order than in a front-back order. This difference is statistically significant (n=737,β=-0.114375,SE=0.011739,t-value=-9.743,p<0.001) as in the optimal model in Table 7.3. There is, however, a significant interaction between the place order and word position in ICI duration (n=737,β=-0.560401,SE=0.011212,t-value=-49.984,p<0.001), as visualised in Figure 7.4. The results of further models[49] reveal that the place order effect is only significant in a word-final position (n=382,β=-0.705238,SE=0.012177,t-value=-57.917,p<0.001), but not in a word-initial position, as in Tables 7.7 and 7.8. Accordingly, the place order as a main effect is a simple effect. The results also reveal that there is a significant interaction between the place order and Context in ICI duration (n=737,β=-0.240191,SE=0.018016,t-value=-13.332,p<0.001), as visualised in Figure 7.1. The results of further models[50] show that the place order effect is greater in sequences including the plain voiced /d/, followed by sequences including the emphatic /tˤ/, and then followed by sequences including the plain voiceless /t/, as in Tables 7.4, 7.5 and 7.6. The sequence duration is significantly longer in a back-front place order than in a front-back order (n=1152,β=-1.196e-02,SE= 5.914e-03,t-value=-2.023,p<0.05) as in Table 7.9. The results also reveal that the place order significantly interacts with word position (n=1152,β=-1.200e-01,SE=5.289e-03,t-value=-22.687,p<0.001) as visualised in Figure 7.5, with Context (n=1152,β=-8.395e-02,SE=6.478e-03,t-value=-12.959,p<0.001) as visualised in Figure 7.2, and with speech rate (n=1152,β=-1.892e-02,SE=5.289e-03,t-value= -3.577,p<0.001) as visualised in Figure 7.3, in the sequence duration. The results of further models[51] show that the place order effect is greater in a word-final position, followed by a word-initial position as in Tables 7.15 and 7.16. The place order effect is greater in sequences including the plain voiced /d/, followed

[49] A new subset was created that included only word-initial consonant sequences and another that included only word-final consonant sequences, then further models were run for each.
[50] A new subset was created that included only plain voiced context, another that included only emphatic context, and a third that included only plain voiceless context. Then further models were run to find out which context exhibits greater effect.
[51] A new subset was created that included only word-initial consonant sequences and another that included only word-final consonant sequences, then further models were run for each.

by sequences including the emphatic /tˤ/, and then followed by sequences including the plain voiceless /t/, as in Tables 7.12, 7.13 and 7.14 [52]. Besides, the place order effect is greater in normal speech rate, followed by fast speech rate as in Tables 7.10 and 7.11[53].

Figure 7.1 ICI_duration in stop/stop sequences in both place orders, split by Context

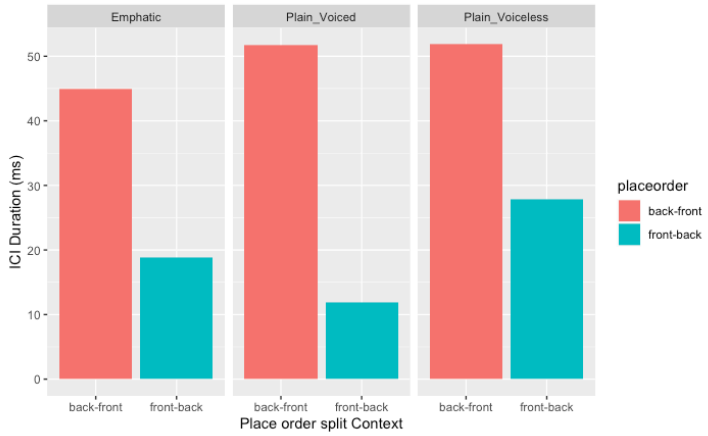
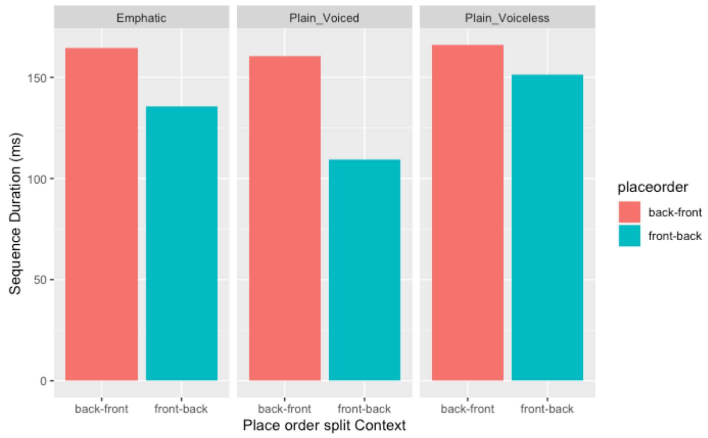


Figure 7.2 Sequence_duration in stop/stop sequences in both place orders, split by Context



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[52] A new subset was created that included only plain voiced context, another that included only emphatic context, and a third that included only plain voiceless context. Then further models were run to find out which context shows a significance of place order effect, or to find out which context exhibits greater effect.

[53] A new subset was created that included only normal speech rate and another that included only fast speech rate, then further models were run for each.

Figure 7.3 Sequence_duration in stop/stop sequences in both place orders, split by speech rate

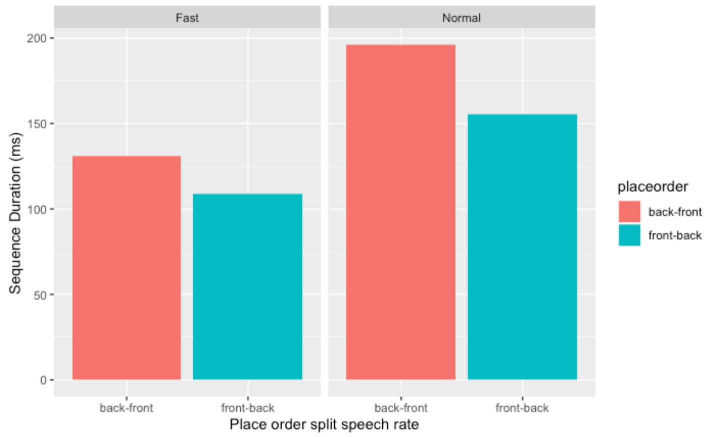


Figure 7.4 ICI_duration in stop/stop sequences in both place orders, split by word position

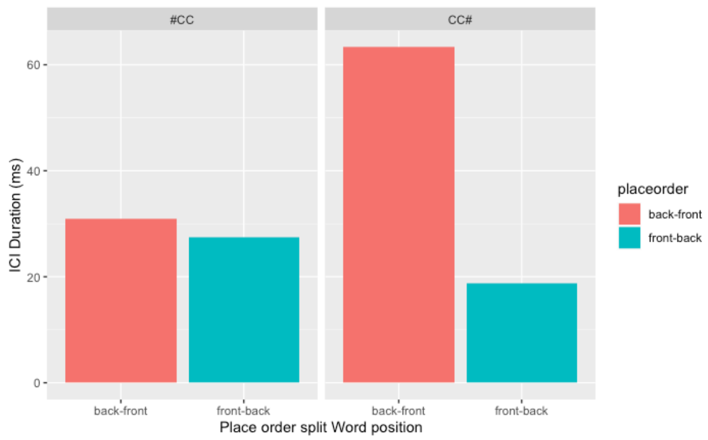
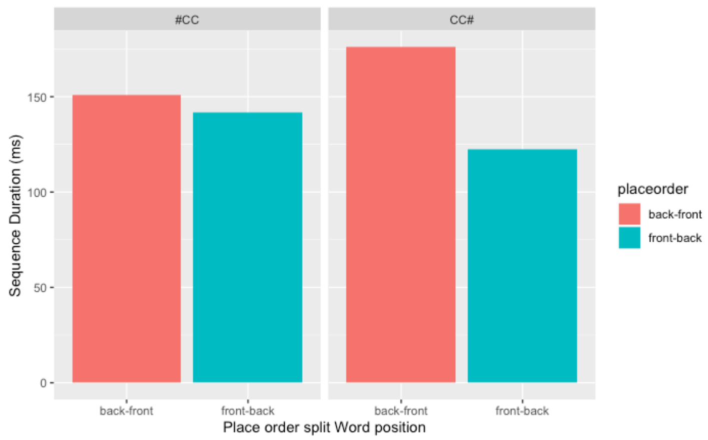


Figure 7.5 Sequence_duration in stop/stop sequences in both place orders, split by word position



In general, the ICI occurs more often in a back-front than in front-back place order across all independent variables. The ICI duration is significantly longer in a back-front than in front-back place order only in a word-final position. The sequence duration is significantly longer in a back-front than in front-back place order across all independent variables. Accordingly, it can be concluded that the place order effect is exhibited in stop/stop sequences, occurring word-initially or finally (#CC and CC#) in Najdi Arabic, *based on ICI count and sequence duration*.

Table 7.3 The optimal model of ICI_duration in stop/stop sequences

```
Formula: icilog ~ rate + gender + Context + placeorder + sequence + placeorder:Context +
    placeorder:sequence + (1 | speaker)
   Data: Bt
Fixed effects:
                                          Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)                               1.362558  0.007281 727.000000 187.132  <2e-16***
rateNormal                                0.112839  0.005161 727.000000  21.863  <2e-16***
genderMale                                0.011165  0.005085 727.000000   2.196  0.0284*
ContextPlain_Voiced                       0.001956  0.008006 727.000000   0.244  0.8071
ContextPlain_Voiceless                    0.095685  0.007193 727.000000  13.303  <2e-16***
placeorderfront-back                     -0.114375  0.011739 727.000000  -9.743  <2e-16***
sequenceCC#                               0.338809  0.006334 727.000000  53.490  <2e-16***
ContextPlain_Voiced:placeorderfront-back -0.240191  0.018016 727.000000 -13.332  <2e-16***
ContextPlain_Voiceless:placeorderfront-back 0.111836 0.013171 727.000000  8.491  <2e-16***
placeorderfront-back:sequenceCC#         -0.560401  0.011212 727.000000 -49.984  <2e-16***
```

FURTHER:

Table 7.4 The optimal model of ICI_duration in stop/stop sequences (in an emphatic Context). n =230

```
Formula: icilog ~ rate + gender + placeorder + sequence + placeorder:sequence + (1 |
speaker)
   Data: Bt_E
Fixed effects:
                                 Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)                      1.364520  0.008746 224.000000 156.010  <2e-16***
rateNormal                       0.128698  0.007917 224.000000  16.257  <2e-16***
genderMale                      -0.049583  0.007812 224.000000  -6.347 1.20e-09***
placeorderfront-back            -0.089225  0.011937 224.000000  -7.475 1.72e-12***
sequenceCC#                      0.375142  0.008937 224.000000  41.976  <2e-16***
placeorderfront-back:sequenceCC# -0.618773  0.019364 224.000000 -31.955  <2e-16***
```

Table 7.5 The optimal model of ICI_duration in stop/stop sequences (in plain voiceless Context). n=346

```
Formula: icilog ~ rate + gender + placeorder + sequence + placeorder:sequence + (1 |
speaker)
   Data: Bt_P_vl
Fixed effects:
                                 Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)                      1.478577  0.007366 340.000000 200.717  <2e-16***
rateNormal                       0.106422  0.006244 340.000000  17.045  <2e-16***
genderMale                       0.056340  0.006201 340.000000   9.085  <2e-16***
placeorderfront-back            -0.058643  0.008620 340.000000  -6.803 4.62e-11***
sequenceCC#                      0.259382  0.008315 340.000000  31.194  <2e-16***
placeorderfront-back:sequenceCC# -0.446859  0.012496 340.000000 -35.761  <2e-16***
```

Table 7.6 The optimal model of ICI_duration in stop/stop sequences (in plain voiced Context). n=161

```
Formula: icilog ~ rate + placeorder + sequence + placeorder:sequence + (1 | speaker)
   Data: Bt_P_vd
Fixed effects:
                                Estimate Std.Error         df tvalue Pr(>|t|)
(Intercept)                     1.299559  0.008794 156.000000  147.78  <2e-16***
rateNormal                      0.123622  0.007475 156.000000   16.54  <2e-16***
placeorderfront-back           -0.239145  0.012617 156.000000  -18.95  <2e-16***
sequenceCC#                     0.428614  0.008834 156.000000   48.52  <2e-16***
placeorderfront-back:sequenceCC# -0.838350  0.021167 156.000000  -39.61  <2e-16***
```

Table 7.7 The optimal model of ICI_duration in stop/stop sequences (in #CC position). n=355

```
Formula: icilog ~ rate + Context + placeorder:Context + (1 | speaker)
   Data: Bini_plos
Fixed effects:
                                         Estimate Std.Error         df tvalue Pr(>|t|)
(Intercept)                              1.347030  0.009163 348.000000 147.007  <2e-16***
rateNormal                               0.118654  0.007831 348.000000  15.152  <2e-16***
ContextPlain_Voiced                     -0.044383  0.014349 348.000000  -3.093 0.00214**
ContextPlain_Voiceless                   0.153601  0.010894 348.000000  14.099  <2e-16***
ContextEmphatic:placeorderfront-back    -0.089506  0.014632 348.000000  -6.117 2.56e-09***
ContextPlain_Voiced:placeorderfront-back -0.238756  0.020151 348.000000 -11.849  <2e-16***
ContextPlain_Voiceless:placeorderfront-back -0.058176  0.010857 348.000000  -5.358 1.53e-07***
```

Table 7.8 The optimal model of ICI_duration in stop/stop sequences (in CC# position). n=382

```
Formula: icilog ~ rate + Context + placeorder + placeorder:Context + (1 | speaker)
   Data: Bfin_plos
Fixed effects:
                                         Estimate Std.Error         df tvalue Pr(>|t|)
(Intercept)                              1.721650  0.005482 375.000000 314.055  <2e-16***
rateNormal                               0.114386  0.004922 375.000000  23.238  <2e-16***
ContextPlain_Voiced                      0.011141  0.006854 375.000000   1.626 0.105
ContextPlain_Voiceless                  -0.040496  0.006854 375.000000  -5.908 7.76e-09***
placeorderfront-back                    -0.705238  0.012177 375.000000 -57.917  <2e-16***
ContextPlain_Voiced:placeorderfront-back -0.367639  0.021276 375.000000 -17.280  <2e-16***
ContextPlain_Voiceless:placeorderfront-back 0.201240  0.014242 375.000000  14.130  <2e-16***
```

Table 7.9 The optimal model of sequence_duration in stop/stop sequences

```
Formula: wslog ~ rate + Context + placeorder + sequence + placeorder:rate +
    placeorder:Context + placeorder:sequence + (1 | speaker)
   Data: Bt
Fixed effects:
                                          Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)                              2.086e+00 4.182e-03 1.142e+03 498.736  <2e-16***
rateNormal                               1.737e-01 3.740e-03 1.142e+03  46.454  <2e-16***
ContextPlain_Voiced                     -1.119e-02 4.581e-03 1.142e+03  -2.442 0.014770*
ContextPlain_Voiceless                   3.767e-03 4.581e-03 1.142e+03   0.822 0.411045
placeorderfront-back                    -1.196e-02 5.914e-03 1.142e+03  -2.023 0.043276*
sequenceCC#                              6.590e-02 3.740e-03 1.142e+03  17.619  <2e-16***
rateNormal:placeorderfront-back         -1.892e-02 5.289e-03 1.142e+03  -3.577 0.000362***
ContextPlain_Voiced:placeorderfront-back -8.395e-02 6.478e-03 1.142e+03 -12.959  <2e-16***
ContextPlain_Voiceless:placeorderfront-back 3.872e-02 6.478e-03 1.142e+03   5.976 3.04e-09***
placeorderfront-back:sequenceCC#        -1.200e-01 5.289e-03 1.142e+03 -22.687  <2e-16***
```

FURTHER:

Table 7.10 The optimal model of sequence_duration in stop/stop sequences (at normal rate). n=576

```
Formula: wslog ~ Context + placeorder + sequence + placeorder:Context +
    placeorder:sequence + (1 | speaker)
   Data: Bt_Normal
Fixed effects:
                                             Estimate Std.Error         df tvalue Pr(>|t|)
(Intercept)                                  2.257591  0.003843 568.000000 587.389  <2e-16***
ContextPlain_Voiced                         -0.016450  0.004707 568.000000  -3.495 0.000512***
ContextPlain_Voiceless                       0.005733  0.004707 568.000000   1.218 0.223748
placeorderfront-back                        -0.022173  0.005435 568.000000  -4.079 5.16e-05***
sequenceCC#                                  0.071452  0.003843 568.000000  18.591  <2e-16***
ContextPlain_Voiced:placeorderfront-back    -0.073178  0.006657 568.000000 -10.993  <2e-16***
ContextPlain_Voiceless:placeorderfront-back  0.045862  0.006657 568.000000   6.889 1.49e-11***
placeorderfront-back:sequenceCC#            -0.149372  0.005435 568.000000 -27.481  <2e-16***
```

Table 7.11 The optimal model of sequence_duration in stop/stop sequences (at fast rate). n=576

```
Formula: wslog ~ placeorder + sequence + placeorder:Context + placeorder:sequence + (1 |
speaker)
   Data: Bt_Fast
Fixed effects:
                                             Estimate Std.Error         df tvalue Pr(>|t|)
(Intercept)                                  2.087201  0.006280 387.326167 332.382  <2e-16***
placeorderfront-back                        -0.020678  0.008825 552.999988  -2.343  0.0195*
sequenceCC#                                  0.060340  0.006240 552.999989   9.669  <2e-16***
placeorderback-front:ContextPlain_Voiced    -0.005919  0.007643 552.999989  -0.775  0.4390
placeorderfront-back:ContextPlain_Voiced    -0.100639  0.007643 552.999989 -13.168  <2e-16***
placeorderback-front:ContextPlain_Voiceless  0.001801  0.007643 552.999989   0.236  0.8138
placeorderfront-back:ContextPlain_Voiceless  0.033372  0.007643 552.999989   4.367 1.51e-05***
placeorderfront-back:sequenceCC#            -0.090633  0.008825 552.999989 -10.270  <2e-16***
```

Table 7.12 The optimal model of sequence_duration in stop/stop sequences (in an emphatic Context). n=384

```
Formula: wslog ~ rate + placeorder + sequence + placeorder:rate + placeorder:sequence +
(1 | speaker)
   Data: Bt_E
Fixed effects:
                                  Estimate Std.Error         df tvalue Pr(>|t|)
(Intercept)                       2.089528  0.003940 378.000000 530.302  < 2e-16***
rateNormal                        0.175946  0.004550 378.000000  38.671  < 2e-16***
placeorderfront-back             -0.012196  0.005572 378.000000  -2.189   0.0292*
sequenceCC#                       0.055685  0.004550 378.000000  12.239  < 2e-16***
rateNormal:placeorderfront-back  -0.030864  0.006434 378.000000  -4.797 2.32e-06***
placeorderfront-back:sequenceCC# -0.107597  0.006434 378.000000 -16.722  < 2e-16***
```

Table 7.13 The optimal model of sequence_duration in stop/stop sequences (in plain voiceless Context). n=384

```
Formula: wslog ~ rate + placeorder + sequence + placeorder:rate + placeorder:sequence +
(1 | speaker)
   Data: Bt_P_vl
Fixed effects:
                                  Estimate Std.Error         df tvalue Pr(>|t|)
(Intercept)                       2.089271  0.007159 378.000000 291.826  <2e-16***
rateNormal                        0.179878  0.008267 378.000000  21.759  <2e-16***
placeorderfront-back             -0.035949  0.010125 378.000000  -3.551  0.00043***
sequenceCC#                       0.059802  0.008267 378.000000   7.234 2.63e-12***
rateNormal:placeorderfront-back  -0.016574  0.006854 378.000000  -2.418  0.01608*
placeorderfront-back:sequenceCC# -0.140745  0.011691 378.000000 -12.039  <2e-16***
```

Table 7.14 The optimal model of sequence_duration in stop/stop sequences (in plain voiced Context). n=384

```
Formula: wslog ~ rate + placeorder + sequence + placeorder:rate + placeorder:sequence +
(1 | speaker)
   Data: Bt_P_vd
Fixed effects:
                                 Estimate Std.Error         df tvalue Pr(>|t|)
(Intercept)                      2.070351  0.004930 378.000000 419.979  <2e-16***
rateNormal                       0.165415  0.005692 378.000000  29.060  <2e-16***
placeorderfront-back            -0.104881  0.006972 378.000000 -15.044  <2e-16***
sequenceCC#                      0.082201  0.005692 378.000000  14.441  <2e-16***
rateNormal:placeorderfront-back -0.009323  0.004320 378.000000  -2.158  0.0316*
placeorderfront-back:sequenceCC# -0.111665  0.008050 378.000000 -13.871  <2e-16***
```

Table 7.15 The optimal model of sequence_duration in stop/stop sequences (in #CC position). n=576

```
Formula: wslog ~ rate + Context + placeorder + placeorder:rate + placeorder:Context + (1 |
speaker)
   Data: Bini_plos
Fixed effects:
                                         Estimate Std.Error         df tvalue Pr(>|t|)
(Intercept)                              2.093406  0.006379 397.597279 328.146  <2e-16***
rateNormal                               0.168190  0.006356 553.000451  26.461  <2e-16***
ContextPlain_Voiced                     -0.024443  0.007785 553.000451  -3.140 0.001781**
ContextPlain_Voiceless                   0.001709  0.007785 553.000451   0.220 0.826323
placeorderfront-back                    -0.032852  0.008989 553.000451  -3.655 0.000282***
rateNormal:placeorderfront-back          0.010449  0.004833 553.000452   2.162 0.03105*
ContextPlain_Voiced:placeorderfront-back -0.081915  0.011009 553.000450  -7.441 3.85e-13***
ContextPlain_Voiceless:placeorderfront-back  0.055290  0.011009 553.000451   5.022 6.90e-07***
```

Table 7.16 The optimal model of sequence_duration in stop/stop sequences (in CC# position). n=576

```
Formula: wslog ~ rate + placeorder + placeorder:rate + placeorder:Context + (1 | speaker)
   Data: Bfin_plos
Fixed effects:
                                         Estimate Std.Error         df tvalue Pr(>|t|)
(Intercept)                              2.143535  0.003412 568.000000 628.288  <2e-16***
rateNormal                               0.179303  0.003412 568.000000  52.555  <2e-16***
placeorderfront-back                    -0.111080  0.004825 568.000000 -23.022  <2e-16***
rateNormal:placeorderfront-back         -0.048289  0.004825 568.000000 -10.008  <2e-16***
placeorderback-front:ContextPlain_Voiced  0.002073  0.004178 568.000000   0.496    0.620
placeorderfront-back:ContextPlain_Voiced -0.083910  0.004178 568.000000 -20.081  <2e-16***
placeorderback-front:ContextPlain_Voiceless  0.005825  0.004178 568.000000   1.394    0.164
placeorderfront-back:ContextPlain_Voiceless  0.027968  0.004178 568.000000   6.693 5.25e-11***
```

Having presented the results of the common hypothesis (i) that is relevant to the place order effect, now we turn to present the results of the common hypothesis (j) which concerns the effect of speech rate.

7.2.2 The results of the speech rate effect (Hypothesis (j))

As made clear in Chapter 2, the main measure to determine whether there is an effect of speech rate on gestural overlap is the ICI count/occurrence (whether an ICI occurs in the sequence or not). Therefore, the ICI count is the only dependent variable considered here.

Table 7.17 ICI count

Speech rate	**Total *n***	**Not**		**Yes**	
		n	**Percentage**	***n***	**Percentage**
Fast	576	279	48.44	297	51.56
Normal	576	136	23.61	440	76.39
Total	1152	415	36.02	737	63.98

As in Table 7.17, the ICIs occur less often in fast speech rate than in normal rate by around 25%. When considering other independent variables (i.e. gender, Context, place order and word position), it turns out that the speech rate effect is not operative in CC# sequences in back-front place order; ICIs occur similarly in both speech rates in this word position (99% across rate). The speech rate effect is, however, observed in CC# in front-back (22% at fast, 43% at normal) and in #CC across place order (52% at fast, 70% at normal). Accordingly, it can be concluded that stop/stop sequences (#CC, CC#) at fast speech rate exhibit greater degree of gestural overlap than in normal speech rate in Najdi Arabic, excluding CC# sequences in back-front place order.

7.2.3 The results of the impact of the state of the glottis (Hypotheses (c) and (d))

As made clear in Chapters 1, 2, 5 and reiterated in Section 7.1, the sequence duration and the individual intervals within the sequence are used as measures to determine the degree of gestural overlap in this thesis in addition to the ICI count and ICI duration. Therefore, this section will be devoted to the timing relations in stop/stop sequences. For example, the timing relations in /btˤ/ were compared to those in /bt/ and in /bd/ in a word-initial position, and similar comparison was made between the same sequences in a word-final position. Also, the timing relations in /tˤb/ were compared to those in /tb/ and in /db/ in a word-initial position, and similar comparison was made between the same sequences in a word-final position.

Due to these specific comparisons, word position (whether #CC or CC#) and the order of place of articulation were not included in the models that were run in these subsections. For instance, the timing relations in /#btˤ/ were compared to those in /#bt/ and to those in /#bd/, and all three sequences are in front-back place order occurring word-initially. Therefore, the order of place of articulation and the word position as independent variables were excluded in the relevant models.

The results presented in this subsection concerns the impact of the state of the glottis, specifically Hypotheses (c) and (d). Accordingly, the results of Hypothesis (c) will be presented first, followed by the results of Hypothesis (d) for each sequence. Linear mixed-effects models were run to test Hypotheses (c) and (d) with Context (plain voiced, plain voiceless or emphatic) and its interaction with other independent variables as the crucial fixed factor(s). As pointed out in Chapter 5, the reference in Context was releveled to be the *plain voiced* in models for the results presented in Hypothesis (c). On the other hand, the reference in Context is the *emphatic* in models for the results presented in Hypothesis (d).

7.2.3.1 #bt ~ #btˤ ~ #bd (word-initial)

The timing relations in /btˤ/ in *btˤa:*gah, those in /bt/ in *bta:kil* and those in /bd/ in *bda:bah* were compared. As in Table 7.18, the ICI occurs less often in /bd/ than in both /btˤ/ than in /bt/. Regarding the difference between the emphatic context and the plain voiceless counterpart, the ICI occurs less often in /btˤ/ than in /bt/. The acoustic measurements are presented in Table 7.19. The summaries of optimal models of all dependent variables are presented in Tables 7.20 (with /d/ as reference) and in 7.21 (with /tˤ/ as reference). As made clear in Chapter 5, C2 VOT was segmented in both /#btˤ/ and /#bt/ sequences since C2 is /tˤ/ or /t/, followed by a vowel; therefore VOT of C2 is included in Table 7.21.

Table 7.18 ICI count

Consonant Sequence	**Total *n***	**Not**		**Yes**	
		n	**Percentage**	***n***	**Percentage**
#bt	96	12	12.5	84	87.5
#btˤ	96	61	63.54	35	36.46
#bd	96	76	79.17	20	20.83
Total	288	149	51.74	139	48.26

Table 7.19 Acoustic measurements for /btˤ/, /bt/ and /bd/ (mean_values)

Consonant Sequence	**C1_HP**	**ICI**	**C2_HP**	**VOT**	**Sequence**	**ICI_Voicing Proportion**
#bt	58.99	32.91	45.58	36	167.55	0.53
#btˤ	53.8	21.87	62.7	21.78	144.23	0.77
#bd	55.18	14.3	58	NA	113.67	1

Table 7.20 The summary of optimal models of all dependent variables (with /d/ as reference, compared to the other two levels: /tˤ/ and /t/). Full optimal models are presented in Appendix B (Section 11.2.2.1.1).

IVs / DVs	Rate	Gender	Context	Context * Rate	Context * Gender
C1 HP	***				
ICI	***		***		
C2 HP	***		***		
Sequence	***		***		
ICI Voicing Proportion			***		

Table 7.21 The summary of optimal models of all dependent variables (with /tˤ/ as reference, compared to /t/). Full optimal models are presented in Appendix B (Section 11.2.2.1.1). In those models, /tˤ/ was compared to the other two levels: /t/ and /d/, but since a comparison between /d/ and /tˤ/ was already presented above, this table only presents the summary of /tˤ/ vs /t/.

IVs / DVs	Rate	Gender	Context	Context * Rate	Context * Gender
C1 HP	***				
ICI	***		***		
C2 HP	***		***		
VOT	***		***		
Sequence	***		***		
ICI Voicing Proportion			***		

7.2.3.1.1 Hypothesis (c)

As explained earlier, the results presented in this subsection are based on Linear mixed-effects models with releveling the reference of Context. The reference is releveled to be the plain voiced /d/. As in Table 7.18, the ICI occurs less often in /bd/ than in both /btˤ/ than in /bt/.

As in Table 7.19, the ICI is shorter in /bd/ than in both /btˤ/ and /bt/. This difference is statistically significant (n=139,β 0.19335,SE=0.01721,t-value=11.24,p<0.001 and n=139,β=0.37806,SE=0.01532,t-value=24.68,p<0.001 respectively). C2 HP is significantly longer in duration in /bd/ than in /bt/ (n=139,β=-0.070294,SE=0.008305,t-value=-8.464,p<0.001), but not than /btˤ/; this does not influence the difference in sequence duration between /bd/ and the other two sequences. Sequence duration is significantly shorter in /bd/ than in both /btˤ/ (n=288,β=1.064e-01,SE=1.003e-02,t-value=10.60,p<0.001) and /bt/ (n=288,β=1.634e-01,SE=1.003e-02,t-value=16.28,p<0.001).

In general, the ICI occurs less often in the voiced/voiced sequence (i.e. /bd/) than in voiced/voiceless sequences (i.e. /btˤ/ and /bt/). The ICI duration is significantly shorter in /bd/

than in both /btˤ/ and /bt/, indicating that the consonantal gestures in /btˤ/ and in /bt/ are further apart than in /bd/ sequence. Sequence duration is significantly shorter in the voiced/voiced sequence than in both voiced/voiceless sequences. Accordingly, it can be concluded that /bd/ sequence exhibits greater degree of gestural overlap than both /btˤ/ and /bt/ sequences, occurring word-initially, indicating that the state of the glottis involved in the plain voiced /d/ has an impact on the degree of gestural overlap. The ICI voicing proportion is significantly higher in /bd/ than in both /btˤ/ ($n=139, \beta=0.23074, SE=0.01307$, t-value=-17.65, $p<0.001$) and /bt/ ($n=139, \beta=-0.46929, SE= 0.01160$, t-value=-40.44, $p<0.001$), supporting this conclusion.

7.2.3.1.2 Hypothesis (d)

As explained earlier, the results presented in this subsection are based on models with the default reference, which is the emphatic /tˤ/. As in Table 7.18, the ICI occurs less often in the emphatic context (i.e., /btˤ/) than in the plain voiceless counterpart (i.e., /bt/).

As in Table 7.19, the ICI is shorter in /btˤ/ than in /bt/, and this difference is statistically significant ($n=139, \beta=0.18471, SE=0.01235$, t-value=14.95, $p<0.001$). C2 HP is significantly longer in duration in /btˤ/ than in /bt/ ($n=139, \beta=-0.124983, SE=0.006697$, t-value=-18.663, $p<0.001$). VOT is significantly shorter in /btˤ/ than in /bt/ ($n=192, \beta=2.261e-01, SE=6.912e-03$, t-value=32.70, $p<0.001$). Likewise, sequence duration is significantly shorter in /btˤ/ than in /bt/ ($n=288, \beta=0.056999, SE=0.010032$, t-value=5.682, $p<0.001$).

In general, the ICI occurs less often in an emphatic context (/btˤ/) than in the plain voiceless counterpart (/bt/). The ICI duration is significantly shorter in /btˤ/ than in /bt/, indicating that the consonantal gestures in /bt/ are further apart than in /btˤ/ sequence. Sequence duration is significantly shorter in an emphatic context than in the plain voiceless counterpart. Accordingly, it can be concluded that /btˤ/ sequence exhibits greater degree of gestural overlap than /bt/ sequence, occurring word-initially. These results could be attributed to the state of the glottis, which is less open in /tˤ/ than in /t/. The ICI voicing proportion is significantly higher in /btˤ/ than in /bt/ ($n=139, \beta=-0.238549, SE=0.009383$, t-value=-25.42, $p<0.001$), supporting this conclusion. In this sense, /btˤ/ sequence behaves similarly to /bd/ sequence in the degree of gestural overlap, compared to /bt/. It is true that /bd/ exhibits greater degree of gestural overlap than /btˤ/ sequence, but both /bd/ and /btˤ/ exhibit greater degree of gestural overlap than /bt/ sequence. Accordingly, it can be concluded that /tˤ/ patterns with /d/ in the degree of gestural overlap, compared to /t/.

7.2.3.2 bt# ~ btˤ# ~ bd# (word-final)

The timing relations in /btˤ/ in *rabtˤ*, those in /bt/ in *kabt* and those in /bd/ in *kabd* were compared. The acoustic measurements are presented in Table 7.23. The summaries of optimal models of all dependent variables are presented in Tables 7.24 (with /d/ as reference) and in 7.25 (with /tˤ/ as reference).

Table 7.22 ICI count

Consonant Sequence	Total *n*	Not		Yes	
		n	Percentage	*n*	Percentage
bt#	96	26	27.08	70	72.92
btˤ#	96	78	81.25	18	18.75
bd#	96	88	91.67	8	8.33
Total	288	192	66.67	96	33.33

Table 7.23 Acoustic measurements for /btˤ/, /bt/ and /bd/ (mean_values)

Consonant Sequence	C1_HP	ICI	C2_HP	Sequence	ICI_Voicing Proportion
bt#	68.22	21.83	44.56	135.63	0.59
btˤ#	71.61	12.76	47.98	126.94	0.77
bd#	61.01	6.02	40.37	104.93	0.98

Table 7.24 The summary of optimal models of all dependent variables (with /d/ as reference, compared to the other two levels: /tˤ/ and /t/). Full optimal models are presented in Appendix B (Section 11.2.2.1.2).

IVs / DVs	Rate	Gender	Context	Context * Rate	Context * Gender
C1 HP	***				
ICI	***		***		
C2 HP	***				
Sequence	***		***		
ICI Voicing Proportion			***		

Table 7.25 The summary of optimal models of all dependent variables (with /tˤ/ as reference, compared to /t/). Full optimal models are presented in Appendix B (Section 11.2.2.1.2). In those models, /tˤ/ was compared to the other two levels: /t/ and /d/, but since a comparison between /d/ and /tˤ/ was already presented above, this table only presents the summary of /tˤ/ vs /t/.

IVs / DVs	Rate	Gender	Context	Context * Rate	Context * Gender
C1 HP	***				
ICI	***		***		***
C2 HP	***				
Sequence	***				
ICI Voicing Proportion			***		

7.2.3.2.1 Hypothesis (c)

The results presented in this subsection are based on models with releveling the reference of Context to be the plain voiced /d/.

As in Table 7.22, the ICI occurs less often in /bd/ than in both /btˤ/ and /bt/ sequences. In those instances where ICIs occur, the ICI is significantly shorter in duration in /bd/ than in both /btˤ/ (n=96,β=0.36153,SE= 0.03307,t-value=10.933,$p<0.001$) and /bt/ (n=96,β=0.60406,SE=0.02935,t-value=20.579,$p<0.001$). Likewise, sequence duration is significantly shorter in /bd/ than in both /btˤ/ (n=288,β=8.391e-02,SE= 5.116e-03,t-value=16.40,$p<0.001$) and /bt/ (n=288,β=1.119e-01,SE=5.116e-03,t-value=21.87,$p<0.001$).

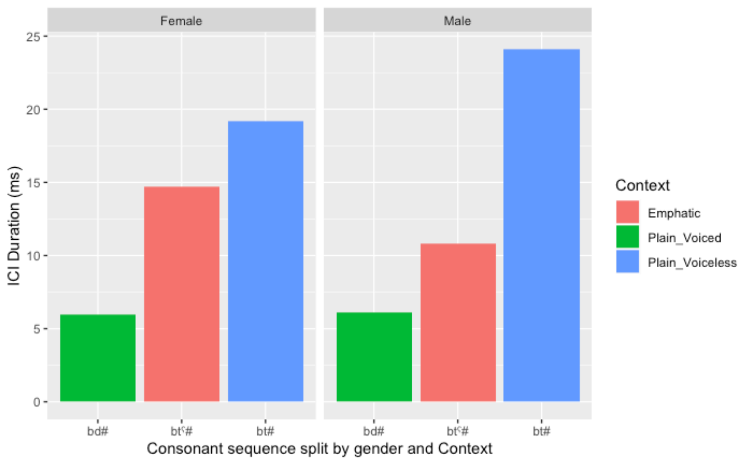
In general, the ICI occurs less often in the sequence with two voiced consonants (i.e. /bd/) than in sequences with mixed voicing (i.e. /btˤ/ and /bt/). The ICI duration is significantly shorter in /bd/ than in both /btˤ/ and /bt/, indicating that the consonantal gestures in /btˤ/ and in /bt/ are further apart than in /bd/ sequence. Sequence duration is significantly shorter in duration in the voiced/voiced sequence than in sequences with mixed voicing (voiced/voiceless sequences). Accordingly, it can be concluded that /bd/ sequence (voiced/voiced consonant sequence) exhibits greater degree of gestural overlap than both /btˤ/ and /bt/ sequences (voiced/voiceless sequences), occurring word-finally. This finding could be attributed to the role of the state of the glottis, which is the same in the voiced/voiced sequence, but different in voiced/voiceless sequences, on gestural overlap. This is consistent with the ICI voicing proportion, which is significantly higher in /bd/ than in both /btˤ/ (n=96,β=-0.21006,SE=0.02107,t-value=-9.967,$p<0.001$) and /bt/ (n=96,β=-0.38818,SE=0.01851,t-value=-20.972,$p<0.001$), supporting this conclusion.

7.2.3.2.2 Hypothesis (d)

The results presented in this subsection are based on models with the default reference, which is the emphatic /tˤ/.

As in Table 7.22, the ICI occurs less often in /btˤ/ than in /bt/ sequence. In those instances where ICIs occur, the ICI is significantly shorter in duration in /btˤ/ than in /bt/ (n=96,β=0.12321,SE=0.02173,t-value=5.671,p<0.001). The results also reveal that there is a significant interaction between Context and gender (n=96,β=0.23040,SE=0.03045,t-value=7.567,p<0.001), as visualised in Figure 7.6. The results of further models[54] reveal that the ICI is significantly shorter in /btˤ/ than in /bt/ across gender, but the effect is greater in the speech of males, compared to that of females (see Appendix B, Section 11.2.2.1.2). No significant differences were found between the two sequences in the other intervals.

Figure 7.6 ICI_duration in rabtˤ, kabt and kabd in both genders



In general, the ICI occurs less often in an emphatic context (/btˤ/) than in the plain voiceless counterpart (/bt/). The ICI duration is significantly shorter in an emphatic context than in the plain voiceless counterpart, indicating that the consonantal gestures in /bt/ are further apart than in /btˤ/ sequence. Accordingly, it can be concluded that /btˤ/ exhibits greater degree of gestural overlap than /bt/ sequence, occurring word-finally. This finding could be attributed to the state of the glottis, which is less open in /tˤ/ than in /t/. The ICI voicing proportion is significantly higher in /btˤ/ than in /bt/ (n=96,β=-0.17813,SE=0.01311,t-value=-13.590,p<0.001), supporting this conclusion. In this respect, /btˤ/ sequence behaves similarly to /bd/ sequence in the degree of gestural overlap, compared to /bt/. It is true that /bd/ exhibits greater degree of gestural overlap than /btˤ/ sequence, but both /bd/ and /btˤ/ exhibit

[54] A new subset was created that included only male speakers and another that included only female speakers, then further models were run for each.

greater degree of gestural overlap than /bt/ sequence. Accordingly, it can be concluded that /tˤ/ patterns with /d/ in the degree of gestural overlap, compared to /t/. This pattern of gestural overlap observed in /bt/ ~ /btˤ/ sequences in a word-final position is similar to the pattern observed in the same sequences in a word-initial position, as reported in Section 7.2.3.1.

7.2.3.3 #tb ~ #tˤb ~ #db (word-initial)

The timing relations in /tˤb/ in *tˤba:*gah, those in /tb/ in *tba:dil* and those in /db/ in *dba:bah* were compared. The acoustic measurements are presented in Table 7.27. The summaries of optimal models of all dependent variables are presented in Tables 7.28 (with /d/ as reference) and in 7.29 (with /tˤ/ as reference).

Table 7.26 ICI count

Consonant Sequence	Total *n*	Not		Yes	
		n	Percentage	*n*	Percentage
#tb	96	0	0	96	100
#tˤb	96	13	13.54	83	86.46
#db	96	59	61.46	37	38.54
Total	288	72	25	216	75

Table 7.27 Acoustic measurements for /tˤb/, /tb/ and /db/ (mean_values)

Consonant Sequence	C1_HP	ICI	C2_HP	Sequence	ICI_Voicing Proportion
#tb	59.28	37.12	58.3	154.7	0.5
#tˤb	65.39	26.84	63.56	153.76	0.68
#db	68.69	24.25	66.57	144.87	0.99

Table 7.28 The summary of optimal models of all dependent variables (with /d/ as reference, compared to the other two levels: /tˤ/ and /t/). Full optimal models are presented in Appendix B (Section 11.2.2.1.3).

IVs / DVs	Rate	Gender	Context	Context * Rate	Context * Gender
C1 HP	***				
ICI	***		***		
C2 HP	***				
Sequence	***		***		
ICI Voicing Proportion			***		

Table 7.29 The summary of optimal models of all dependent variables (with /tˤ/ as reference, compared to /t/). Full optimal models are presented in Appendix B (Section 11.2.2.1.3). In those models, /tˤ/ was compared to the other two levels: /t/ and /d/, but since a comparison between /d/ and /tˤ/ was already presented above, this table only presents the summary of /tˤ/ vs /t/.

IVs / DVs	Rate	Gender	Context	Context * Rate	Context * Gender
C1 HP	***				
ICI	***		***		
C2 HP	***				
Sequence	***				
ICI Voicing Proportion			***		

7.2.3.3.1 Hypothesis (c)

The results presented in this subsection are based on models with releveling the reference of Context to be the plain voiced /d/.

As in Table 7.26, the ICI occurs less often in /db/ than in both /tˤb/ and /tb/ sequences. In those instances where ICIs occur, the ICI is significantly shorter in duration in /db/ than in /tb/ (n=216,β=0.19828,SE= 0.01535,t-value=12.917,p<0.001), but no significant differences were found between /db/ and /tˤb/ in the ICI duration. Sequence duration is significantly shorter in /db/ than in both /tˤb/ (n=288,β=2.444e-02,SE=4.541e-03,t-value=5.383, p<0.001) and /tb/ (n=288,β=2.615e-02,SE=4.541e-03,t-value=5.759,p<0.001).

In general, the ICI occurs less often in the voiced/voiced consonant sequence (i.e. /db/) than in voiced/voiceless sequences (i.e. /tˤb/ and /tb/). The ICI duration is significantly shorter in /db/ than in /tb/, but not in /tˤb/ sequence, indicating that the consonantal gestures in /tb/ are further apart than in /db/ sequence. The sequence duration is significantly shorter in the voiced/voiced sequence than in sequences with mixed voicing (voiced/voiceless sequences). Accordingly, it can be concluded that /db/ sequence exhibits greater degree of gestural overlap than both /tˤb/ and /tb/ sequences, occurring word-initially based on ICI count and sequence duration, indicating that the state of the glottis involved in the plain voiced /d/ has an impact on gestural overlap; the state of the glottis is the same in the voiced/voiced sequence but different in voiced/voiceless sequences. The ICI voicing proportion is significantly higher in /db/ than in both /tˤb/ (n=216,β=-0.309990,SE=0.007440,t-value=-41.66,p<0.001) and /tb/ (n=216,β=-0.493446,SE=0.007283,t-value=-67.75,p<0.001), supporting this conclusion.

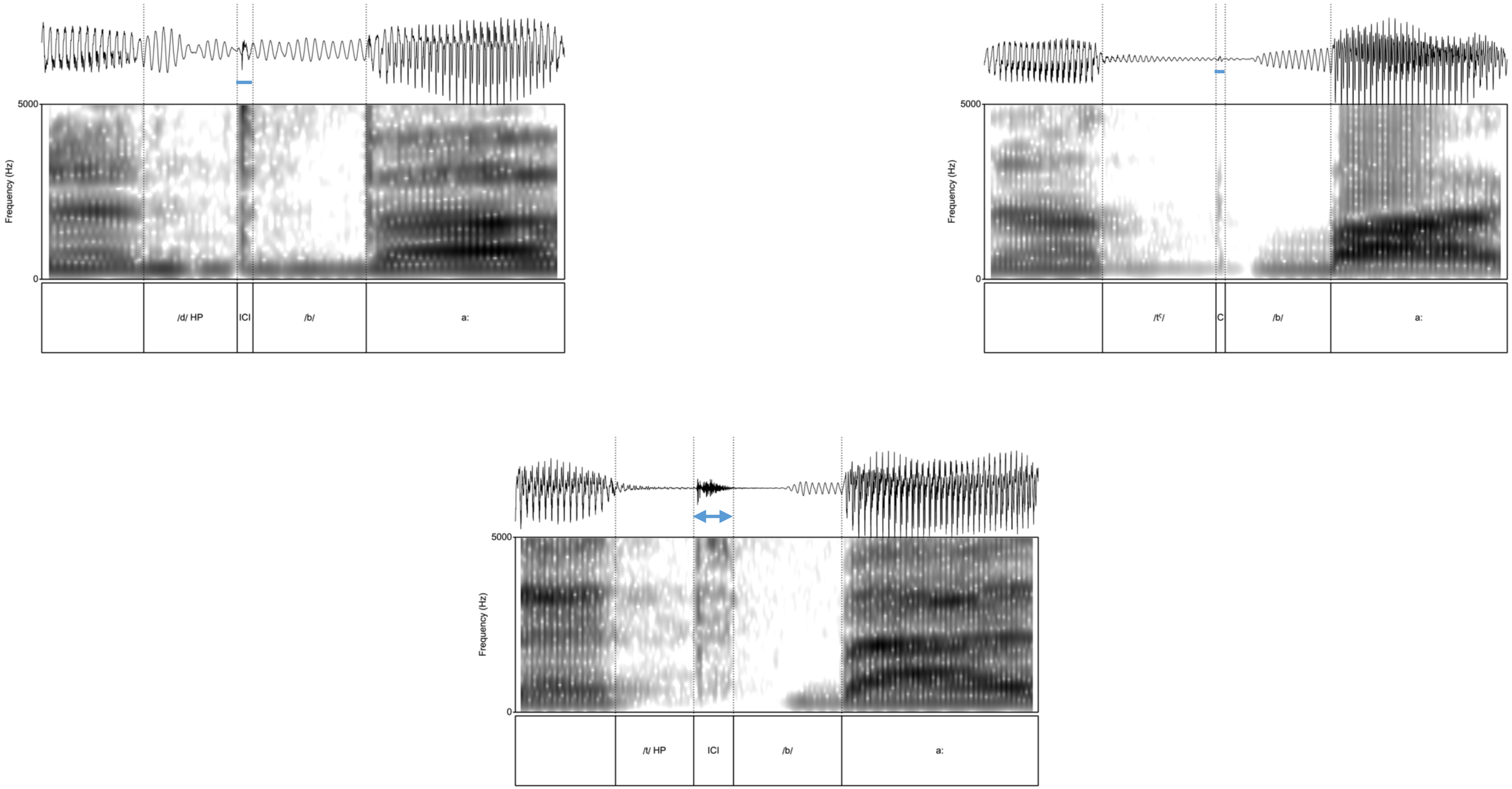
7.2.3.3.2 Hypothesis (d)

The results presented in this subsection are based on models with the default reference, which is the emphatic /tˤ/.

As in Table 7.26, the ICI occurs less often in /tˤb/ than in /tb/ sequence. The ICI is significantly shorter in duration in /tˤb/ than in /tb/ ($n=216, \beta=0.15379, SE=0.01188, t\text{-value}=12.950, p<0.001$). No significant differences were found between the two sequences in C1 HP, C2 HP and sequence durations.

In general, the ICI occurs less often in an emphatic context than in the plain voiceless counterpart. The ICI duration is significantly shorter in an emphatic context than in the plain voiceless counterpart. Accordingly, it can be concluded that /tˤb/ sequence exhibits greater degree of gestural overlap than /tb/ sequence, occurring word-initially. This finding could be attributed to the state of the glottis, which is less open in /tˤ/ than in /t/. The ICI voicing proportion is significantly higher in /tˤb/ than in /tb/ ($n=216, \beta=-0.183456, SE=0.005641, t\text{-value}=-32.52, p<0.001$), supporting this conclusion. In this sense, /tˤb/ sequence behaves similarly to /db/ sequence in the degree of gestural overlap, compared to /tb/; both /db/ and /tˤb/ exhibit greater degree of gestural overlap than /tb/ sequence. As reported earlier, no significant differences were found between /db/ and /tˤb/ sequences in ICI duration as shown in Figure 7.7. Accordingly, it can be concluded that /tˤ/ patterns with /d/ in the degree of gestural overlap, compared to /t/.

Figure 7.7 Both ICIs in dba:bah (top left) and in tˤba:gah (top right) are shorter than the ICI in tba:dil (bottom)



7.2.3.4 tb# ~ tˤb# ~ db# (word-final)

The timing relations in /tˤb/ in *ʃatˤb*, those in /tb/ in *katb* and those in /db/ in *nadb* were compared. As in Table 7.30, the ICI occurrence is similar in all three sequences. The acoustic measurements are presented in Table 7.31. The summaries of optimal models of all dependent variables are presented in Tables 7.32 (with /d/ as reference) and in 7.33 (with /tˤ/ as reference).

Table 7.30 ICI count

Consonant Sequence	Total *n*	Not		Yes	
		n	**Percentage**	***n***	**Percentage**
tb#	96	0	0	96	100
tˤb#	96	2	2.08	94	97.92
db#	96	0	0	96	100
Total	288	2	0.69	286	99.31

Table 7.31 Acoustic measurements for /tˤb/, /tb/ and /db/ (mean_values)

Consonant Sequence	C1_HP	ICI	C2_HP	Sequence	ICI_Voicing Proportion
tb#	48.26	66.56	62.26	177.09	0.92
tˤb#	50.95	60.95	64.28	175.05	0.93
db#	52.4	62.37	61.02	175.79	1

Table 7.32 The summary of optimal models of all dependent variables (with /d/ as reference, compared to the other two levels: /tˤ/ and /t/). Full optimal models are presented in Appendix B (Section 11.2.2.1.4).

IVs / DVs	Rate	Gender	Context	Context * Rate	Context * Gender
C1 HP	***				
ICI	***				
C2 HP	***				
Sequence	***				
ICI Voicing Proportion					

Table 7.33 The summary of optimal models of all dependent variables (with /tˤ/ as reference, compared to /t/). Full optimal models are presented in Appendix B (Section 11.2.2.1.4). In those models, /tˤ/ was compared to the other two levels: /t/ and /d/, but since a comparison between /d/ and /tˤ/ was already presented above, this table only presents the summary of /tˤ/ vs /t/.

IVs / DVs	Rate	Gender	Context	Context * Rate	Context * Gender
C1 HP	***				
ICI	***				
C2 HP	***				
Sequence	***				
ICI Voicing Proportion					

7.2.3.4.1 Hypothesis (c)

The results presented in this subsection are based on models with releveling the reference of Context to be the plain voiced /d/.

The intervals in Table 7.31, are similar between the three sequences. No significant differences were found between /db/ and the other two sequences (/tˤb/ and /tb/) in all durations (i.e. C1 HP, ICI, C2 HP and sequence durations). Accordingly, there is no evidence to conclude that the voiced/voiced sequence (i.e. /db/) exhibits greater degree of gestural overlap than voiced/voiceless sequences (i.e. /tˤb/ and /tb/). The role of the state of the glottis is not operative in this word position, unlike the case in a word-initial position, as reported in Section 7.2.3.3. The ICI voicing proportion is also similar in all three sequences, and no significant differences were found between them in the ICI voicing proportion. It can be noted that the ICI durations here (in a word-final position) are longer than ICI durations occurring word-initially in all three contexts. The ICI in a word-final position could have the characteristics of epenthetic vowels in the sense that they are longer and all are voiced regardless of Context (plain voiced, plain voiceless or emphatic), compared to the ICI in a word-initial position. The differences between ICIs in various word positions will be discussed in detail in Chapter 8.

7.2.3.4.2 Hypothesis (d)

The results presented in this subsection are based on models with the default reference, which is the emphatic /tˤ/.

The durations of the parameters in Table 7.31, are similar between the two sequences; no significant differences were found between /tˤb/ and /tb/ in all durations (i.e. C1 HP, ICI, C2 HP and sequence durations). Accordingly, there is no evidence to conclude that /tˤb/ sequence exhibits greater degree of gestural overlap than /tb/ sequence. The role of the state of the glottis, that was operative in a word-initial position as reported in Section 7.2.3.3, is not operative in this word-final position. The ICI voicing proportion is also similar in the two sequences, and no significant differences were found between them in the ICI voicing proportion. In this respect, all the three sequences (/db/, /tˤb/ and /tb/) behave similarly in the degree of gestural overlap when occurring word-finally. Accordingly, there is no evidence to conclude that /tˤ/ patterns with /d/ in the degree of gestural overlap, compared to /t/.

As indicated above, it can be noted that the ICIs here (in a word-final position) are longer in duration than ICIs occurring word-initially. The ICI in a word-final position could have the characteristics of epenthetic vowels in the sense that they are longer and all are voiced regardless of Context (plain voiceless or emphatic), compared to the ICI in a word-initial position. The differences between ICIs in various word positions will be discussed in detail in Chapter 8.

7.3 Stop/alveolar fricative sequences

7.3.1 The results of the place order effect (Hypothesis (i))

Linear mixed-effects models were run to test Hypothesis (i) with the place order and its interaction with other independent variables as the crucial fixed factor(s). The independent variables that were included in these models are Context (plain voiced, plain voiceless, emphatic), order of place of articulation, word position, speech rate and gender.

The ICI count, ICI duration and sequence duration in back-front were compared to those in front-back stop/alveolar fricative sequences, occurring word-initially or finally (#CC and CC#). Sequences in a back-front place order include /sb/, /sˤb/ and /zb/, and sequences in a front-back order include /bs/, /bsˤ/ and /bz/ sequences.

Table 7.34 ICI count

Place Order	**Total *n***	**Not**		**Yes**	
		n	**Percentage**	***n***	**Percentage**
back-front	576	296	51.39	280	48.61
front-back	576	339	58.85	237	41.15
Total	1152	635	55.12	517	44.88

Table 7.35 Acoustic measurements for stop/alveolar fricative sequences (mean_values)

Place order	**ICI_duration**	**Sequence_duration**
back-front	59.09	197.61
front-back	20.82	159.50

As in Table 7.34, the ICI count percentage is 48% in a back-front place order and 41% in a front-back order; this difference is only around 7%. When considering other independent variables, however, it turns out that the ICI occurs more often in back-front than in front-back place order in restricted environments. The ICI count in relation to the place order effect is only exhibited in a word-final position (92% in back-front vs 21% in front-back), compared to a word-initial position (0% in back-front vs 60% in front-back). The fact that the ICI count in front-back place order (i.e. /bs/, /bsˤ/ and /bz/) scores 60% higher than in back-front order (i.e. /sb/, /sˤb/ and /zb/) in word-initial sequences could be due to C1 identity. C1 in /bs/, /bsˤ/ and /bz/ is the bilabial stop /b/, and ICIs are prone to occur if C1 is a stop in the sequence because there is a release in stops, unlike C1 in /sb/, /sˤb/ and /zb/ in two consonant sequences which is a fricative, and ICIs occur less often because there is no a release after a fricative. This is, however, not operative in marked sequences where epenthetic vowels are likely to occur such as /sb#/ (since it violates the sonority sequencing in Najdi Arabic) as will be discussed in Section 7.3.3.4.

Besides, the place order effect on ICI count is only exhibited in the plain voiced context; i.e. only in sequences including the plain voiced /z/ (44% in back-front vs 15% in front-back), compared to the emphatic context (45% in back-front vs 52% in front-back) and the plain voiceless context (47% in back-front vs 56% in front-back). In addition, the place order effect on ICI count is only exhibited in a fast speech rate (45% in back-front vs 29% in front-back), compared to the normal speech rate (46% in back-front vs 52% in front-back). Accordingly, the place order effect is exhibited on ICI count in very restricted environments. Now we turn to the ther measures: ICI and sequence durations.

As in Table 7.35, the ICI is longer in a back-front place order than in a front-back order. This difference is statistically significant (n=517,β=-0.551971,SE=0.013284,t-value=-41.551,p<0.001) as in Table 7.36[55]. The results also reveal that the place order significantly interacts with Context (n=517,β=-0.528079,SE=0.015998,t-value=-33.010,p<0.001), as visualised in Figure 7.8. The results of further models[56] show that the place order effect on ICI duration is greater in sequences including the plain voiced /z/, compared to sequences including the emphatic /sˤ/ and to sequences including the plain voiceless /s/, as in Tables 7.39, 7.40 and 7.41. The

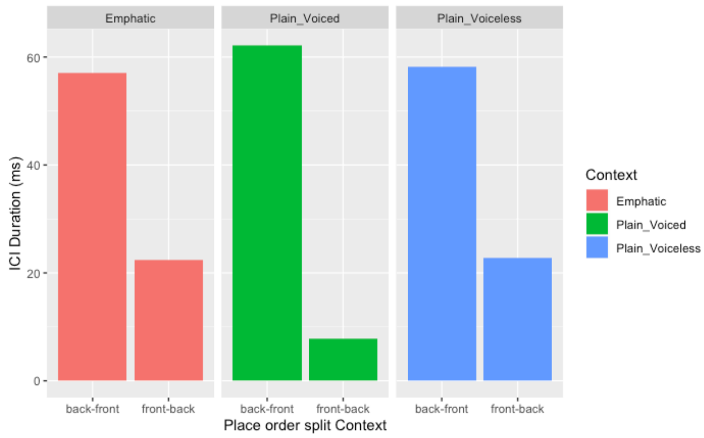
[55] When adding the interaction between place order and word position to the model, it gives a warning note: (fixed-effect model matrix is rank deficient so dropping 1 column / coefficient). This could be due to ICIs that do not occur in back-front order in a word-initial position.

[56] A new subset was created that included only plain voiced context, another that included only emphatic context, and a third that included only plain voiceless context. Then further models were run to find out which context shows a significance of place order effect, or to find out which context exhibits greater effect.

results also reveal that the place order significantly interacts with speech rate (n=517,β=0.056616,SE=0.011246,t-value=5.034,p<0.001), as visualised in Figure 7.9. The results of further models[57] show that the place order effect on ICI duration is greater in a normal speech rate, compared to the fast speech rate as in Tables 7.37 and 7.38.

Likewise, sequence duration is significantly longer in a back-front place order than in a front-back order (n=1152,β=-2.018e-02,SE=2.852e-03,t-value=-7.076,p<0.001) as in Table 7.42. There is, however, a significant interaction between the place order and word position (n=1152,β=-2.165e-01,SE=4.033e-03,t-value=-53.689,p<0.001) in sequence duration, as visualised in Figure 7.10. The results of further models[58] reveal that the place order effect is only significant in a word-final position (n=576,β=-0.196353,SE=0.002875,t-value=-68.295,p<0.001),but not in a word-initial position, as in Tables 7.43 and 7.44. Accordingly, the place order as a main effect is a simple effect.

Figure 7.8 ICI_duration in stop/alveolar fricative sequences in both place orders, split by Context



[57] A new subset was created that included only normal speech rate and another that included only fast speech rate, then further models were run for each.

[58] A new subset was created that included only word-initial consonant sequences and another that included only word-final consonant sequences, then further models were run for each.

Figure 7.9 ICI_duration in stop/alveolar fricative sequences in both place orders, split by speech rate

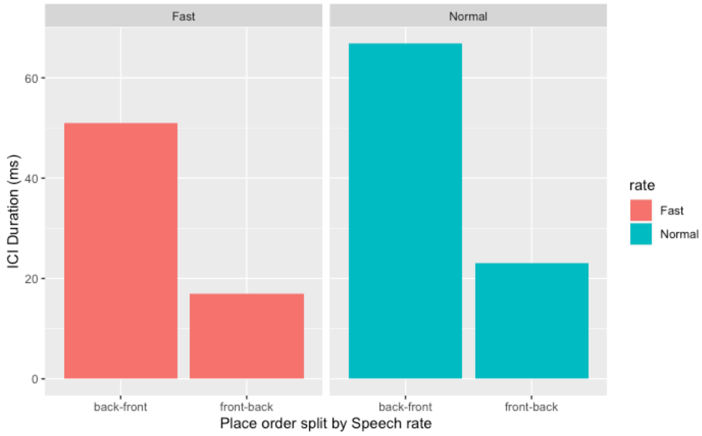
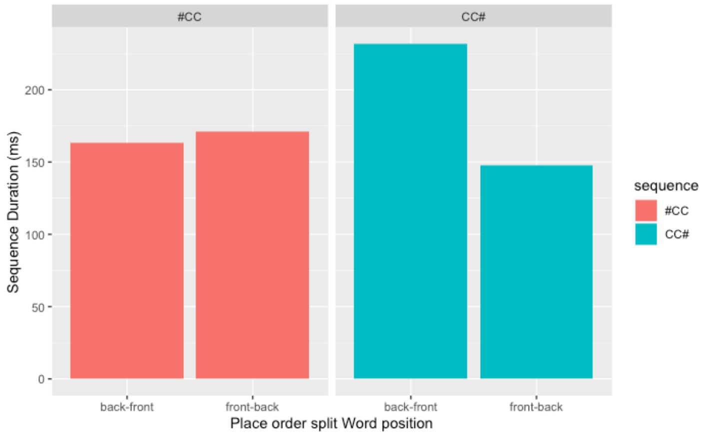


Figure 7.10 Sequence_duration in stop/alveolar fricative sequences in both place orders, split by word position



In general, the ICI count is similar in both place orders across all independent variables, and the place order effect on ICI count is exhibited in very restricted environments as indicated above. The ICI duration is significantly longer in a back-front than in front-back place order,but it should be noted that no ICIs occurred in back-front sequences in a word-initial position although ICI duration is still significantly longer in back-front than in front-back place sequences as reported above. The sequence duration is significantly longer in a back-front than in front-back place order only in a word-final position. Based on the above findings, evidence to conclude that the place order effect is exhibited in stop/alveolar fricative sequences, occurring word-initially or finally (#CC and CC#), is *not* as strong as that for stop/stop sequences as reported in Section 7.2.1. The place order effect is ***only exhibited*** in stop/alveolar fricative sequences, occurring ***word-finally (CC#),*** *based on sequence duration*.

Table 7.36 The optimal model of ICI_duration in stop/alveolar fricative sequences

```
Formula: icilog ~ rate + Context + placeorder + sequence + placeorder:rate + placeorder:Context
+ (1 | speaker)
   Data: Bs
Fixed effects:
                                         Estimate Std.Error         df tvalue Pr(>|t|)
(Intercept)                              1.805349   0.011822 508.000000 152.707  <2e-16***
rateNormal                               0.118521   0.007438 508.000000  15.936  <2e-16***
ContextPlain_Voiced                      0.036014   0.009147 508.000000   3.937 9.39e-05***
ContextPlain_Voiceless                   0.008591   0.009048 508.000000   0.950  0.343
placeorderfront-back                    -0.551971   0.013284 508.000000 -41.551  <2e-16***
sequenceCC#                             -0.114961   0.009176 508.000000 -12.529  <2e-16***
rateNormal:placeorderfront-back          0.056616   0.011246 508.000000   5.034 6.67e-07***
ContextPlain_Voiced:placeorderfront-back -0.528079   0.015998 508.000000 -33.010  <2e-16***
ContextPlain_Voiceless:placeorderfront-back  0.007880   0.012508 508.000000   0.630  0.529
```

FURTHER:

Table 7.37 The optimal model of ICI_duration in stop/alveolar fricative sequences (at normal rate). n=317

```
Formula: icilog ~ Context + placeorder + sequence + placeorder:Context + (1 | speaker)
   Data: Bs_Normal
Fixed effects:
                                            Estimate StdError         df tvalue
Pr(>|t|)
(Intercept)                                 1.894059   0.011864 288.000000 159.644
<2e-16***
ContextPlain_Voiced                         0.031586   0.010528 288.000000   3.000
0.00293**
ContextPlain_Voiceless                      0.012470   0.010528 288.000000   1.185
0.23718
placeorderfront-back                       -0.478973   0.011877 288.000000 -40.327
<2e-16***
sequenceCC#                                -0.084967   0.009238 288.000000  -9.197
<2e-16***
ContextPlain_Voiced:placeorderfront-back   -0.465426   0.016894 288.000000 -27.549
<2e-16***
ContextPlain_Voiceless:placeorderfront-back  -0.002811   0.013861 288.000000  -0.203
0.83943
```

Table 7.38 The optimal model of ICI_duration in stop/alveolar fricative sequences (at fast rate). n=200

```
Formula: icilog ~ Context + placeorder + sequence + placeorder:Context +      (1 |
speaker)
   Data: Bs_Fast
Fixed effects:
                                              Estimate Std.Error        df tvalue
Pr(>|t|)
(Intercept)                                   1.869507   0.019279 215.000000  96.973
<2e-16***
ContextPlain_Voiced                           0.040944   0.013668 215.000000   2.995
0.00306**
ContextPlain_Voiceless                        0.004634   0.013364 215.000000   0.347
0.72915
placeorderfront-back                         -0.594738   0.019703 215.000000 -30.185
<2e-16***
sequenceCC#                                  -0.179310   0.016775 215.000000 -10.689
<2e-16***
ContextPlain_Voiced:placeorderfront-back     -0.659642   0.027636 215.000000 -23.869
<2e-16***
ContextPlain_Voiceless:placeorderfront-back   0.024588   0.019897 215.000000   1.236
0.21790
```

Table 7.39 The optimal model of ICI_duration in stop/alveolar fricative sequences (in an emphatic Context). n=194

```
Formula: icilog ~ rate + placeorder + sequence + placeorder:rate + (1 | speaker)
   Data: Bs_E
Fixed effects:
                              Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)                    1.85479   0.01360 189.00000 136.340  <2e-16***
rateNormal                     0.11889   0.01021 189.00000  11.644  <2e-16***
placeorderfront-back          -0.58288   0.01438 189.00000 -40.531  <2e-16***
sequenceCC#                   -0.16459   0.01148 189.00000 -14.335  <2e-16***
rateNormal:placeorderfront-back 0.04668 0.01454 189.00000   3.209 0.00156**
```

Table 7.40 The optimal model of ICI_duration in stop/alveolar fricative sequences (in plain voiceless Context). n=203

```
Formula: icilog ~ rate + placeorder + sequence + (1 | speaker)
   Data: Bs_P_vl
Fixed effects:
                      Estimate Std. Error         df t value Pr(>|t|)
(Intercept)           1.832627   0.011065 199.000000  165.62   <2e-16***
rateNormal            0.137182   0.006413 199.000000   21.39   <2e-16***
placeorderfront-back -0.531421   0.009467 199.000000  -56.14   <2e-16***
sequenceCC#          -0.143076   0.009662 199.000000  -14.81   <2e-16***
```

Table 7.41 The optimal model of ICI_duration in stop/alveolar fricative sequences (in plain voiced Context). n=120

```
Formula: icilog ~ rate + placeorder + sequence + placeorder:rate + (1 | speaker)
   Data: Bs_P_vd
Fixed effects:
                              Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)                    1.58064   0.02680 115.00000  58.989  <2e-16***
rateNormal                     0.10954   0.01268 115.00000   8.641 3.74e-14***
placeorderfront-back          -0.99786   0.02954 115.00000 -33.777  <2e-16***
sequenceCC#                    0.15050   0.02516 115.00000   5.981 2.56e-08***
rateNormal:placeorderfront-back 0.21829 0.02742 115.00000   7.962 1.33e-12***
```

Table 7.42 The optimal model of sequence_duration in stop/alveolar fricative sequences

```
Formula: wslog ~ rate + Context + placeorder + sequence + placeorder:sequence + (1 |
speaker)
   Data: Bs
Fixed effects:
                                   Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)                       2.160e+00  2.668e-03  1.145e+03 809.710  <2e-16***
rateNormal                        1.450e-01  2.017e-03  1.145e+03  71.918  <2e-16***
ContextPlain_Voiced              -8.648e-02  2.470e-03  1.145e+03 -35.017  <2e-16***
ContextPlain_Voiceless           -3.184e-03  2.470e-03  1.145e+03  -1.289    0.198
placeorderfront-back             -2.018e-02  2.852e-03  1.145e+03  -7.076 2.58e-12***
sequenceCC#                       1.555e-01  2.852e-03  1.145e+03  54.542  <2e-16***
placeorderfront-back:sequenceCC# -2.165e-01  4.033e-03  1.145e+03 -53.689  <2e-16***
```

Further:

Table 7.43 The optimal model of sequence_duration in stop/alveolar fricative sequences (in #CC position). n =576

```
Formula: wslog ~ rate + Context + (1 | speaker)
   Data: Bini_fric_alv
Fixed effects:
                         Estimate Std.Error          df tvalue Pr(>|t|)
(Intercept)              2.165585  0.002427 193.594263 892.233   <2e-16***
rateNormal               0.155116  0.002103 556.000000  73.774   <2e-16***
ContextPlain_Voiced     -0.118547  0.002575 556.000000 -46.036   <2e-16***
ContextPlain_Voiceless  -0.002921  0.002575 556.000000  -1.134    0.257
```

Table 7.44 The optimal model of sequence_duration in stop/alveolar fricative sequences (in CC# position). n=576

```
Formula: wslog ~ rate + Context + placeorder + (1 | speaker)
   Data: Bfin_fric_alv
Fixed effects:
                         Estimate Std.Error          df tvalue Pr(>|t|)
(Intercept)              2.310020  0.003214 571.000000 718.642   <2e-16***
rateNormal               0.134937  0.002875 571.000000  46.934   <2e-16***
ContextPlain_Voiced     -0.054422  0.003521 571.000000 -15.455   <2e-16***
ContextPlain_Voiceless  -0.003448  0.003521 571.000000  -0.979    0.328
placeorderfront-back    -0.196353  0.002875 571.000000 -68.295   <2e-16***
```

7.3.2 The results of the speech rate effect (Hypothesis (j))

As made clear in Chapter 2, the main measure to determine whether there is an effect of speech rate on gestural overlap is the ICI count/occurrence (whether an ICI occurs in the sequence or not). Therefore, the ICI count is the only dependent variable considered here.

Table 7.45 ICI count. Yes (count and percentage of occurring ICIs), Not (count and percentage of non-occurring ICIs)

Speech rate	**Total *n***	**Not**		**Yes**	
		n	**Percentage**	***n***	**Percentage**
Fast	576	376	65.28	200	34.72
Normal	576	259	44.97	317	55.03
Total	1152	635	55.12	517	44.88

As in Table 7.45, the ICIs occur less often in fast speech rate than in normal rate by around 21%. When considering other independent variables (i.e. gender, Context, place order and word position), however, it turns out that the speech rate effect is not operative in back-front sequences whether occurring word-initially or finally. No ICIs occurred in #CC sequences in back-front place order, while ICIs occurred similarly in both speech rates in CC# sequences in back-front order (97% across rate). The speech rate effect is, however, observed in #CC in front-back (46% at fast, 74% at normal) and in CC# in front-back (13% at fast, 30% at normal). Accordingly, it can be concluded that stop/alveolar fricative sequences (#CC, CC#) at fast speech rate exhibit greater degree of gestural overlap than in normal speech rate only in front-back place order in Najdi Arabic.

7.3.3 The results of the impact of the state of the glottis (Hypotheses (c) and (e))

The sequence duration and the individual intervals within the sequence are used as measures to determine the degree of gestural overlap in this thesis in addition to the ICI count and ICI duration. Therefore, this section will be devoted to the timing relations of stop/alveolar fricative sequences. For example, the timing relations in /bsˤ/ were compared to those in /bs/ and in /bz/ in a word-initial position and similar comparison was made between the same sequences in a word-final position. Also, the timing relations in /sˤb/ were compared to those in /sb/ and in /zb/ in a word-initial position and similar comparison was made between the same sequences in a word-final position.

Due to these specific comparisons, word position (whether #CC or CC#) and the order of place of articulation were not included in the models that were run in these subsections. For instance, the timing relations in /#bsˤ/ were compared to those in /#bs/ and to those in /#bz/, and all three sequences are in front-back place order occurring word-initially. Therefore, the order of place of articulation and the word position as independent variables were excluded in the relevant models.

The results presented in this subsection concerns the impact of the state of the glottis, specifically Hypotheses (c) and (e). Accordingly, the results of Hypothesis (c) will be presented first, followed by the results of Hypothesis (e) for each sequence. Linear mixed-effects models were run to test Hypotheses (c) and (e) with Context (plain voiced, plain voiceless or emphatic) and its interaction with other independent variables as the crucial fixed factor(s). As pointed out in Chapter 5 and in Section 7.2.3 above, the reference in Context was releveled to be the *plain voiced* in models for the results presented in Hypothesis (c). On the other hand, the reference in Context is the *emphatic* in models for the results presented in Hypothesis (e).

7.3.3.1 #bs ~ #bsˁ ~ #bz (word-initial)

The timing relations in /bsˁ/ in *bsˁa:dʒah*, those in /bs/ in *bsa:gah* and those in /bz/ in *bza:dah* were compared. The acoustic measurements are presented in Table 7.47. The summaries of optimal models of all dependent variables are presented in Tables 7.48 (with /z/ as reference) and in 7.49 (with /sˁ/ as reference).

Table 7.46 ICI count

Consonant Sequence	Total *n*	Not		Yes	
		n	Percentage	*n*	Percentage
#bs	96	18	18.75	78	81.25
#bsˁ	96	21	21.88	75	78.13
#bz	96	75	78.13	21	21.88
Total	288	114	39.58	174	60.42

Table 7.47 Acoustic measurements for /bsˁ/, /bs/ and /bz/ (mean_values)

Consonant Sequence	C1_HP	ICI	C2_Frication	Sequence	ICI_Voicing Proportion
#bs	53.83	24.54	109.7	183.49	0.66
#bsˁ	55.62	24.04	113.64	187.36	0.67
#bz	60.84	6.86	91.8	142.71	1

Table 7.48 The summary of optimal models of all dependent variables (with /z/ as reference, compared to the other two levels: /sˁ/ and /s/). Full optimal models are presented in Appendix B (Section 11.2.2.2.1).

IVs / DVs	Rate	Gender	Context	Context * Rate	Context * Gender
C1 HP	***				
ICI	***		***		
C2 Frication	***		***		
Sequence	***		***		
ICI Voicing Proportion			***		

Table 7.49 The summary of optimal models of all dependent variables (with /sˤ/ as reference, compared to /s/). Full optimal models are presented in Appendix B (Section 11.2.2.2.1). In those models, /sˤ/ was compared to the other two levels: /s/ and /z/, but since a comparison between /z/ and /sˤ/ was already presented above, this table only presents the summary of /sˤ/ vs /s/.

IVs / DVs	Rate	Gender	Context	Context * Rate	Context * Gender
C1 HP	***				
ICI	***				
C2 Frication	***				
Sequence	***				
ICI Voicing Proportion					

7.3.3.1.1 Hypothesis (c)

As explained earlier, the results presented in this subsection are based on models with releveling the reference of Context. The reference is releveled to be the plain voiced /z/.

As in Table 7.46, the ICI occurs less often in /bz/ than in both /bsˤ/ and /bs/. In those instances where ICIs occur, the ICI is significantly shorter in duration in /bz/ than in both /bsˤ/ (n=174,β=5.801e-01,SE=1.541e-02,t-value=37.65,p<0.001) and /bs/ (n=174,β=5.921e-01,SE=1.536e-02,t-value=38.56,p<0.001); this indicates that the consonantal gestures are further apart in /bsˤ/ and /bs/ than in /bz/. /z/ frication is significantly shorter in duration than both /sˤ/ (n=288,β=1.019e-01,SE= 4.218e-03,t-value=24.17,p<0.001) and /s/ (n=288,β=8.542e-02,SE=4.218e-03,t-value=20.25,p<0.001). Likewise, sequence duration is significantly shorter in /bz/ than in both /bsˤ/ (n=288,β=1.178e-01,SE=3.949e-03,t-value=29.84,p<0.001) and /bs/ (n=288,β=1.085e-01,SE=3.949e-03,t-value=27.47,p<0.001). Accordingly, it can be concluded that the voiced/voiced sequence (/bz/) exhibits greater degree of gestural overlap than voiced/voiceless sequences (/bsˤ/ and /bs/), occurring word-initially. This finding could be attributed to the state of the glottis, which is the same in the voiced/voiced sequence but different in voiced/voiceless sequences. The ICI voicing proportion is significantly higher in /bz/ than in both /bsˤ/ (n=174,β=-0.32855,SE=0.01245,t-value=-26.40,p<0.001) and /bs/ (n=174,β=-0.34206,SE=0.01242,t-value=-27.54,p<0.001), supporting this conclusion.

7.3.3.1.2 Hypothesis (e)

As explained earlier, the results presented in this subsection are based on models with the default reference, which is the emphatic /sˤ/.

As in Table 7.46, the ICI occurrence is similar in both /bsˤ/ than in /bs/. The intervals in Table 7.47 are also similar in both /bsˤ/ than in /bs/. No significant differences were found between the two sequences in all intervals. Accordingly, there is no evidence to conclude that /bsˤ/ exhibits greater degree of gestural overlap than /bs/ sequence when occurring word-initially, indicating that the state of the glottis does not have any role in gestural overlap in these two sequences. Therefore, the state of the glottis could be the same in both /sˤ/ and /s/. No significant differences were found between the two sequences in the ICI voicing proportion, supporting this conclusion. In this sense, /bsˤ/ sequence does not behave similarly to /bz/ sequence in the degree of gestural overlap, compared to /bs/. /bsˤ/, however, behaves like /bs/ in the degree of gestural overlap, compared to /bz/. Accordingly, there is no evidence to conclude that /sˤ/ patterns with /z/ in the degree of gestural overlap, compared to /s/.

7.3.3.2 bs# ~ bsˤ# ~ bz# (word-final)

The timing relations in /bsˤ/ in *gabsˤ*, those in /bs/ in *kabs* and those in /bz/ in *xabz* were compared. The acoustic measurements are presented in Table 7.51. The summaries of optimal models of all dependent variables are presented in Tables 7.52 (with /z/ as reference) and in 7.53 (with /sˤ/ as reference).

Table 7.50 ICI count

Consonant Sequence	Total *n*	Not		Yes	
		n	**Percentage**	***n***	**Percentage**
bs#	96	66	68.75	30	31.25
bsˤ#	96	71	73.96	25	26.04
bz#	96	88	91.67	8	8.33
Total	288	225	78.13	63	21.88

Table 7.51 Acoustic measurements for /bsˤ/, /bs/ and /bz/ (mean_values)

Consonant Sequence	C1_HP	ICI	C2_Frication	Sequence	ICI_Voicing Proportion
bs#	50.97	18.37	96.87	157.55	0.59
bsˤ#	53.3	17.58	100.58	158.93	0.54
bz#	56.76	10.3	75.76	126.99	0.97

Table 7.52 The summary of optimal models of all dependent variables (with /z/ as reference,compared to the other two levels: /sˤ/ and /s/). Full optimal models are presented in Appendix B (Section 11.2.2.2.2).

IVs / DVs	Rate	Gender	Context	Context * Rate	Context * Gender
C1 HP	***				
ICI	***		***		
C2 Frication	***		***		
Sequence	***		***		
ICI Voicing Proportion			***		

*Table 7.53 The summary of optimal models of all dependent variables (with /sˤ/ as reference, compared to /s/). Full optimal models are presented in Appendix B (Section 11.2.2.2.2). In those models, /sˤ/ was compared to the other two levels: /s/ and /z/, but since a comparison between /z/ and /sˤ/ was already presented above, this table only presents the summary of /sˤ/ vs /s/. Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05*

IVs / DVs	Rate	Gender	Context	Context * Rate	Context * Gender
C1 HP	***				
ICI	***				
C2 Frication	***				
Sequence	***				
ICI Voicing Proportion					

7.3.3.2.1 Hypothesis (c)

The results presented in this subsection are based on models with releveling the reference of Context to be the plain voiced /z/.

As in Table 7.50, the ICI occurs less often in /bz/ than in both /bsˤ/ than in /bs/. In those instances where ICIs occur, the ICI is significantly shorter in duration in /bz/ than in both /bsˤ/ (n=63,β 0.25458,SE=0.03300,t-value=7.714,p<0.001) and /bs/ (n=63,β=0.29044,SE=0.03237,t-value=8.972,p<0.001); this indicates that the consonantal gestures are further apart in /bsˤ/ and /bs/ than in /bz/. /z/ frication is significantly shorter in duration than both /sˤ/ (n=284,β=1.537e-01,SE=5.225e-03,t-value=29.42,p<0.001) and /s/ (n=284,β=1.409e-01,SE=5.225e-03,t-value=26.97,p<0.001). Likewise, sequence duration is significantly shorter in /bz/ than in both /bsˤ/ (n=288,β=9.920e-02,SE=4.611e-03,t-value=21.51,p<0.001) and /bs/ (n=288, β=9.524e-02,SE=4.611e-03,t-value=20.65,p<0.001). Accordingly, it can be concluded that the voiced/voiced sequence (/bz/) exhibits greater degree of gestural overlap than voiced/voiceless sequences (/bsˤ/ and /bs/), occurring word-initially. This finding could be attributed to the state of the glottis, which is the same in the voiced/voiced sequence but different in voiced/voiceless sequences. The ICI voicing proportion is significantly higher in /bz/

than in both /bsˤ/ (n=63,β=-0.43742,SE=0.01669,t-value=-26.21,p<0.001) and /bs/ (n=63 β=-0.38227,SE=0.01635,t-value=-23.38,p<0.001), supporting this conclusion. This pattern of gestural overlap, observed in /bz/ vs /bsˤ/ and /bs/ sequences in a word-final position, is similar to the pattern observed in the same sequences in a word-initial position, as reported in Section 7.3.3.1.

7.3.3.2.2 Hypothesis (e)

The results presented in this subsection are based on models with the default reference, which is the emphatic /sˤ/.

As in Table 7.50, the ICI occurrence is similar in both /bsˤ/ than in /bs/. The intervals in Table 7.51 are also similar in both /bsˤ/ than in /bs/. No significant differences were found between the two sequences in all intervals. Accordingly, there is no evidence to conclude that /bsˤ/ exhibits greater degree of gestural overlap than /bs/ sequence when occurring word-finally, indicating that the state of the glottis does not have any role in gestural overlap in these two sequences. Therefore, the state of the glottis could be the same in both /sˤ/ and /s/. No significant differences were found between the two sequences in the ICI voicing proportion, supporting this conclusion. In this sense, /bsˤ/ sequence does not behave similarly to /bz/ sequence in the degree of gestural overlap, compared to /bs/. Rather, /bsˤ/ behaves similarly to /bs/ in the degree of gestural overlap, compared to /bz/. Accordingly, there is no evidence to conclude that /sˤ/ patterns with /z/ in the degree of gestural overlap, compared to /s/. These findings are in line with the findings of the same sequences in a word-initial position, as reported in Section 7.3.3.1.

7.3.3.3 #sb ~ #sˤb ~ #zb (word-initial)

The timing relations in /sˤb/ in *sˤba:*dʒah, those in /sb/ in *sba:gah* and those in /zb/ in *zba:lah* were compared. No ICIs occurred in these three sequences as in Table 7.54. The acoustic measurements are presented in Table 7.55. The summaries of optimal models of all dependent variables are presented in Tables 7.56 (with /z/ as reference) and in 7.57 (with /sˤ/ as reference).

Table 7.54 ICI count

Consonant Sequence	Total *n*	Not		Yes	
		n	Percentage	*n*	Percentage
#sb	96	96	100	0	0
#sˤb	96	96	100	0	0
#zb	96	96	100	0	0
Total	288	288	100	0	0

Table 7.55 Acoustic measurements for /sˤb/, /sb/ and /zb/ (mean_values)

Consonant Sequence	C1_Frication	ICI	C2_HP	Sequence	ICI_Voicing Proportion
#sb	99.54	NA	78.9	178.44	NA
#sˤb	98.68	NA	78.06	176.74	NA
#zb	76.84	NA	58.79	135.63	NA

NA = ICI does not occur

Table 7.56 The summary of optimal models of all dependent variables (with /z/ as reference, compared to the other two levels: /sˤ/ and /s/). Full optimal models are presented in Appendix B (Section 11.2.2.2.3).

IVs / DVs	Rate	Gender	Context	Context * Rate	Context * Gender
C1 Frication	***		***		
ICI	NA	NA	NA	NA	NA
C2 HP	***		***		
Sequence	***		***		
ICI Voicing Proportion	NA	NA	NA	NA	NA

Table 7.57 The summary of optimal models of all dependent variables (with /sˤ/ as reference, compared to /s/). Full optimal models are presented in Appendix B (Section 11.2.2.2.3). In those models, /sˤ/ was compared to the other two levels: /s/ and /z/, but since a comparison between /z/ and /sˤ/ was already presented above, this table only presents the summary of /sˤ/ vs /s/.

IVs / DVs	Rate	Gender	Context	Context * Rate	Context * Gender
C1 Frication	***				
ICI	NA	NA	NA	NA	NA
C2 HP	***				
Sequence	***				
ICI Voicing Proportion	NA	NA	NA	NA	NA

7.3.3.3.1 Hypothesis (c)

The results presented in this subsection are based on models with releveling the reference of Context to be the plain voiced /z/.

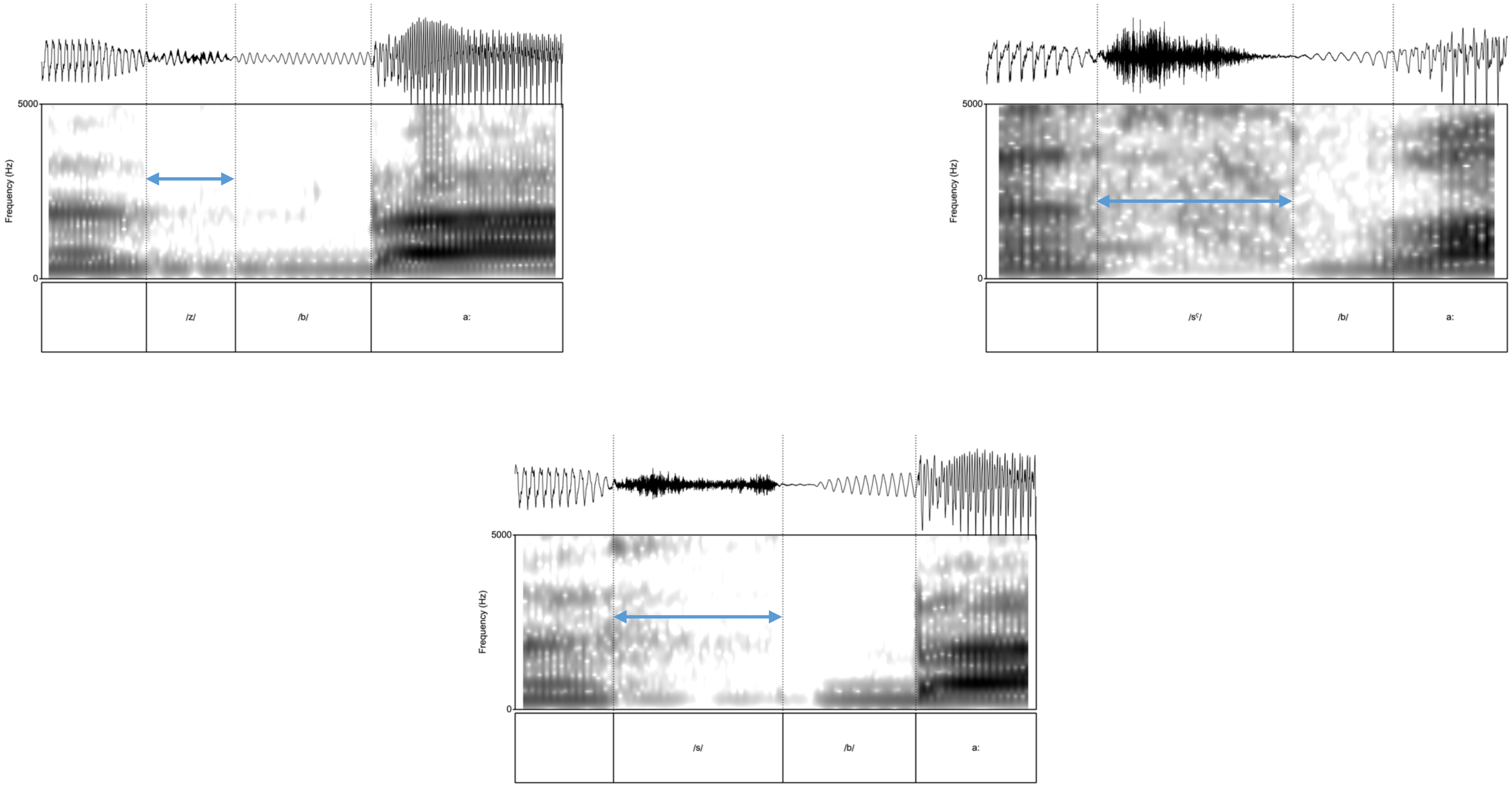
As in Table 7.55, /z/ frication is significantly shorter in duration than both /sˤ/ ($n=288, \beta=1.117e\text{-}01, SE=4.200e\text{-}03, t\text{-}value=26.61, p<0.001$) and /s/ frication ($n=288, \beta=1.151e\text{-}01, SE=4.200e\text{-}03, t\text{-}value=27.40, p<0.001$) as in Figure 7.11. C2 HP is significantly shorter in /zb/ than in both /sˤb/ and /sb/. Likewise, sequence duration is significantly shorter in /zb/ than in both /sˤb/ ($n=288, \beta=1.193e\text{-}01, SE=3.214e\text{-}03, t\text{-}value=37.11, p<0.001$) and /sb/ sequences ($n=288, \beta=1.228e\text{-}01, SE=3.214e\text{-}03, t\text{-}value=38.21, p<0.001$). Longer C1 frication, C2 HP and sequence durations in /sˤb/ and /sb/ sequences indicate that the consonantal gestures are further apart in these two sequences than the consonantal gestures in /zb/ sequence. Accordingly, it can be concluded that the voiced/voiced sequence (/zb/) exhibits greater degree of gestural overlap than voiced/voiceless sequences (/sˤb/ and /sb/), occurring word-initially. This finding could be attributed to the state of the glottis, which is the same in the voiced/voiced sequence but different in voiced/voiceless sequences.

7.3.3.3.2 Hypothesis (e)

The results presented in this subsection are based on models with the default reference, which is the emphatic /sˤ/.

The intervals in Table 7.55 are similar in both /sˤb/ than in /sb/. No significant differences were found between the two sequences in all intervals. Accordingly, there is no evidence to conclude that /sˤb/ exhibits greater degree of gestural overlap than /sb/ sequence when occurring word-initially, indicating that the state of the glottis does not have any role on gestural overlap in these two sequences. Therefore, the state of the glottis could be the same in both /sˤ/ and /s/. This finding is consistent with the findings of /bsˤ/ and /bs/ sequences occurring word initially, as reported in Section 7.3.3.1, and word-finally as reported in Section 7.3.3.2. In this respect, /sˤb/ sequence does not behave similarly with /zb/ sequence in the degree of gestural overlap, compared to /sb/. Rather, /sˤb/ behaves similarly to /sb/ in the degree of gestural overlap, compared to /zb/. Accordingly, there is no evidence to conclude that /sˤ/ patterns with /z/ in the degree of gestural overlap, compared to /s/.

Figure 7.11 /z/ frication in zba:lah (top left) is shorter in duration than both /sˤ/ frication in sˤba:dʒah (top right) and /s/ frication in sba:gah (bottom)



7.3.3.4 sb# ~ sˤb# ~ zb# (word-final)

The timing relations in /sˤb/ in *gasˤb*, those in /sb/ in *kasb* and those in /zb/ in *xazb* were compared. As in Table 7.58, the ICI occurrence is similar in all three sequences. The acoustic measurements are presented in Table 7.59. The summaries of optimal models of all dependent variables are presented in Tables 7.60 (with /z/ as reference) and in 7.61 (with /sˤ/ as reference).

Table 7.58 ICI count

Consonant Sequence	Total *n*	Not		Yes	
		n	**Percentage**	***n***	**Percentage**
sb#	96	1	1.04	95	98.96
sˤb#	96	2	2.08	94	97.92
zb#	96	5	5.21	91	94.79
Total	288	8	2.78	280	97.22

Table 7.59 Acoustic measurements for /sˤb/, /sb/ and /zb/ (mean_values)

Consonant Sequence	C1_Frication	ICI	C2_HP	Sequence	ICI_Voicing Proportion
sb#	101.94	58.19	72.59	232.3	0.9
sˤb#	103.74	57.06	73.77	233.67	0.92
zb#	93	62.12	76.29	228.85	1

Table 7.60 The summary of optimal models of all dependent variables (with /z/ as reference, compared to the other two levels: /sˤ/ and /s/). Full optimal models are presented in Appendix B (Section 11.2.2.2.4).

IVs / DVs	Rate	Gender	Context	Context * Rate	Context * Gender
C1 Frication	***				
ICI	***				
C2 HP	***				
Sequence	***				
ICI Voicing Proportion					

Table 7.61 The summary of optimal models of all dependent variables (with /sˤ/ as reference, compared to /s/). Full optimal models are presented in Appendix B (Section 11.2.2.2.4). In those models, /sˤ/ was compared to the other two levels: /s/ and /z/, but since a comparison between /z/ and /sˤ/ was already presented above, this table only presents the summary of /sˤ/ vs /s/.

IVs / DVs	Rate	Gender	Context	Context * Rate	Context * Gender
C1 Frication	***				
ICI	***				
C2 HP	***				
Sequence	***				
ICI Voicing Proportion					

7.3.3.4.1 Hypothesis (c)

The results presented in this subsection are based on models with releveling the reference of Context to be the plain voiced /z/.

The intervals in Table 7.59, are similar between the three sequences. No significant differences were found between /zb/ and the other two sequences (/sˤb/ and /sb/) in all durations (i.e. C1 frication, ICI, C2 HP and sequence durations). Accordingly, there is no evidence to conclude that the voiced/voiced sequence (i.e. /zb/) exhibits greater degree of gestural overlap than voiced/voiceless sequences (i.e. /sˤb/ and /sb/) in a word-final position. The role of the state of the glottis, in /z/, is not operative in this word position, unlike the same sequence when occurring in a word-initial position, as reported in Section 7.3.3.3. The ICI voicing proportion is also similar in all three sequences, and no significant differences were found between them in the ICI voicing proportion. It can be noted that the ICI durations here (in a word-final position) are longer than ICI durations occurring word-initially in all three contexts. The ICI in a word-final position could have the characteristics of epenthetic vowels in the sense that they are longer and all are voiced regardless of Context (plain voiced, plain voiceless or emphatic), compared to the ICI in a word-initial position. The differences between ICIs in various word positions will be discussed in detail in Chapter 8.

7.3.3.4.2 Hypothesis (e)

The results presented in this subsection are based on models with the default reference, which is the emphatic /sˤ/.

The intervals in Table 7.59, are similar between the three sequences. No significant differences were found between /sˤb/ and /sb/ sequences in all durations (i.e. C1 frication, ICI, C2 HP and sequence durations). Accordingly, there is no evidence to conclude that the /sˤb/ sequence exhibits greater degree of gestural overlap than /sb/. The state of the glottis does not have any role in gestural overlap in these two sequences. The ICI voicing proportion is also similar in all three sequences, and no significant differences were found between them in the ICI voicing proportion. In this respect, all the three sequences (/zb/, /sˤb/ and /sb/) behave similarly in the degree of gestural overlap. Accordingly, there is no evidence to conclude that /sˤ/ patterns with /z/ in the degree of gestural overlap, compared to /s/.

7.4 Interim discussion

This chapter presented the results concerning the state of the glottis and gestural overlap: Research Question 1b and the associated specific hypotheses (c), (d) and (e). The results of each sequence type (stop/stop and stop/alveolar fricative) were provided separately. The results of the common hypotheses (i) and (j) were presented first, followed by the results of the specific hypotheses (c), (d) and (e) for each word position (#CC and CC#).

Table 7.62 Summary of the impact of place order, by sequence type and position. (√) indicates that the impact is exhibited

	Stop/stop	**Stop/alveolar fricative**
#CC	√	X
CC#	√	√

Table 7.63 Summary of the impact of speech rate, by sequence type, position and place order.(√) indicates that the impact is exhibited. NA=no ICIs occurred

	Stop/stop		**Stop/alveolar fricative**	
	Front-back	**Back-front**	**Front-back**	**Back-front**
#CC	√	√	√	NA
CC#	√	X	√	X

Table 7.64 Summary of the impact of the state of the glottis of voiced consonants, by sequence type and place order.(√) indicates that the impact is exhibited

	Front-back	**Back-front**
#CC	√	√
CC#	√	X

Table 7.65 Summary of the impact of the state of the glottis of emphatic coronals, by sequence type, position and place order.(√) indicates that the impact is exhibited

	Stop/stop		**Stop/alveolar fricative**	
	Front-back	**Back-front**	**Front-back**	**Back-front**
#CC	√	√	X	X
CC#	√	X	X	X

As in Table, 7.62, the impact of the place order was exhibited in stop/stop sequences and only in CC# position in stop/alveolar sequences. Back-front sequences exhibit lower degree of gestural overlap than front-back sequences. This impact is generally characterised by higher ICI count percentage, longer ICI and/or sequence durations in back-front than in front-back sequences. Based on the results reported in this chapter, it can be concluded that Hypothesis (i) is ***supported for stop/stop*** but ***partially supported for stop/alveolar*** sequences. ICIs do not occur in sequences where C1 is a fricative in a word-initial position. Hence, ICIs do not occur in /#sb/, /#sˤb/ and /#zb/ back-front sequences, whereas ICIs occur in /#bs/, /#bsˤ/ and /#bz/front-back sequences; this may explain why the place order effect was not exhibited in #CC position in stop/alveolar fricative sequences. Therefore, the place order effect is greater in stop/stop than in stop/alveolar fricative sequences in #CC and CC# word positions in Najdi Arabic. The place order effect can be attributed to perceptual recoverability. The impact of place order and Hypothesis (i) will be discussed further in Chapter 9.

As in Table, 7.63, the impact of the speech rate effect varies as a function of sequence type, word position and place order. Stop/stop sequences at fast rate exhibit greater degree of gestural overlap than those at the normal rate in both positions, excluding CC# sequences in back-front order. Stop/alveolar fricative sequences at fast rate exhibit greater degree of gestural overlap than those at the normal rate in both positions only in front-back order; it is not exhibited in #CC and CC# sequences in back-front order. Greater degree of gestural overlap is characterised by lower ICI count percentage at fast rate than at the normal rate. Accordingly, Hypothesis (j) is ***partially*** supported in #CC and CC# positions. As indicated above, ICIs do not occur in sequences where C1 is a fricative in a word-initial position. Hence, ICIs do not occur in /#sb/, /#sˤb/ and /#zb/ back-front sequences, whereas ICIs occur in /#bs/, /#bsˤ/ and /#bz/front-back sequences; this explains why the the speech rate effect was not exhibited in #CC stop/alveolar fricative sequences in back-front order, since the measure that is used to examine the speech rate effect is ICI count/occurrence in this thesis. The finding that the speech rate effect was not exhibited in CC# sequences in back-front order in both sequence types could be attributed to the type of the ICI. The ICI in CC# sequences in back-front place order appears to exhibit the characteristics of epenthetic vowels; the ICI in this word position is mostly voiced, regardless of the state of the glottis of the surrounding consonants, and longer than the ICI in the other word positions (#CC sequences in both place orders and CC# sequences in front-back place order), in which the ICI appears to exhibit the characteristics of intrusive vowels. Intrusive vowels are variable and may disappear in fast rate, while epenthetic vowels are not influenced by speech rate (Hall, 2006). Intrusive and epenthetic vowels will be discussed in detail in Chapter 8.

As in Table, 7.64, the impact of the state of the glottis of voiced consonants was exhibited in both sequence types,but this impact is constrained by the word position and place order. Voiced/voiced sequences exhibit greater degree of gestural overlap than voiced/voiceless sequences, excluding CC# sequences in back-front place order. This can be attributed to the role of the state of the glottis in gestural overlap. Voiced/voiced (sharing the same state of the glottis) exhibit greater degree of gestural overlap than voiced/voiceless sequences since they differ in the state of the glottis. The finding that this effect was not exhibited in CC# sequences in back-front order could be attributed to the type of the ICI. As indicated above, the ICI in CC# sequences in back-front place order appears to exhibit the characteristics of epenthetic vowels, while the ICI in the other word positions (#CC sequences in both place orders and CC# sequences in front-back place order) appears to exhibit the characteristics of intrusive vowels. Intrusive vowels are variable in duration and voicing, and are influenced by surrounding consonants, while epenthetic vowels are independent in terms of duration and voicing (Hall, 2006; Plug et al, 2019). Accordingly, Hypothesis (c) is ***supported if*** we exclude CC# sequences in back-front order. This hypothesis is supported in in sequences where intrusive vowels occur, but not in sequences where epenthetic vowels occur. Intrusive and epenthetic vowels will be discussed in detail in Chapter 8. The pattern of gestural overlap observed in #CC (in both place orders) and in CC# (in front-back order) is generally characterised by lower ICI count percentage, shorter ICI, shorter sequence durations and/or shorter individual intervals in voiced/voiced than in voiced/voiceless sequences.

Likewise, as in Table, 7.65, the impact of the less open glottis of the emphatic coronal /tˤ/ was exhibited,but this impact is constrained by the word position and place order. Voiced/emphatic /tˤ/ sequences (i.e., /btˤ/ and /tˤb/) exhibit greater degree of gestural overlap than voiced/plain /t/ sequences (i.e., /bt/ and /tb/) in #CC sequences (in both place orders) and in CC# sequences (in front-back order). This pattern of gestural overlap is generally characterised by lower ICI count percentage, shorter ICI, shorter sequence durations and/or shorter individual intervals in voiced/emphatic /tˤ/ sequences than in voiced/plain /t/

sequences. This can be attributed to the role of the state of the glottis in gestural overlap. Accordingly, /tˁ/ patterns with the plain voiced counterpart /d/ in the degree of gestural overlap, compared to the plain voiceless counterpart /t/ since both sequences including /tˁ/ and those including /d/ exhibit greater degree of gestural overlap than sequences including /t/. The ICI in CC# sequences in back-front place order appears to exhibit the characteristics of epenthetic vowels; the ICI in this word position is mostly voiced, regardless of the state of the glottis of the surrounding consonants, and longer than the ICI in the other word positions (#CC sequences in both place orders and CC# sequences in front-back place order), in which the ICI exhibits the characteristics of intrusive vowels. Accordingly, Hypothesis (d) is ***supported if*** we exclude CC# sequences in back-front order. This hypothesis, similar to Hypothesis (c), is supported in sequences in which intrusive vowels occur, but not in sequences in which epenthetic vowels occur. Intrusive and epenthetic vowels will be discussed in detail in Chapter 8.

On the other hand, no significant differences were found between sequences including the emphatic coronal /sˁ/ and those including the plain voiceless counterpart /s/ in the degree of gestural overlap as in Table 7.65. These findings are *not expected*. Accordingly, Hypothesis (e) is ***not supported***, indicating that there are no differences between /sˁ/ and /s/ in the state of the glottis, unlike the case in /tˁ/ ~ /t/.

Having presented the results concerning the impact of the secondary articulation of emphasis on gestural overlap in Chapter 6 and the results of the impact of the state of the glottis on gestural overlap in Chapter 7, now we turn to present the results concerning the types of vowel insertion and their interaction with emphasis impact in Chapter 8.

8 Results: the types of inserted vowels and emphasis

8.1 Introduction

This chapter presents the results concerning the two types of vowel insertion (i.e. intrusive and epenthetic vowels). The relevant word set in this chapter is word set C (see Table 5.3 in Chapter 5 for word set C). To reiterate, word set C was designed to address Research Question 2 and test hypotheses (f), (g) and (h), as restated below:

RQ2: If yes, is emphasis impact observed in intrusive vowels, epenthetic vowels, or in both?

Hypothesis (f) Intrusive vowels will occur in word-initial sequences (#CC), two-consonant sequences across the word boundary (C#C) and in word-final sequences (CC# that obey the sonority sequencing), whereas epenthetic vowels will occur in four-consonant sequences at the word boundary (CC#CC) and in word-final sequences (CC# that violate the sonority sequencing in Najdi Arabic).

Hypothesis (g) emphasis impact, if any, will be observed in intrusive vowels but not in epenthetic vowels.

Hypothesis (h) word-initial clusters will exhibit a lower degree of gestural overlap than word-final clusters and sequences across the word boundary.

As explained in Chapters 1, 4 and 5, the types of vowel insertion were investigated by examining the ICI. It was investigated whether the ICI exhibits the characteristics of intrusive vowels or epenthetic vowels. To address Research Question 2, ICI duration and voicing proportion were examined in various word positions considering the context (emphatic or plain).

As stated in Chapter 5, word sets A and B contain various word sequences that are relevant for Hypotheses (f) and (g), but not a full set. Therefore, word set C was designed to include various word positions including four-consonant sequences occurring at the word boundary (CC#CC). This word set consists of further labial/coronal sequences occurring word-initially, word-finally and across the word boundary to test Hypotheses (f) and (h). Since dorsal/coronal sequences (e.g., /gt/, /tg/, /gs/ or /sg/) were already considered in word set A to test the impact of the secondary articulation of emphatic coronals on gestural overlap, as reported in Chapter 6, those dorsal/coronal sequences were excluded in this word set C, and hence only labial/coronal sequences (e.g., /bt/, /tb/, /bs/, /sb/) were included here. Similarly, the plain voiced /d/ and /z/ were already considered in word set B, as reported in Chapter 7, therefore they were excluded in this word set C, and hence only the emphatic coronals (/tˤ/, /sˤ/) and their plain voiceless counterparts (/t/, /s/) were included here to test Hypothesis (g). The dental fricatives /ðˤ/ and /ð/ were excluded in word set C because the state of the glottis is the same in both which is voiced. Therefore, based on the literature, there is no motivation to examine sequences including /ðˤ/ or /ð/ to investigate the role of the state of the glottis in gestural overlap, as explained in Chapter 7 (see Section 7.1 in Chapter 7). The focus in the additional four consonant sequences (CC#CC) is on the two consonants at the word boundary (i.e., C2 and C3 in C1C2#C3C4). These sequences consist of labial/coronal sequences (/btˤ/ ~ /bt/, /tˤb/ ~ /tb/, /bsˤ/ ~ /bs/, /sˤb/ ~ /sb/). Accordingly, the exclusions explained above makes the comparison in this word set consistent since all consonant sequences in all word positions in this word set are composed of labial/coronal sequences (see Tables 5.3 in Chapter 5 for word set C).

As also explained in Chapter 5 and reiterated in Chapters 6 and 7, Hypotheses (i) and (j), as restated below, are common hypotheses that are tested in all three word sets.

Hypothesis (i) back-front consonant sequences will exhibit a lower degree of gestural overlap than front-back consonant sequences.

Hypothesis (j) consonant sequences at a fast speech rate will exhibit a greater degree of gestural overlap than sequences at a normal speech rate.

The independent variables that are considered in this chapter are as follows:

1. Word position (#CC, CC#, C#C, CC#CC)
2. Context (plain, emphatic)
3. Order of place of articulation (front-back, back-front)
4. Speech rate (normal, fast)
5. Gender (male, female)

Apart from consonant sequences occurring at the word boundary in four consonant sequences (CC#CC), the results of timing relations in all consonant sequences in word set C were presented in Chapters 6 and 7. Therefore, this chapter starts with presenting the results of the timing relations in two consonant sequences occurring at the word boundary in CC#CC.

The timing relations in /btˤ/ in /tb#tˤb/ were compared to those in /bt/ in /tb#tb/ sequences. Also, the timing relations in /tˤb/ in /btˤ#bt/ were compared to those in /tb/ in /bt#bt/ sequences. The timing relations in /bsˤ/ in /sb#sˤb/ were compared to those in /bs/ in /sb#sb/ sequences. Also, the timing relations in /sˤb/ in /bsˤ#bs/ were compared to those in /sb/ in /bs#bs/ sequences. Due to these specific comparisons, the order of place of articulation was not included in the models that were run in these subsections. For instance, the timing relations in /btˤ/ were compared to those in /bt/, and both sequences are in front-back place order. Therefore, the order of place of articulation as an independent variable was excluded in the relevant models.

There are two sequence types in word set C: stop/stop sequences (e.g., /bt/ and /tb/) and stop/alveolar fricative sequences (e.g., /bs/ and /sb/). The results of timing relations in each sequence type will be presented separately in two consecutive sections. Each section will start with reporting the results of the common hypotheses (i) and (j), and the remainder of each section will be devoted to the results of the impact of the state of the glottis. After that, the results of the specific hypotheses (f), (g) and (h) will be presented in three consecutive sections (8.3, 8.4 and 8.5). In each section, the results of stop/stop sequences will be presented first, followed by the results of stop/alveolar fricative sequences. The results of all sections will be summarised in Section 8.6, where it will be made clear whether the hypotheses are supported or not for all sequence types. Accordingly, this chapter consists of six sections. Section 8.1 is an introductory section. Section 8.2 presents the results of timing relations in CC#CC sequences. Sections 8.3, 8.4 and 8.5 present the results of Hypotheses (f), (g) and (h) respectively. The chapter ends with an interim discussion in Section 8.6 in which the results of the chapter are summarised, and it will be made clear whether the common hypotheses (i) and (j) for CC#CC sequences, and the specific hypotheses (f), (g) and (h) are supported.

8.2 Timing relations in sequences occurring at the word boundary in four consonant sequences (CC#CC)

8.2.1 Stop/stop sequences

8.2.1.1 The results of the place order effect (Hypothesis (i))

Linear mixed-effects models were run to test Hypothesis (i) with the place order and its interaction with other independent variables as the crucial fixed factor(s). The independent variables that were included in these models are Context (plain, emphatic), order of place of articulation, speech rate and gender.

The ICI count, ICI duration and sequence duration in back-front stop/stop sequences were compared to those in front-back stop/stop sequences, occurring at the word boundary in four consonant sequences (CC#CC). Sequences in a back-front place order include /tb/ and /tˤb/, and sequences in a front-back order include /bt/ and /btˤ/ sequences.

Table 8.1 ICI count. Yes (count and percentage of occurring ICIs), Not (count and percentage of non-occurring ICIs)

Place Order	**Total *n***	**Not**		**Yes**	
		n	**Percentage**	***n***	**Percentage**
back-front	192	0	0	192	100
front-back	192	0	0	192	100
Total	384	0	0	384	100

Table 8.2 Acoustic measurements for stop/stop sequences (mean_values)

Place order	**ICI_duration**	**Sequence_duration**
back-front	61.33	176.82
front-back	63.83	175.03

As in Table 8.1, the ICI count is the same in both place orders. As in Table 8.2, the ICI and sequence durations are similar between the two place orders. The results reveal that there are no significant differences between back-front and front-back place orders in the ICI and sequence durations as in Tables 8.3 and 8.4 (optimal models). Accordingly, there is *no evidence* to conclude that there is a place order effect in these sequences.

Table 8.3 The optimal model of ICI_duration in stop/stop sequences (n=384)

```
Formula: icilog ~ rate + (1 | speaker)
   Data: Ct4
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 1.739e+00  2.263e-03 3.820e+02  768.70   <2e-16***
rateNormal  1.054e-01  3.200e-03 3.820e+02   32.93   <2e-16***
```

Table 8.4 The optimal model of sequence_duration in stop/stop sequences (n=384)

```
Formula: wslog ~ rate + (1 | speaker)
   Data: Ct4
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 2.140e+00  1.365e-03 3.820e+02 1568.35   <2e-16***
rateNormal  1.886e-01  1.930e-03 3.820e+02   97.72   <2e-16***
```

8.2.1.2 The results of the speech rate effect (Hypothesis (j))

As made clear in Chapter 2, the main measure to determine whether there is an effect of speech rate on gestural overlap is the ICI count/occurrence (whether an ICI occurs in the sequence or not). Therefore, the ICI count is the only dependent variable considered here.

Table 8.5 ICI count

Speech Rate	**Total *n***	**Not**		**Yes**	
		n	**Percentage**	***n***	**Percentage**
Fast	192	0	0	192	100
Normal	192	0	0	192	100
Total	384	0	0	384	100

As in Table 8.5, ICIs always occur in both sequences. Accordingly, it can be concluded that speech rate does not have any impact on gestural overlap in stop/stop sequences, occurring at the word boundary in four consonant sequences (CC#CC) in Najdi Arabic.

Having presented the results of the common hypotheses (i) and (j) that are relevant to the place order effect and speech rate effect, now we turn to present the results of the impact of the state of the glottis of emphatic coronals on gestural overlap.

8.2.1.3 Cb#tC vs Cb#tˤC

The timing relations in /btˤ/ in *katb#tˤba:gah* were compared to those in /bt/ in *katb#tba:dil*. As in Table 8.6, the ICI occurrence is the same in both sequences. The acoustic measurements are presented in Table 8.7. The summary of optimal models of all dependent variables is presented in Table 8.8.

Table 8.6 ICI count

Consonant Sequence	**Total *n***	**Not**		**Yes**	
		n	**Percentage**	***n***	**Percentage**
tb#tb	96	0	0	96	100
tb#tˤb	96	0	0	96	100
Total	192	0	0	192	100

Table 8.7 Acoustic measurements for /btˤ/ and /bt/ (mean_values)

Consonant Sequence	C1_HP	ICI	C2_HP	Sequence	ICI_Voicing Proportion
tb#tb	57.85	63.23	51.29	172.36	0.94
tb#tˤb	55.33	64.43	57.96	177.71	0.96

Table 8.8 The summary of optimal models of all dependent variables. Full optimal models are presented in Appendix B (Section 11.2.3.1.1).

IVs / DVs	Rate	Gender	Context	Context * Rate	Context * Gender
C1 HP	***				
ICI	***				
C2 HP	***				
Sequence	***				
ICI Voicing Proportion					

As in Table 8.7, the durations of all dependent variables are similar in both contexts (emphatic and plain). The results reveal that no significant differences were found between an emphatic context and the plain counterpart in all these dependent variables. Accordingly, there is no evidence to conclude that /Cb#tˤC/ sequence exhibits greater degree of gestural overlap than /Cb#tC/ sequence when occurring at the word boundary in four consonant sequences (CC#CC). This finding indicates that the role of the state of the glottis is not operative here in this word position, unlike the same sequences in C#C as reported in Chapter 6, #CC and CC# as reported in Chapter 7. The ICI voicing proportion is almost the same in both sequences. It can be noted that the ICI duration in these sequences is longer than in the other word positions, reported in Chapters 6 (i.e. C#C) and 7 (i.e. #CC and CC# that obey the sonority sequencing). The ICI in CC#CC sequences, however, seems to be similar in duration to the ICI in CC# sequences that violate the sonority sequencing, reported in Chapter 7. Thus, these two longer ICIs (occurring in CC#CC and in CC# violating the sonority sequencing) seem to exhibit the characteristics of epenthetic vowels. This will be discussed in detail in Section 8.3.

8.2.1.4 Ct#bC vs Ctˤ#bC

The timing relations in /tˤb/ in *rabtˤ#bta:kil* were compared to those in /tb/ in *kabt#bta:kil*. As in Table 8.9, the ICI occurrence is the same in both sequences. The acoustic measurements are presented in Table 8.10. The summary of optimal models of all dependent variables is presented in Table 8.11.

Table 8.9 ICI count

Consonant Sequence	Total *n*	Not		Yes	
		n	**Percentage**	***n***	**Percentage**
bt#bt	96	0	0	96	100
btˤ#bt	96	0	0	96	100
Total	192	0	0	192	100

Table 8.10 Acoustic measurements for /tˤb/ and /tb/ (mean_values)

Consonant Sequence	C1_HP	ICI	C2_HP	Sequence	ICI_Voicing Proportion
bt#bt	47.69	63.42	66.2	177.32	0.9
btˤ#bt	51.97	59.24	65.11	176.32	0.93

Table 8.11 The summary of optimal models of all dependent variables. Full optimal models are presented in Appendix B (Section 11.2.3.1.2).

IVs / DVs	Rate	Gender	Context	Context * Rate	Context * Gender
C1 HP	***				
ICI	***				
C2 HP	***				
Sequence	***				
ICI Voicing Proportion					

As in Table 8.10, the durations of all dependent variables are similar in both contexts. The results reveal that no significant differences were found between an emphatic context and the plain counterpart in all these dependent variables. Accordingly, there is no evidence to conclude that /Ctˤ#bC/ sequence exhibits greater degree of gestural overlap than /Ct#bC/ sequence when occurring at the word boundary in four consonant sequences (CC#CC). This finding indicates that the role of the state of the glottis is not operative here in this word position similar to the same sequence in CC# as reported in Chapter 7,but unlike the same sequences in C#C as reported in Chapter 6 and in #CC as reported in Chapter 7. The ICI voicing proportion is almost the same in both sequences. It can be noted that the ICI duration in these sequences is longer than in the other word positions, reported in Chapters 6 (i.e. C#C) and 7 (i.e. #CC and CC# that obey the sonority sequencing). The ICI in CC#CC sequences, however, seems to be similar in duration to the ICI in CC# sequences that violate the sonority sequencing, reported in Chapter 7. Thus, these two longer ICIs (occurring in CC#CC and CC# violating the sonority sequencing) seem to exhibit the characteristics of epenthetic vowels. This will be discussed in detail in Section 8.3.

8.2.2 Stop/alveolar fricative sequences

8.2.2.1 The results of the place order effect (Hypothesis (i))

Linear mixed-effects models were run to test Hypothesis (i) with the place order and its interaction with other independent variables as the crucial fixed factor(s). The independent variables that were included in these models are Context (plain, emphatic), order of place of articulation, speech rate and gender.

The ICI count, ICI duration and sequence duration in back-front stop/alveolar fricative sequences were compared to those in front-back stop/alveolar fricative sequences, occurring at the word boundary in four consonant sequences (CC#CC). Sequences in a back-front place order include /sb/ and /sˤb/, and sequences in a front-back order include /bs/ and /bsˤ/ sequences.

Table 8.12 ICI count

Place Order	**Total *n***	**Not**		**Yes**	
		n	**Percentage**	***n***	**Percentage**
back-front	192	0	0	192	100
front-back	192	0	0	192	100
Total	384	0	0	384	100

Table 8.13 Acoustic measurements for stop/alveolar fricative sequences (mean_values)

Place order	**ICI_duration**	**Sequence_duration**
back-front	62.83	229.63
front-back	67.30	223.14

As in Table 8.12, the ICI count is the same in both place orders. As in Table 8.13, the ICI and sequence durations are similar between the two place orders. The results reveal that there are no significant differences between back-front and front-back place orders in the ICI and sequence durations as in Tables 8.14 and 8.15 (optimal models). Accordingly, there is *no evidence* to conclude that there is a place order effect in these sequences.

Table 8.14 The optimal model of ICI_duration in stop/alveolar fricative sequences (n=384)

```
Formula: icilog ~ rate + (1 | speaker)
   Data: Cs4
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 1.751e+00  2.061e-03 3.820e+02  849.22   <2e-16 ***
rateNormal  1.161e-01  2.915e-03 3.820e+02   39.84   <2e-16 ***
```

Table 8.15 The optimal model of sequence_duration in stop/alveolar fricative sequences (n=384)

```
Formula: wslog ~ rate + (1 | speaker)
   Data: Cs4
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 2.266e+00  1.568e-03 5.042e+01 1445.74   <2e-16 ***
rateNormal  1.609e-01  2.133e-03 3.670e+02   75.46   <2e-16 ***
```

8.2.2.2 The results of the speech rate effect (Hypothesis (j))

As made clear in Chapter 2, the main measure to determine whether there is an effect of speech rate on gestural overlap is the ICI count/occurrence (whether an ICI occurs in the sequence or not). Therefore, the ICI count is the only dependent variable considered here.

Table 8.16 ICI count

Speech Rate	**Total *n***	**Not**		**Yes**	
		n	**Percentage**	***n***	**Percentage**
Fast	192	0	0	192	100
Normal	192	0	0	192	100
Total	384	0	0	384	100

As in Table 8.16, ICIs always occur in both sequences. Accordingly, it can be concluded that speech rate does not have any impact on gestural overlap in stop/alveolar fricative sequences, occurring at the word boundary in four consonant sequences (CC#CC) in Najdi Arabic.

Having presented the results of the common hypotheses (i) and (j) that are relevant to the place order effect and speech rate effect, now we turn to present the results of the impact of the state of the glottis of emphatic coronals on gestural overlap.

8.2.2.3 Cb#sC vs Cb#sˤC

The timing relations in /bsˤ/ in *kasb#sˤba:dʒah* were compared to those in /bs/ in *kasb#sba:gah*. As in Table 8.17, the ICI occurrence is the same in both sequences. The acoustic measurements are presented in Table 8.18. The summary of optimal models of all dependent variables is presented in Table 8.19.

Table 8.17 ICI count

Consonant Sequence	Total *n*	Not		Yes	
		n	**Percentage**	***n***	**Percentage**
sb#sb	96	0	0	96	100
sb#sˤb	96	0	0	96	100
Total	192	0	0	192	100

Table 8.18 Acoustic measurements for /bsˤ/ and /bs/ (mean_values)

Consonant Sequence	C1_HP	ICI	C2_Frication	Sequence	ICI_Voicing Proportion
sb#sb	58.99	66.45	98.52	223.96	0.92
sb#sˤb	57.29	68.16	96.88	222.32	0.89

Table 8.19 The summary of optimal models of all dependent variables. Full optimal models are presented in Appendix B (Section 11.2.3.2.1).

IVs / DVs	Rate	Gender	Context	Context * Rate	Context * Gender
C1 HP	***				
ICI	***				
C2 Frication	***				
Sequence	***				
ICI Voicing Proportion					

As in Table 8.18, the durations of all dependent variables are similar in both contexts. The results reveal that no significant differences were found between an emphatic context and the plain counterpart in all these dependent variables. Accordingly, there is no evidence to conclude that /Cb#sˤC/ sequence exhibits greater degree of gestural overlap than /Cb#sC/ sequence when occurring at the word boundary in four consonant sequences (CC#CC). This finding is consistent with the findings of the same sequence in other word positions reported in Chapters 6 (i.e. in two consonant sequences, C#C) and 7 (i.e. in #CC and CC# sequences). This provides a further evidence that the state of the glottis does not play any role in the distinction between /bsˤ/ and /bs/ sequences in various word positions (C#C, #CC, CC# and

CC#CC). These findings indicate that both /sˤ/ and /s/ share the same state of the glottis, unlike /tˤ/ and /t/.

8.2.2.4 Cs#bC vs Csˤ#bC

The timing relations in /sˤb/ in *gabsˤ#bsa:gah* were compared to those in /sb/ in *kabs#bsa:gah*. As in Table 8.20, the ICI occurs in all tokens of both sequences. The acoustic measurements are presented in Table 8.21. The summary of optimal models of all dependent variables is presented in Table 8.22.

Table 8.20 ICI count

Consonant Sequence	**Total *n***	**Not**		**Yes**	
		n	**Percentage**	***n***	**Percentage**
bs#bs	96	0	0	96	100
bsˤ#bs	96	0	0	96	100
Total	192	0	0	192	100

Table 8.21 Acoustic measurements for /sˤb/ and /sb/ (mean_values)

Consonant Sequence	**C1_Frication**	**ICI**	**C2_HP**	**Sequence**	**ICI_Voicing Proportion**
bs#bs	88.61	64.14	78.43	231.19	0.9
bsˤ#bs	92.35	61.52	74.2	228.07	0.93

Table 8.22 The summary of optimal models of all dependent variables. Full optimal models are presented in Appendix B (Section 11.2.3.2.2).

IVs / **DVs**	Rate	Gender	Context	Context * Rate	Context * Gender
C1 Frication	***				
ICI	***				
C2 HP	***				
Sequence	***				
ICI Voicing Proportion					

As in Table 8.21, the durations of all dependent variables are similar in both contexts. The results reveal that no significant differences were found between an emphatic context and the plain counterpart in all these dependent variables. Accordingly, it can be concluded that

/Csˤ#bC/ sequence does not exhibit greater degree of gestural overlap than /Cs#bC/ sequence when occurring at the word boundary in four consonant sequences (CC#CC). This finding is consistent with the findings of the same sequence in other word positions reported in Chapters 6 (i.e. in two consonant sequences, C#C) and 7 (i.e. in #CC and CC# sequences). This provides a further evidence that the state of the glottis does not play any role in the distinction between /sˤb/ and /sb/ sequences in various word positions (C#C, #CC, CC# and CC#CC). These findings indicate that both /sˤ/ and /s/ share the same state of the glottis, unlike /tˤ/ and /t/.

Having presented the results of timing relations in sequences occurring at the word boundary in four consonant sequences (CC#CC), now we present the results of the specific hypothesis (f) which concerns the types of vowel insertion and word position.

8.3 The results of the types of vowel insertion and word position (Hypothesis (f))

As reiterated in Section 8.1, to test Hypothesis (f), various word positions were considered in word set C (see Table 5.3 in Chapter 5). The types of vowel insertion were investigated by examining the ICI; i.e., whether the ICI exhibits the characteristics of intrusive vowels or those of epenthetic vowels. If both intrusive and epenthetic vowels occur in Najdi Arabic, ICI durations should not be normally distributed, given that intrusive vowels are generally shorter than epenthetic vowels. Likewise, if both intrusive and epenthetic vowels occur in Najdi Arabic, ICI voicing proportion should not be normally distributed, given that voicing of intrusive vowels is influenced by surrounding consonants, unlike epenthetic vowels that are generally described as voiced regardless of the state of the glottis of surrounding consonants. Since there are two sequence types (stop/stop and stop/alveolar fricative) in word set C, the results of each will be presented separately. Accordingly, the results of stop/stop sequences will be presented first, followed by the results of stop/alveolar fricative sequences.

8.3.1 Stop/stop sequences

8.3.1.1 ICI duration

As in Figure 8.1, there is bimodality in the distribution of ICI durations; there are two main peaks: a portion of the ICIs is below 40ms and the other portion is above 40ms. The distribution of ICI durations is significantly different from normal (Shapiro-Wilk: W=0.87181,p-value<0.001).

Figure 8.1 The distribution of ICI_durations across word position

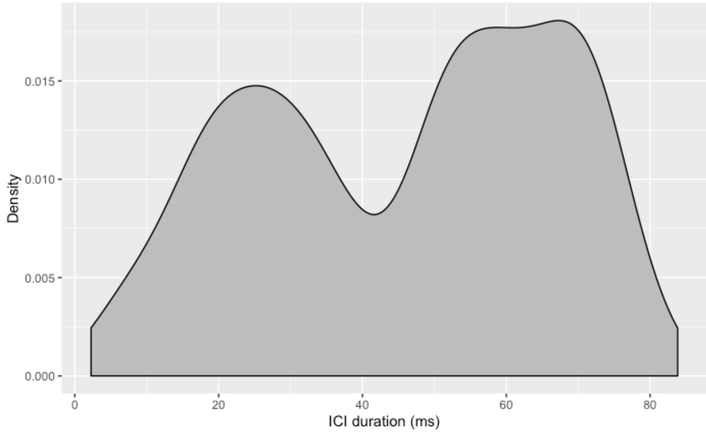


Figure 8.2 shows the ICI durations distribution split by the word position (#CC, C#C, CC#, CC#CC). It can be seen that in #CC and C#C word positions, where intrusive vowels are expected to occur, majority of the ICI durations are below 40ms. In CC#CC word position, where epenthetic vowels are expected to occur, the ICI durations are above 40ms. In CC# word position, however, there is bimodality in the distribution of ICI durations. This is because both intrusive and epenthetic vowels are expected to occur in in this word position (i.e. word-final position), according to the sonority sequencing. Intrusive vowels are expected to occur in CC# sequences that obey the sonority sequencing principle (SSP), whereas epenthetic vowels are expected to occur in CC# sequences that violate the SSP. The sequences that obey the SSP for stop/stop sequences occurring word-finally in word set C are /bt#/ and /btˤ#/ (see Section 4.7.2 in Chapter 4 for the SSP in Najdi Arabic). The sequences that violate the SSP for stop/stop sequences occurring word-finally in word set C are /tb#/ and /tˤb#/. It can be noted that all sequences that obey the SSP are in front-back place order, while all sequences that violate the SSP are in back-front place order. Figure 8.3 shows the distribution of ICI durations split by the order of place of articulation (front-back and back-front) in CC# word position. It can be seen that ICI durations in a back-front place order are above 40ms, whereas ICI durations in a front-back place order are below 40ms, and centred around 20ms. The distribution of ICI durations in CC# word position is significantly different from normal (Shapiro-Wilk: W=0.83324,p-value<0.001).

Figure 8.2 The distribution of ICI_durations in various word positions

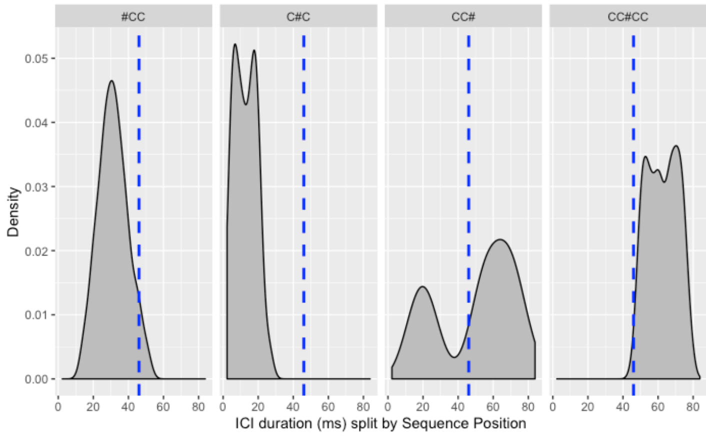
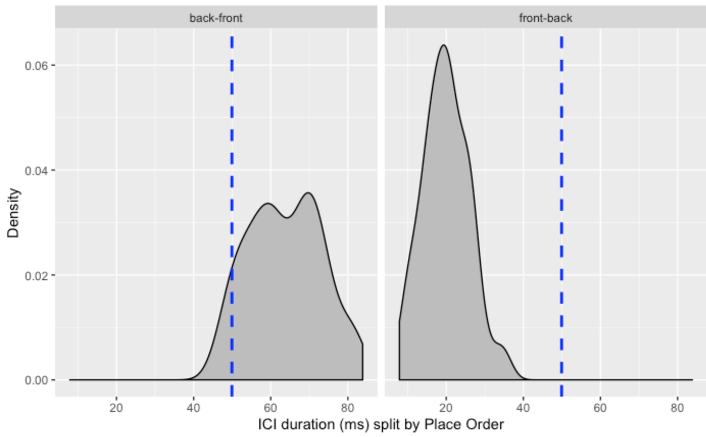


Figure 8.3 The distribution of ICI_durations in a word-final position, split by place order



To test the role of the place order in each word position, four new subsets were created: one that included only #CC position, another included C#C, another included CC# and another included CC#CC position. The results reveal that the effect of place order on ICI duration is statistically significant only in CC# position as in Tables 8.23, 8.24, 8.25 and 8.28. The results also reveal that there is a significant interaction between place order and Context in CC# position as in Table 8.25. The results of further models[59] show that the effect of Context is only exhibited in front-back order in a word-final position as in Tables 8.26 and 8.27.

The above results provide evidence that there are two types of vowel insertion occurring in Najdi Arabic, based on ICI duration, supporting Hypothesis (f).

[59] A new subset was created that included only front-back sequences in CC# position and another that included only back-front sequences in CC# position, then further models were run for each.

Table 8.23 The optimal model of ICI_duration in stop/stop sequences (in #CC position, n=298)

```
Formula: icilog ~ rate + Context + (1 | speaker)
   Data: Ct_Initial
Fixed effects:
               Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)   1.325e+00 9.499e-03 2.950e+02 139.52   <2e-16***
rateNormal    1.106e-01 9.630e-03 2.950e+02  11.48   <2e-16***
ContextPlain  1.525e-01 9.781e-03 2.950e+02  15.59   <2e-16***
```

Table 8.24 The optimal model of ICI_duration in stop/stop sequences (in C#C position, n=91)

```
Formula: icilog ~ rate + Context + (1 | speaker)
   Data: Ct_2b
Fixed effects:
              Estimate Std.Error       df tvalue Pr(>|t|)
(Intercept)    0.63047   0.02989 88.00000 21.091  <2e-16***
rateNormal     0.16724   0.02816 88.00000  5.939 5.59e-08***
ContextPlain   0.45573   0.02630 88.00000 17.331  <2e-16***
```

Table 8.25 The optimal model of ICI_duration in stop/stop sequences (in CC# position, n=278)

```
Formula: icilog ~ rate + Context + placeorder + placeorder:Context + (1 | speaker)
   Data: Ct_Final
Fixed effects:
                                 Estimate Std.Error         df tvalue Pr(>|t|)
(Intercept)                      1.721545  0.006061 150.247727 284.024  <2e-16***
rateNormal                       0.114560  0.006071 259.651569  18.869  <2e-16***
ContextPlain                     0.040515  0.007268 258.228622   5.574 6.26e-08***
placeorderfront-back            -0.705302  0.012928 266.466789 -54.558  <2e-16***
ContextPlain:placeorderfront-back 0.201278  0.015109 264.811071  13.322  <2e-16***
```

<u>Further:</u>

Table 8.26 The optimal model of ICI_duration in stop/stop sequences in CC# position (in front-back order, n=88)

```
Formula: icilog ~ rate + Context + Context:gender + (1 | speaker)
   Data: Ct_FB_fin
Fixed effects:
                           Estimate Std.Error       df tvalue Pr(>|t|)
(Intercept)                 1.07135   0.02028 83.00000 52.833  <2e-16***
rateNormal                  0.13113   0.01227 83.00000 10.686  <2e-16***
ContextPlain                0.12321   0.02101 83.00000  5.865 8.87e-08***
ContextEmphatic:genderMale -0.13221   0.02624 83.00000 -5.038 2.70e-06***
ContextPlain:genderMale     0.09819   0.01336 83.00000  7.351 1.26e-10***
```

Table 8.27 The optimal model of ICI_duration in stop/stop sequences in CC# position (in back-front order, n=190)

```
Formula: icilog ~ rate + (1 | speaker)
   Data: Ct_BF_fin
Fixed effects:
                           Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)                1.719740   0.004486 188.000000 383.383  <2e-16***
rateNormal                 0.118127   0.006277 188.000000  18.818  <2e-16***
```

Table 8.28 The optimal model of ICI_duration in stop/stop sequences (in CC#CC position, n=384)

```
Formula: icilog ~ rate + (1 | speaker)
   Data: Ct_4b
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 1.739e+00  2.263e-03 3.820e+02 768.70   <2e-16***
rateNormal  1.054e-01  3.200e-03 3.820e+02  32.93   <2e-16***
```

8.3.1.2 ICI voicing proportion

As in Figure 8.4, there is bimodality in the distribution of ICI voicing proportion; there are two main peaks: the voicing proportion of a portion of the ICIs is below 0.70 and that of the other portion is above 0.80. The distribution of ICI voicing proportion is significantly different from normal (Shapiro-Wilk: W=0.8874,p-value<0.001).

Figure 8.4 The distribution of ICI_voicing_proportion across word position

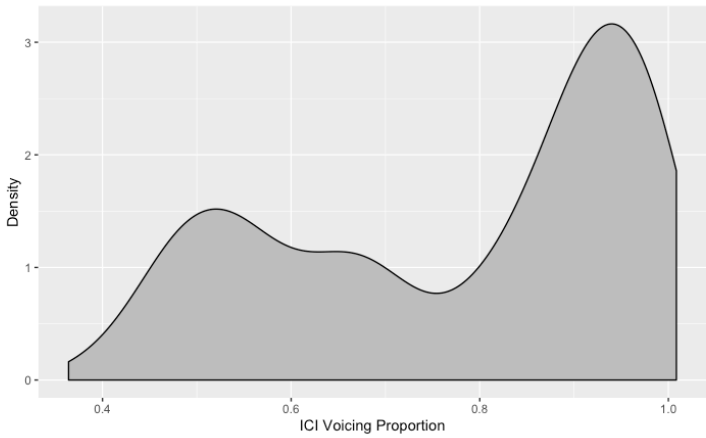


Figure 8.5 shows the ICI voicing proportion distribution split by the word position. It can be seen that the ICI voicing proportion is above 0.80 in CC#CC sequences, where epenthetic vowels are expected to occur. The ICI voicing proportion is, however, variable in #CC and C#C sequences, where intrusive vowels are expected to occur although the voicing proportion of

the majority of the ICIs is below 0.70 in both #CC and C#C sequences. On the other hand, in CC# sequences, where epenthetic vowels are expected to occur, there are clearly two main peaks: the highest is above 0.80 and the other one is below 0.70. This is because both intrusive and epenthetic vowels are expected to occur in this word position (i.e. word-final position), according to the sonority sequencing. Intrusive vowels are expected to occur in CC# sequences that obey the sonority sequencing principle (SSP), whereas epenthetic vowels are expected to occur in CC# sequences that violate the SSP. As shown earlier in Section 8.3.1.1, the sequences that obey the SSP in word set C are in a front-back place order, while all sequences that violate the SSP are in back-front place order. Figure 8.6 shows the distribution of ICI voicing proportion split by the order of place of articulation (front-back and back-front) in CC# word position. It can be seen that ICI voicing proportion in a back-front place order is above 0.80, whereas ICI voicing proportion in a front-back place order is below 0.80. The distribution of ICI voicing proportion in CC# word position is significantly different from normal (Shapiro-Wilk: W=0.86663,p-value<0.001).

Figure 8.5 The distribution of ICI_voicing_proportion in various word positions

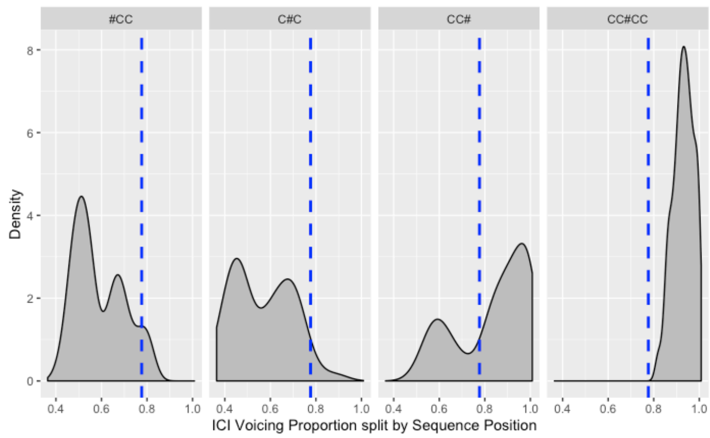
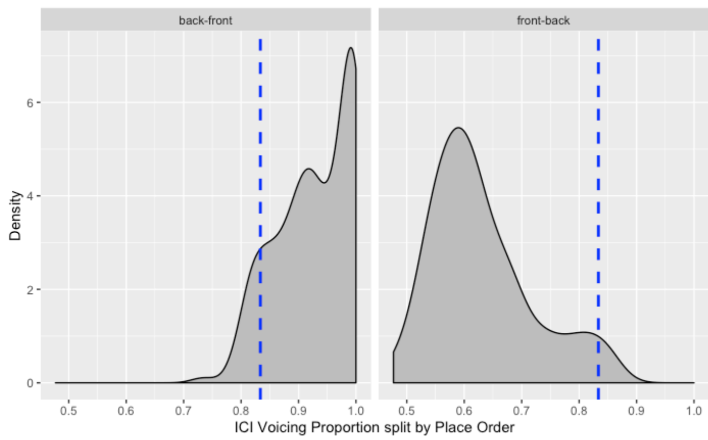


Figure 8.6 The distribution of ICI_voicing_proportion in a word-final position, split by place order



To test the role of the place order in each word position, four new subsets were created: one that included only #CC position, another included C#C, another included CC# and another included CC#CC position. The results reveal that the effect of place order on ICI voicing proportion is statistically significant only in CC# position as in Tables 8.29, 8.30 and 8.31[60]. The results also reveal that there is a significant interaction between place order and Context in CC# position as in Table 8.31. The results of further models[61] show that the effect of Context is only exhibited in front-back order in a word-final position as in Table 8.32[62].

The above results provide evidence that there are two types of vowel insertion occurring in Najdi Arabic, based on ICI voicing proportion, supporting Hypothesis (f).

Table 8.29 The optimal model of ICI_voicing_proportion in stop/stop sequences (in #CC position, n=298)

```
Formula: ici_voicing ~ Context + (1 | speaker)
   Data: Ct_Initial
Fixed effects:
              Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)   0.706819  0.004853 296.000000 145.66  <2e-16***
ContextPlain -0.194069  0.006244 296.000000 -31.08  <2e-16***
```

Table 8.30 The optimal model of ICI_voicing_proportion in stop/stop sequences (in C#C position, n=91)

```
Formula: ici_voicing ~ Context + (1 | speaker)
   Data: Ct_2b
Fixed effects:
             Estimate Std.Error      df tvalue Pr(>|t|)
(Intercept)   0.69394   0.01463 89.00000  47.44  <2e-16***
ContextPlain -0.20238   0.01848 89.00000 -10.95  <2e-16***
```

Table 8.31 The optimal model of ICI_voicing_proportion in stop/stop sequences (in CC# position, n=278)

```
Formula: ici_voicing ~ placeorder + placeorder:Context + (1 | speaker)
   Data: Ct_Final
Fixed effects:
                                   Estimate Std.Error         df tvalue Pr(>|t|)
(Intercept)                        0.931977  0.006311  98.397011 147.676  <2e-16***
placeorderfront-back              -0.160727  0.015512 267.139915 -10.362  <2e-16***
placeorderback-front:ContextPlain -0.007822  0.008741 259.402434  -0.895   0.372
placeorderfront-back:ContextPlain -0.178188  0.015934 267.582233 -11.183  <2e-16***
```

[60] None of the independent variables was significant for ICI voicing proportion in CC#CC position.

[61] A new subset was created that included only front-back sequences in CC# position and another that included only back-front sequences in CC# position, then further models were run for each.

[62] None of the independent variables was significant for ICI voicing proportion in back-front sequences in CC# position.

Further:

Table 8.32 The optimal model of ICI_voicing_proportion in stop/stop sequences in CC# position (in front-back order, n=88)

```
Formula: ici_voicing ~ Context + (1 | speaker)
   Data: Ct_FB_fin
Fixed effects:
              Estimate Std.Error       df tvalue Pr(>|t|)
(Intercept)    0.77094   0.01196 77.32275  64.44   <2e-16***
ContextPlain  -0.17784   0.01334 77.83978 -13.33   <2e-16***
```

In general, in word positions where epenthetic vowels are expected to occur (i.e. in CC# violating the SSP and in CC#CC sequences), ICI durations are longer than 40ms and they are mostly voiced, regardless of the surrounding consonants. In other word positions (i.e. #CC, C#C and CC# obeying the SSP), where intrusive vowels are expected to occur, ICI durations are mostly below 40ms and the ICI voicing proportion is influenced by state of the glottis of surrounding consonants. Accordingly, ICIs in #CC and C#C exhibit the characteristics of intrusive vowels, whereas ICIs in CC#CC exhibit the characteristics of epenthetic vowels. In a word-final position (CC#), however, the ICI exhibits the characteristics of intrusive vowels if the sequence obeys the SSP; if it violates the SSP, the ICI exhibits the characteristics of epenthetic vowels. These findings support Hypothesis (f) for stop/stop sequences.

Having established that the two types of vowel insertion occur in stop/stop sequences, now we present the results of stop/alveolar fricative sequences.

8.3.2 Stop/alveolar fricative sequences

8.3.2.1 ICI duration

As in Figure 8.7, there is bimodality in the distribution of ICI durations; there are two main peaks: a portion of the ICIs is below 37ms and the other portion is above 37ms. The distribution of ICI durations is significantly different from normal (Shapiro-Wilk: W=0.83764,p-value<0.001). Figure 8.8 shows the ICI durations distribution split by the word position. It can be seen that in #CC and C#C word positions, where intrusive vowels are expected to occur, the ICI durations are below 35ms. In CC#CC word position, where epenthetic vowels are expected to occur, the ICI durations are above 40ms. In CC# word position, however, there is bimodality in the distribution of ICI durations. This is because both intrusive and epenthetic vowels are expected to occur in in this word position (i.e. word-final position), according to the sonority sequencing. Intrusive vowels are expected to occur in CC# sequences that obey the sonority sequencing principle (SSP), whereas epenthetic vowels are expected to occur in CC# sequences that violate the SSP. The sequences that obey the SSP for stop/alveolar fricative sequences occurring word-finally in word set C are /bs#/ and /bsˤ#/. The sequences that violate the SSP for stop/alveolar fricative sequences occurring word-finally in word set C are /sb#/ and /sˤb#/. It can be noted that all sequences that obey the SSP are in front-back place order, while all sequences that violate the SSP are in back-front place order. Figure 8.9 shows the distribution of ICI durations split by the order of place of articulation (front-back and back-front) in CC# word position. It can be seen that ICI durations in a back-front place order are above 40ms, whereas ICI durations in a front-back place order are below 30ms. The distribution of ICI durations in CC# word position is significantly different from normal (Shapiro-Wilk: W=0.79966,p-value<0.001).

Figure 8.7 The distribution of ICI_durations across word position

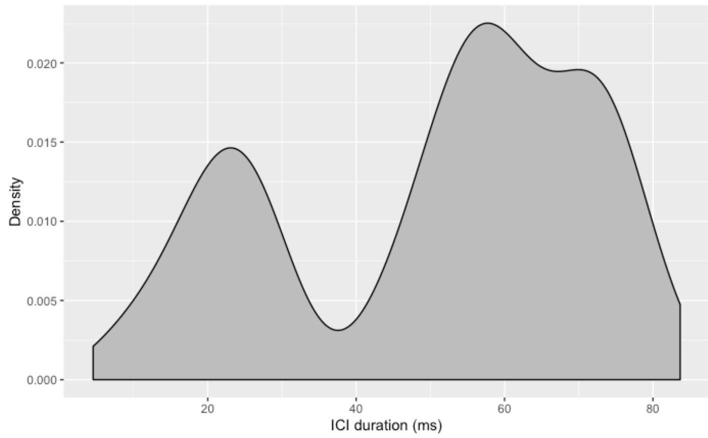


Figure 8.8 The distribution of ICI_durations in various word positions

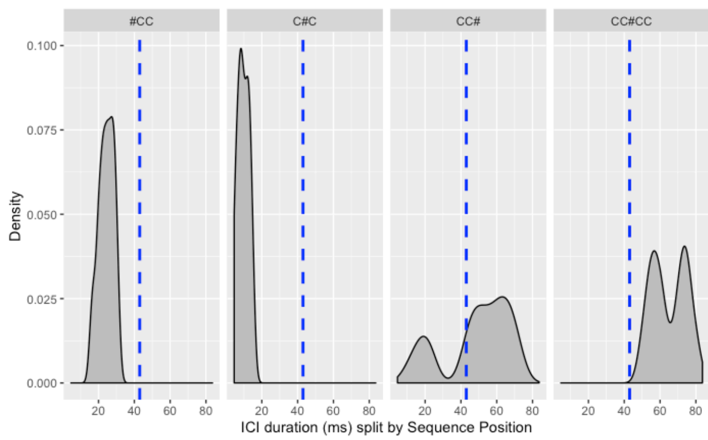
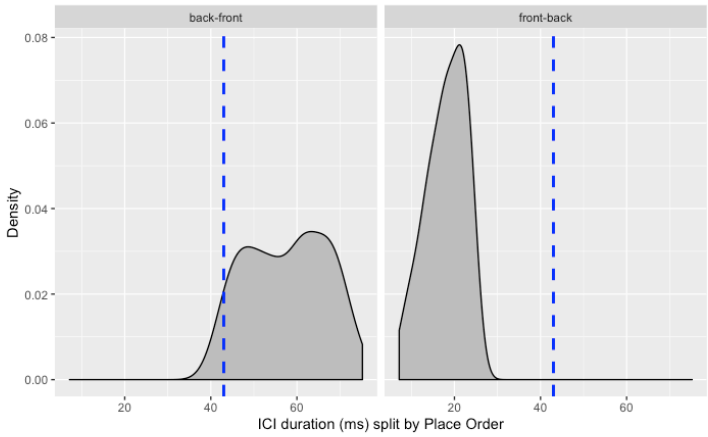


Figure 8.9 The distribution of ICI_durations in word-final position, split by place order



To test the role of the place order in each word position, four new subsets were created: one that included only #CC position, another included C#C, another included CC# and another included CC#CC position. The results reveal that the effect of place order on ICI duration is statistically significant only in CC# position as in Tables 8.33, 8.34, 8.35 and 8.36.

The above results provide evidence that there are two types of vowel insertion occurring in Najdi Arabic, based on ICI duration, supporting Hypothesis (f).

Table 8.33 The optimal model of ICI_duration in stop/alveolar fricative sequences (in #CC position, n=153)

```
Formula: icilog ~ rate + (1 | speaker)
   Data: Cs_Initial
Fixed effects:
              Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 1.298e+00  5.776e-03 6.790e+01  224.80   <2e-16***
rateNormal  1.322e-01  7.237e-03 1.400e+02   18.27   <2e-16***
```

Table 8.34 The optimal model of ICI_duration in stop/alveolar fricative sequences (in C#C position, n=24)

```
Formula: icilog ~ rate + (1 | speaker)
   Data: Cs_2b
Fixed effects:
             Estimate Std.Error       df tvalue Pr(>|t|)
(Intercept)  0.76631    0.04249 22.00000  18.037 1.14e-14***
rateNormal   0.26068    0.04906 22.00000   5.314 2.47e-05***
```

Table 8.35 The optimal model of ICI_duration in stop/alveolar fricative sequences (in CC# position, n=244)

```
Formula: icilog ~ rate + placeorder + (1 | speaker)
   Data: Cs_Final
Fixed effects:
                      Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)           1.682039   0.004978 241.000000  337.92   <2e-16***
rateNormal            0.143459   0.006593 241.000000   21.76   <2e-16***
placeorderfront-back -0.542053   0.007850 241.000000  -69.05   <2e-16***
```

Table 8.36 The optimal model of ICI_duration in stop/alveolar fricative sequences (in CC#CC position, n=384)

```
Formula: icilog ~ rate + (1 | speaker)
   Data: Cs_4b
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 1.751e+00  2.061e-03 3.820e+02  849.22   <2e-16***
rateNormal  1.161e-01  2.915e-03 3.820e+02   39.84   <2e-16***
```

8.3.2.2 ICI voicing proportion

As in Figure 8.10, there is bimodality in the distribution of ICI voicing proportion; there are two main peaks: the voicing proportion of a portion of the ICIs is below 0.78 and that of the other portion is above 0.78. The distribution of ICI voicing proportion is significantly different from normal (Shapiro-Wilk: W=0.85782,p-value<0.001). Figure 8.11 shows the ICI voicing proportion distribution split by the word position. It can be seen that the ICI voicing proportion is above 0.80 in CC#CC sequences, where epenthetic vowels are expected to occur. The ICI voicing proportion in #CC and C#C sequences, where intrusive vowels are expected to occur, is below 0.80 in both #CC and C#C sequences. On the other hand, in CC# sequences, where epenthetic vowels are expected to occur, there are clearly two main peaks: the highest is above 0.70 and the other one is below 0.70. This is because both intrusive and epenthetic vowels are expected to occur in this word position (i.e. word-final position), according to the sonority sequencing. Intrusive vowels are expected to occur in CC# sequences that obey the sonority sequencing principle (SSP), whereas epenthetic vowels are expected to occur in CC# sequences that violate the SSP. As shown earlier in Section 8.3.2.1, the sequences that obey the SSP in word set C are in a front-back place order, while all sequences that violate the SSP are in back-front place order. Figure 8.12 shows the distribution of ICI voicing proportion split by the order of place of articulation (front-back and back-front) in CC# word position. It can be seen that ICI voicing proportion in a back-front place order are above 0.80, whereas ICI voicing proportion in a front-back place order are below 0.70. The distribution of ICI voicing proportion in CC# word position is significantly different from normal (Shapiro-Wilk: W=0.78649,p-value<0.001).

Figure 8.10 The distribution of ICI_voicing_proportion across word position

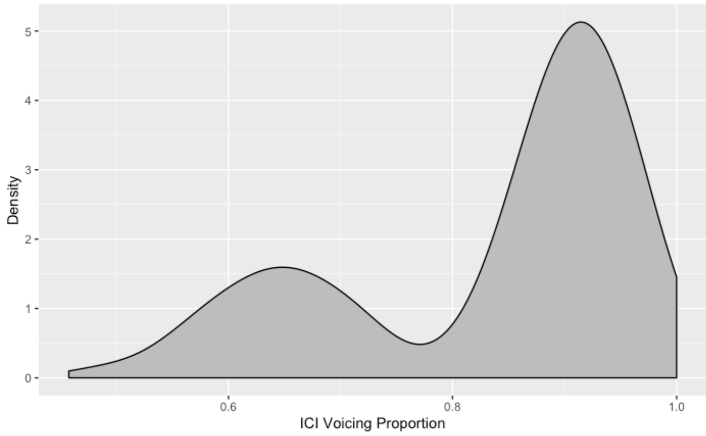


Figure 8.11 The distribution of ICI_voicing_proportion in various word positions

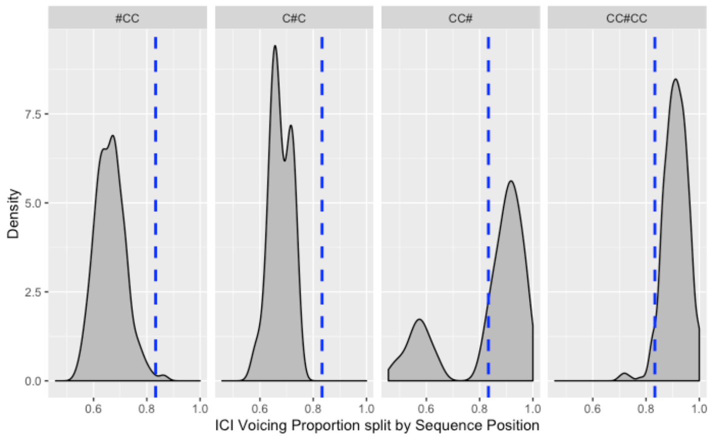
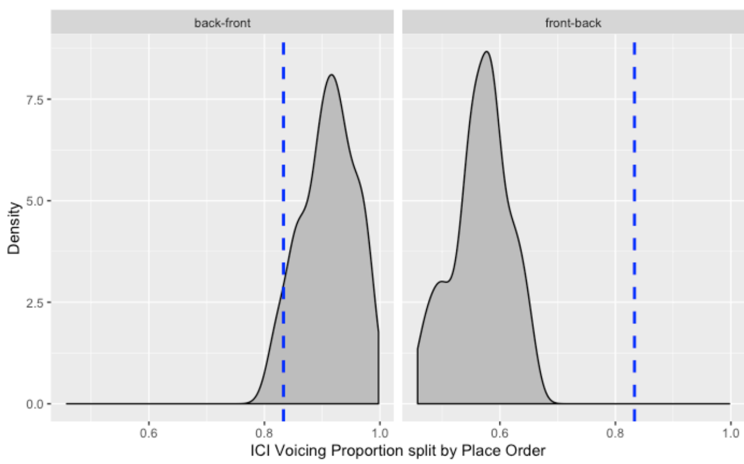


Figure 8.12 The distribution of ICI_voicing_proportion in word-final position, split by place order



To test the role of the place order in each word position, four new subsets were created: one that included only #CC position, another included C#C, another included CC# and another included CC#CC position. The results reveal that the effect of place order on ICI voicing proportion is statistically significant only in CC# position as in Tables 8.37 [63].

The above results provide evidence that there are two types of vowel insertion occurring in Najdi Arabic, based on ICI voicing proportion, supporting Hypothesis (f).

Table 8.37 The optimal model of ICI_voicing_proportion in stop/alveolar fricative sequences (in CC# position, n=244)

```
Formula: ici_voicing ~ placeorder + (1 | speaker)
   Data: Cs_Final
Fixed effects:
                      Estimate Std.Error          df tvalue Pr(>|t|)
(Intercept)           0.910497  0.003405 242.000000  267.4   <2e-16***
placeorderfront-back -0.343522  0.007171 242.000000  -47.9   <2e-16***
```

Having established that the two types of vowel insertion (intrusive and epenthetic vowels) occur in Najdi Arabic, now we turn to find out whether emphasis impact is observed in intrusive vowels, epenthetic vowels or in both.

8.4 The results of the types of vowel insertion and emphasis (Hypothesis (g))

As explained in Chapter 5, word set C included labial/lingual sequences, and this helps to test the impact of the less open glottis of the emphatic coronals /tˤ/ and /sˤ/ on gestural overlap in various word positions. The impact of the secondary articulation of emphatic coronals was examined in word set A as reported in Chapter 6. Therefore, emphasis impact in this section refers to the impact of the less open glottis of emphatic coronals.

[63] None of the independent variables was significant for ICI voicing proportion in #CC, C#C and in CC#CC positions.

8.4.1 Stop/stop sequences

Table 8.38 Summary of Emphasis impact on ICI_duration in stop/stop sequences in various word positions. (√) indicates that there is an emphasis impact, while (X) indicates that there no impact

Front-back place order		**Back-front place order**	
/bt/ vs /btˤ/	**Emphasis impact**	**/tb/ vs /tˤb/**	**Emphasis impact**
C#C	√ [64]	C#C	√ [65]
#CC	√ [66]	#CC	√ [67]
CC#	√ [68]	CC#	X [69]
CC#CC	X [70]	CC#CC	X [71]

Table 8.39 Summary of Emphasis impact on ICI_voicing_proportion in stop/stop sequences in various word positions. (√) indicates that there is an emphasis impact, while (X) indicates that there no impact

Front-back place order		**Back-front place order**	
/bt/ vs /btˤ/	**Emphasis impact**	**/tb/ vs /tˤb/**	**Emphasis impact**
C#C	√ [72]	C#C	√ [73]
#CC	√ [74]	#CC	√ [75]
CC#	√ [76]	CC#	X [77]
CC#CC	X [78]	CC#CC	X [79]

A summary of the impact of emphasis (i.e., the impact of the less open glottis of the emphatic coronal /tˤ/) on gestural overlap is provided in Tables 8.38 (for ICI duration) and 8.39 (for ICI voicing proportion). As in Tables 8.38 and 8.39, emphasis impact is observed in ICIs that exhibit the characteristics of intrusive vowels, occurring in C#C, #CC and in CC# front-back

[64] Based on the results presented in Chapter 6 (Section 6.2.4.1).
[65] Based on the results presented in Chapter 6 (Section 6.2.4.2).
[66] Based on the results presented in Chapter 7 (Section 7.2.3.1.2).
[67] Based on the results presented in Chapter 7 (Section 7.2.3.3.2).
[68] Based on the results presented in Chapter 7 (Section 7.2.3.2.2).
[69] Based on the results presented in Chapter 7 (Section 7.2.3.4.2).
[70] Based on the results presented in Chapter 8 (Section 8.2.1.3).
[71] Based on the results presented in Chapter 8 (Section 8.2.1.4).
[72] Based on the results presented in Chapter 6 (Section 6.2.4.1).
[73] Based on the results presented in Chapter 6 (Section 6.2.4.2).
[74] Based on the results presented in Chapter 7 (Section 7.2.3.1.2).
[75] Based on the results presented in Chapter 7 (Section 7.2.3.3.2).
[76] Based on the results presented in Chapter 7 (Section 7.2.3.2.2).
[77] Based on the results presented in Chapter 7 (Section 7.2.3.4.2).
[78] Based on the results presented in Chapter 8 (Section 8.2.1.3).
[79] Based on the results presented in Chapter 8 (Section 8.2.1.4).

sequencing in Najdi Arabic, supporting Hypothesis (g). In back-front place order, emphasis impact is observed in ICIs that exhibit the characteristics of intrusive vowels, occurring in C#C and #CC in back-front place order,but not in CC#CC or in CC# word positions in back-front place order, in which epenthetic vowels occurred, in Najdi Arabic, supporting Hypothesis (g). In conclusion, the results provide evidence that emphasis impact is observed in intrusive vowels but not in epenthetic vowels, supporting Hypothesis (g) for front-back stop/stop sequences in Najdi Arabic.

8.4.2 Stop/alveolar fricative sequences

Table 8.40 Summary of Emphasis impact on ICI_duration in stop/alveolar fricative sequences in various word positions. (√) indicates that there is an emphasis impact, while (X) indicates that there no impact

Front-back place order		**Back-front place order**	
/bs/ vs /bsˤ/	**Emphasis impact**	**/sb/ vs /sˤb/**	**Emphasis impact**
C#C	X [80]	C#C	NA [81]
#CC	X [82]	#CC	NA [83]
CC#	X [84]	CC#	X [85]
CC#CC	X [86]	CC#CC	X [87]

[80] Based on the results presented in Chapter 6 (Section 6.3.4.1).
[81] Based on the results presented in Chapter 6 (Section 6.3.4.2).
[82] Based on the results presented in Chapter 7 (Section 7.3.3.1.2).
[83] Based on the results presented in Chapter 7 (Section 7.3.3.3.2).
[84] Based on the results presented in Chapter 7 (Section 7.3.3.2.2).
[85] Based on the results presented in Chapter 7 (Section 7.3.3.4.2).
[86] Based on the results presented in Chapter 8 (Section 8.2.2.3).
[87] Based on the results presented in Chapter 8 (Section 8.2.2.4).

Table 8.41 Summary of Emphasis impact on ICI_voicing_proportion in stop/alveolar fricative sequences in various word positions. (√) indicates that there is an emphasis impact, while (X) indicates that there no impact

Front-back place order		**Back-front place order**	
/bs/ vs /bsˤ/	**Emphasis impact**	**/sb/ vs /sˤb/**	**Emphasis impact**
C#C	X [88]	C#C	NA [89]
#CC	X [90]	#CC	NA [91]
CC#	X [92]	CC#	X [93]
CC#CC	X [94]	CC#CC	X [95]

A summary of the impact of emphasis (i.e., the impact of the state of the glottis of the emphatic coronal /sˤ/) on gestural overlap is provided in Tables 8.40 (for ICI duration) and 8.41 (for ICI voicing proportion). As in Tables 8.40 and 8.41, no significant differences were found between an emphatic context and the plain counterpart in stop/alveolar sequences in all word positions. This indicates that the state of the glottis is the same in both /sˤ/ and /s/ as pointed out in Chapters 6 and 7, and accordingly no differences were found between sequences including /sˤ/ and sequences including /s/ in the degree of gestural overlap in all word positions, as summarized in Tables 8.40 and 8.41. Therefore, emphasis impact (i.e., the impact of the state of the glottis of emphatic coronals) is not operative in stop/alveolar fricative sequences, unlike in stop/stop sequences as reported in Chapters 6, 7 and earlier in this chapter. Accordingly, only the findings for stop/stop sequences are considered to test Hypothesis (g).

To conclude, Hypothesis (g) is supported based on the findings in stop/stop sequences as reported in Section 8.4.1. Now we turn to present the results of Hypothesis (h).

8.5 The results of the word position and gestural overlap (Hypothesis (h))

Linear mixed-effects models were run to test Hypothesis (h) with word position and its interaction with other independent variables as the crucial fixed factor(s). The independent

[88] Based on the results presented in Chapter 6 (Section 6.3.4.1).
[89] Based on the results presented in Chapter 6 (Section 6.3.4.2).
[90] Based on the results presented in Chapter 7 (Section 7.3.3.1.2).
[91] Based on the results presented in Chapter 7 (Section 7.3.3.3.2)
[92] Based on the results presented in Chapter 7 (Section 7.3.3.2.2).
[93] Based on the results presented in Chapter 7 (Section 7.3.3.4.2).
[94] Based on the results presented in Chapter 8 (Section 8.2.2.3).
[95] Based on the results presented in Chapter 8 (Section 8.2.2.4).

variables that were included in these models are word position (#CC, C#C, CC# and CC#CC), speech rate, gender and Context (plain, emphatic). The ICI count, ICI and sequence durations were compared between various word positions in labial/lingual sequences. The results of each sequence type (stop/stop or stop/alveolar fricative sequences) will be presented separately; and for each sequence type, the results of sequences in front-back place order will be presented first, followed by those in back-front order.

8.5.1 Stop/stop sequences

Table 8.42 ICI count in front-back place order. Yes (count and percentage of occurring ICIs), Not (count and percentage of non-occurring ICIs)

Consonant Sequence	Total *n*	Not		Yes	
		n	Percentage	*n*	Percentage
#CC	192	73	38.02	119	61.98
C#C	192	170	88.54	22	11.46
CC#	192	104	54.17	88	45.83
CC#CC	192	0	0.00	192	100.00
Total	768	347	45.18	421	54.82

Table 8.43 Acoustic measurements for stop/stop sequences in front-back place order (mean_values)

Sequence Position	ICI_duration	Sequence_duration
#CC	29.67	155.89
C#C	14.86	122.18
CC#	19.98	131.28
CC#CC	63.83	175.03

As in Table 8.42, the ICI occurs less often in C#C, followed by CC#, followed by #CC and then by CC#CC in stop/stop sequences in front-back place order. This indicates that greater degree of gestural overlap is exhibited in C#C, followed by CC#, followed by #CC and then by CC#CC word position. The acoustic measurements are presented in Table 8.43.

In front-back place order, ICI is significantly longer in #CC than in C#C and in CC#, but significantly shorter in #CC than in CC#CC sequences as in the optimal model in Table 8.46. The results also reveal that there is a significant interaction between word position and Context in ICI duration as in the optimal model in Table 8.46, and as in Figure 8.13. The results of further models[96] show that emphasis impact (the impact of the less open glottis of the emphatic coronal on gestural overlap) is observed in C#C, #CC and CC# word positions but not in CC#CC as in Tables 8.47, 8.48, 8.49 and 8.50. Likewise, sequence duration is significantly longer in #CC than in C#C and in CC#, but significantly shorter in #CC than in CC#CC sequences as in the optimal model in Table 8.51. The results also reveal that there is a significant interaction between word position and Context in sequence duration as in Table 8.51 and in Figure 8.14. The results of further models[97] show that emphasis impact is observed in C#C, #CC and CC# word positions but not in CC#CC as in Tables 8.52, 8.53, 8.54 and 8.55.

Figure 8.13 ICI_duration in stop/stop sequences in both contexts, split by word position

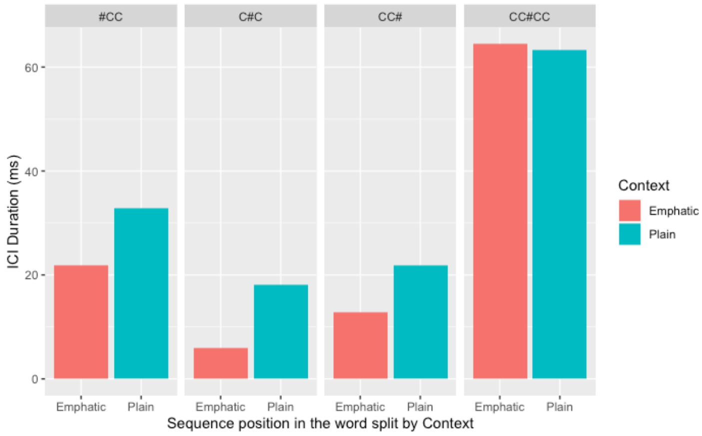
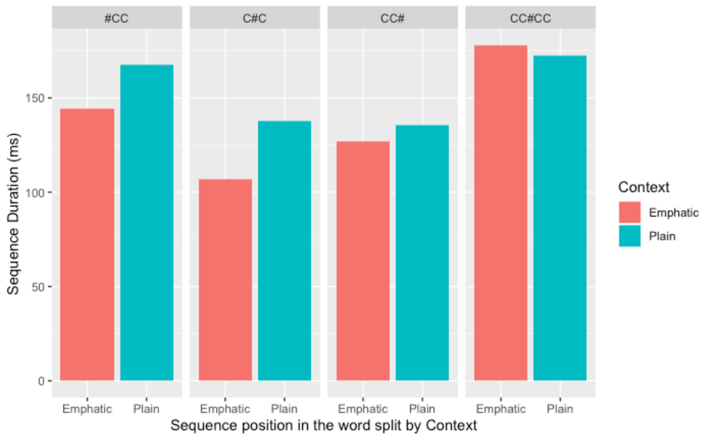


Figure 8.14 Sequence_duration in stop/stop sequences in both contexts, split by word position



[96] A new subset was created that included only #CC sequences, another that included only C#C sequences, another that included only CC# sequences, and another that included only CC#CC sequences. Then, further models were run to find out which word position shows a significance of Context effect, or to find out which word position exhibits a greater effect.

[97] A new subset was created that included only #CC sequences, another that included only C#C sequences, another that included only CC# sequences, and another that included only CC#CC sequences. Then, further models were run.

Table 8.44 ICI count in back-front place order

Consonant Sequence	Total *n*	Not		Yes	
		n	**Percentage**	***n***	**Percentage**
#CC	192	13	6.77	179	93.23
C#C	192	123	64.06	69	35.94
CC#	192	2	1.04	190	98.96
CC#CC	192	0	0.00	192	100.00
Total	768	138	17.97	630	82.03

Table 8.45 Acoustic measurements for stop/stop sequences in back-front place order (mean_values)

Sequence Position	ICI_duration	Sequence_duration
#CC	32.36	154.23
C#C	11.89	118.39
CC#	63.79	176.07
CC#CC	61.33	176.82

In stop/stop sequences in back-front place order, the ICI occurs less often in C#C word position, followed by #CC, CC# and CC#CC as in Table 8.44. This indicates that greater degree of gestural overlap is exhibited in C#C than in other word positions in back-front order. The acoustic measurements are presented in Table 8.45.

In back-front place order, ICI is significantly longer in #CC than in C#C, but significantly shorter in #CC than in CC# and in CC#CC sequences as in the optimal model in Table 8.56. The results also reveal that there is a significant interaction between word position and Context in ICI duration as in the optimal model in Table 8.56, and as in Figure 8.15. The results of further models[98] show that emphasis impact is observed only in C#C and in #CC but not in CC# or in CC#CC as in Tables 8.57, 8.58, 8.59 and 8.60. Sequence duration is significantly longer in #CC than in C#C, but significantly shorter in #CC than in CC# and in CC#CC sequences as in the optimal model in Table 8.61. The results also reveal that there is a significant interaction between word position and Context in sequence duration as in the optimal model in Table

[98] A new subset was created that included only #CC sequences, another that included only C#C sequences, another that included only CC# sequences, and another that included only CC#CC sequences. Then, further models were run for each.

8.61. The results of further models[99] show that emphasis impact is observed only in C#C but not in #CC, in CC# or in CC#CC as in Figure 8.16 and Tables 8.62, 8.63, 8.64 and 8.65.

Figure 8.15 ICI_duration in stop/stop sequences in both contexts, split by word position

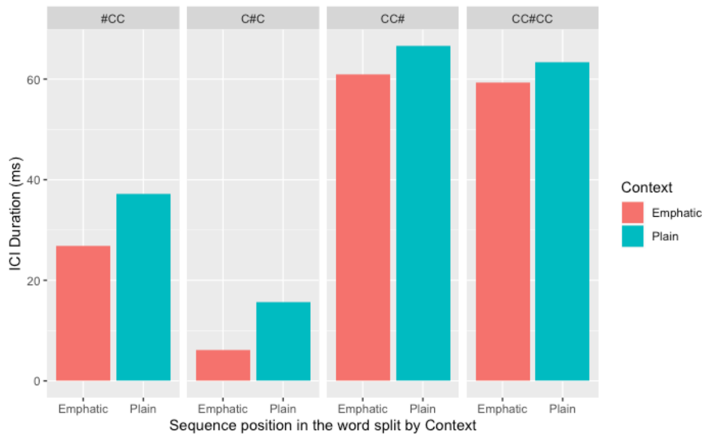
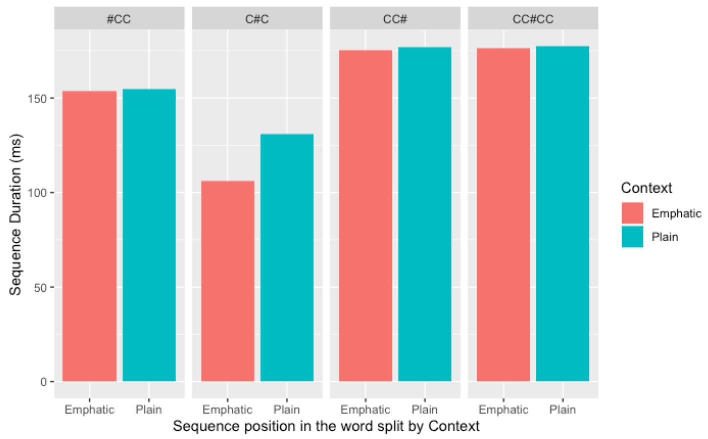


Figure 8.16 Sequence_duration in stop/stop sequences in both contexts, split by word position



To conclude, word-initial sequences exhibit lower degree of gestural overlap than elsewhere, excluding CC# (in back-front place order) and CC#CC sequences. Thus, Hypothesis (h) is supported in stop/stop sequences if we exclude word positions, in which epenthetic vowels occurred (i.e., CC#CC in both place orders; and CC# in back-front place order).

[99] A new subset was created that included only #CC sequences, another that included only C#C sequences, another that included only CC# sequences, and another that included only CC#CC sequences. Then, further models were run for each.

Table 8.46 The optimal model of ICI_duration in stop/stop sequences in front-back place order (with #CC position as the reference, n=421)

Formula: icilog ~ rate + Context + sequence + Context:sequence + (1 | speaker)
Data: Ct_FB
Fixed effects:

	Estimate	Std.Error	df	tvalue	Pr(>|t|)
(Intercept)	1.262716	0.010887	411.722155	115.989	<2e-16***
rateNormal	0.110395	0.006043	411.866422	18.269	<2e-16***
ContextPlain	0.184459	0.012148	411.907361	15.184	<2e-16***
sequenceC#C	-0.636746	0.026764	411.982496	-23.791	<2e-16***
sequenceCC#	-0.243642	0.017508	411.922777	-13.916	<2e-16***
sequenceCC#CC	0.487441	0.011943	411.906507	40.813	<2e-16***
ContextPlain:sequenceC#C	0.344914	0.031352	411.970544	11.001	<2e-16***
ContextPlain:sequenceCC#	0.057068	0.020047	411.911296	2.847	0.00464**
ContextPlain:sequenceCC#CC	-0.192762	0.014949	411.886944	-12.895	<2e-16***

FURTHER:

Table 8.47 The optimal model of ICI_duration in stop/stop sequences in front-back place order (in #CC position, n=119)

Formula: icilog ~ rate + Context + (1 | speaker)
Data: Ct_FB_ini
Fixed effects:

	Estimate	Std.Error	df	tvalue	Pr(>|t|)
(Intercept)	1.26064	0.01239	116.00000	101.74	<2e-16***
rateNormal	0.11370	0.01123	116.00000	10.12	<2e-16***
ContextPlain	0.18465	0.01214	116.00000	15.22	<2e-16***

Table 8.48 The optimal model of ICI_duration in stop/stop sequences in front-back place order (in C#C position, n=22)

Formula: icilog ~ rate + Context + (1 | speaker)
Data: Ct_FB_2b
Fixed effects:

	Estimate	Std.Error	df	tvalue	Pr(>|t|)
(Intercept)	0.61018	0.09945	15.98335	6.135	1.44e-05***
rateNormal	0.12505	0.08304	14.53457	1.506	0.154
ContextPlain	0.53678	0.06302	14.05514	8.518	6.36e-07***

Table 8.49 The optimal model of ICI_duration in stop/stop sequences in front-back place order (in CC# position, n=88)

Formula: icilog ~ rate + Context + Context:gender + (1 | speaker)
Data: Ct_FB_fin
Fixed effects:

	Estimate	Std.Error	df	tvalue	Pr(>|t|)
(Intercept)	1.07135	0.02028	83.00000	52.833	<2e-16***
rateNormal	0.13113	0.01227	83.00000	10.686	<2e-16***
ContextPlain	0.12321	0.02101	83.00000	5.865	8.87e-08***
ContextEmphatic:genderMale	-0.13221	0.02624	83.00000	-5.038	2.70e-06***
ContextPlain:genderMale	0.09819	0.01336	83.00000	7.351	1.26e-10***

Table 8.50 The optimal model of ICI_duration in stop/stop sequences in front-back place order (in CC#CC position, n=192)

Formula: icilog ~ rate + (1 | speaker)
Data: Ct_FB_4b
Fixed effects:

	Estimate	Std.Error	df	tvalue	Pr(>|t|)
(Intercept)	1.752e+00	3.052e-03	1.900e+02	573.93	<2e-16***
rateNormal	9.896e-02	4.316e-03	1.900e+02	22.93	<2e-16***

Table 8.51 The optimal model of sequence_duration in stop/stop sequences in front-back place order (with #CC position as the reference, n=768)

Formula: wslog ~ rate + Context + sequence + Context:sequence + (1 | speaker)
Data: Ct_FB
Fixed effects:

	Estimate	Std.Error	df	tvalue	Pr(>|t|)
(Intercept)	2.072103	0.005325	759.000000	389.114	<2e-16***
rateNormal	0.155541	0.003550	759.000000	43.813	<2e-16***
ContextPlain	0.056999	0.007100	759.000000	8.028	3.77e-15***
sequenceC#C	-0.127988	0.007100	759.000000	-18.026	<2e-16***
sequenceCC#	-0.051912	0.007100	759.000000	-7.311	6.73e-13***
sequenceCC#CC	0.089599	0.007100	759.000000	12.619	<2e-16***
ContextPlain:sequenceC#C	0.053656	0.010041	759.000000	5.344	1.21e-07***
ContextPlain:sequenceCC#	-0.029031	0.010041	759.000000	-2.891	0.00395**
ContextPlain:sequenceCC#CC	-0.070753	0.010041	759.000000	-7.046	4.13e-12***

FURTHER:

Table 8.52 The optimal model of sequence_duration in stop/stop sequences in front-back place order (in #CC position, n =192)

Formula: wslog ~ rate + Context + (1 | speaker)
Data: Ct_FB_ini
Fixed effects:

	Estimate	Std.Error	df	tvalue	Pr(>|t|)
(Intercept)	2.060e+00	9.439e-03	1.890e+02	218.19	<2e-16***
rateNormal	1.807e-01	1.090e-02	1.890e+02	16.58	<2e-16***
ContextPlain	5.700e-02	1.090e-02	1.890e+02	5.23	4.48e-07***

Table 8.53 The optimal model of sequence_duration in stop/stop sequences in front-back place order (in C#C position, n=192)

Formula: wslog ~ rate + Context + (1 | speaker)
Data: Ct_FB_2b
Fixed effects:

	Estimate	Std.Error	df	tvalue	Pr(>|t|)
(Intercept)	1.959e+00	4.879e-03	1.890e+02	401.50	<2e-16***
rateNormal	1.260e-01	5.634e-03	1.890e+02	22.36	<2e-16***
ContextPlain	1.107e-01	5.634e-03	1.890e+02	19.64	<2e-16***

Table 8.54 The optimal model of sequence_duration in stop/stop sequences in front-back place order (in CC# position, n=192)

```
Formula: wslog ~ rate + Context + (1 | speaker)
   Data: Ct_FB_fin
Fixed effects:
              Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)  2.034e+00  4.454e-03 1.890e+02 456.688  <2e-16***
rateNormal   1.277e-01  5.143e-03 1.890e+02  24.829  <2e-16***
ContextPlain 2.797e-02  5.143e-03 1.890e+02   5.438 1.65e-07***
```

Table 8.55 The optimal model of sequence_duration in stop/stop sequences in front-back place order (in CC#CC position, n=192)

```
Formula: wslog ~ rate + (1 | speaker)
   Data: Ct_FB_4b
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 2.139e+00  2.103e-03 1.900e+02 1017.19   <2e-16***
rateNormal  1.878e-01  2.973e-03 1.900e+02   63.16   <2e-16***
```

BF Models

Table 8.56 The optimal model of ICI_duration in stop/stop sequences in back-front place order (with #CC position as the reference, n=630)

```
Formula: icilog ~ rate + Context + sequence + Context:sequence + (1 | speaker)
   Data: Ct_BF
Fixed effects:
                            Estimate Std.Error         df tvalue Pr(>|t|)
(Intercept)                 1.347513   0.007479 621.000000 180.176   <2e-16***
rateNormal                  0.117819   0.005041 621.000000  23.374   <2e-16***
ContextPlain                0.153535   0.009413 621.000000  16.311   <2e-16***
sequenceC#C                -0.668592   0.013730 621.000000 -48.695   <2e-16***
sequenceCC#                 0.372384   0.009457 621.000000  39.376   <2e-16***
sequenceCC#CC               0.361191   0.009413 621.000000  38.372   <2e-16***
ContextPlain:sequenceC#C    0.276133   0.018030 621.000000  15.315   <2e-16***
ContextPlain:sequenceCC#   -0.113002   0.013094 621.000000  -8.630   <2e-16***
ContextPlain:sequenceCC#CC -0.122570   0.013062 621.000000  -9.383   <2e-16***
```

FURTHER:

Table 8.57 The optimal model of ICI_duration in stop/stop sequences in back-front place order (in #CC position, n=179)

```
Formula: icilog ~ rate + Context + (1 | speaker)
   Data: Ct_BF_ini
Fixed effects:
              Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)    1.34904   0.01175 176.00000 114.847   <2e-16***
rateNormal     0.11517   0.01261 176.00000   9.132   <2e-16***
ContextPlain   0.15333   0.01261 176.00000  12.157   <2e-16***
```

Table 8.58 The optimal model of ICI_duration in stop/stop sequences in back-front place order (in C#C position, n=69)

```
Formula: icilog ~ rate + Context + (1 | speaker)
   Data: Ct_BF_2b
Fixed effects:
             Estimate Std.Error       df tvalue Pr(>|t|)
(Intercept)   0.63810   0.02984 66.00000  21.38  <2e-16***
rateNormal    0.17497   0.02907 66.00000   6.02 8.57e-08***
ContextPlain  0.43425   0.02790 66.00000  15.56  <2e-16***
```

Table 8.59 The optimal model of ICI_duration in stop/stop sequences in back-front place order (in CC# position, n=190)

```
Formula: icilog ~ rate + (1 | speaker)
   Data: Ct_BF_fin
Fixed effects:
                         Estimate Std.Error         df tvalue Pr(>|t|)
(Intercept)              1.719740  0.004486 188.000000 383.383  <2e-16***
rateNormal               0.118127  0.006277 188.000000  18.818  <2e-16***
```

Table 8.60 The optimal model of ICI_duration in stop/stop sequences in back-front place order (in CC#CC position, n=192)

```
Formula: icilog ~ rate + (1 | speaker)
   Data: Ct_BF_4b
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 1.727e+00  3.055e-03 1.900e+02  565.37   <2e-16***
rateNormal  1.118e-01  4.320e-03 1.900e+02   25.87   <2e-16***
```

Table 8.61 The optimal model of sequence_duration in stop/stop sequences in back-front place order (with #CC position as the reference, n=768)

```
Formula: wslog ~ rate + Context + sequence + Context:sequence + (1 | speaker)
   Data: Ct_BF
Fixed effects:
                          Estimate Std.Error         df tvalue Pr(>|t|)
(Intercept)               2.089208  0.003283 759.000000 636.308   <2e-16***
rateNormal                0.176586  0.002189 759.000000  80.674   <2e-16***
ContextPlain              0.001709  0.004378 759.000000   0.390    0.696
sequenceC#C              -0.165152  0.004378 759.000000 -37.725   <2e-16***
sequenceCC#               0.055685  0.004378 759.000000  12.720   <2e-16***
sequenceCC#CC             0.058001  0.004378 759.000000  13.249   <2e-16***
ContextPlain:sequenceC#C  0.096268  0.006191 759.000000  15.549   <2e-16***
ContextPlain:sequenceCC#  0.004116  0.006191 759.000000   0.665    0.506
ContextPlain:sequenceCC#CC 0.001204 0.006191 759.000000   0.194    0.846
```

<u>FURTHER:</u>

Table 8.62 The optimal model of sequence_duration in stop/stop sequences in back-front place order (in #CC position, n=192)

```
Formula: wslog ~ rate + gender + (1 | speaker)
   Data: Ct_BF_ini
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 2.085e+00  3.526e-03 1.890e+02 591.300   <2e-16***
rateNormal  1.773e-01  4.071e-03 1.890e+02  43.558   <2e-16***
genderMale  9.965e-03  4.071e-03 1.890e+02   2.448   0.0153*
```

Table 8.63 The optimal model of sequence_duration in stop/stop sequences in back-front place order (in C#C position, n=192)

```
Formula: wslog ~ rate + Context + (1 | speaker)
   Data: Ct_BF_2b
Fixed effects:
              Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)  1.932e+00  5.669e-03 9.820e+01  340.77   <2e-16***
rateNormal   1.611e-01  6.517e-03 1.740e+02   24.72   <2e-16***
ContextPlain 9.798e-02  6.517e-03 1.740e+02   15.03   <2e-16***
```

Table 8.64 The optimal model of sequence_duration in stop/stop sequences in back-front place order (in CC# position, n=192)

```
Formula: wslog ~ rate + (1 | speaker)
   Data: Ct_BF_fin
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 2.147e+00  2.306e-03 4.394e+01  930.93   <2e-16***
rateNormal  1.785e-01  3.022e-03 1.750e+02   59.06   <2e-16***
```

Table 8.65 The optimal model of sequence_duration in stop/stop sequences in back-front place order (in CC#CC position, n=192)

```
Formula: wslog ~ rate + (1 | speaker)
   Data: Ct_BF_4b
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 2.142e+00  1.760e-03 5.082e+01  1217.3   <2e-16***
rateNormal  1.894e-01  2.425e-03 1.750e+02    78.1   <2e-16***
```

8.5.2 Stop/alveolar fricative sequences

Table 8.66 Acoustic measurements for stop/alveolar fricative sequences in front-back place order (mean_ values)

Sequence Position	ICI_duration	Sequence_duration
#CC	24.29	185.43
C#C	9.69	127.83
CC#	18.01	158.24
CC#CC	67.30	223.14

Table 8.67 ICI count in front-back place order. Yes (count and percentage of occurring ICIs), Not (count and percentage of non-occurring ICIs)

Consonant Sequence	Total *n*	Not		Yes	
		n	Percentage	*n*	Percentage
#CC	192	39	20.31	153	79.69
C#C	192	168	87.50	24	12.50
CC#	192	137	71.35	55	28.65
CC#CC	192	0	0.00	192	100.00
Total	768	344	44.79	424	55.21

As in Table 8.66, the ICI occurs less often in C#C, followed by CC#, followed by #CC and then by CC#CC in stop/stop sequences in front-back place order. This indicates that greater degree of gestural overlap is exhibited in C#C, followed by CC#, followed by #CC and then by CC#CC word position. The acoustic measurements are presented in Table 8.67.

In front-back place order, ICI is significantly longer in #CC than in C#C and in CC#, but significantly shorter in #CC than in CC#CC sequences as in the optimal model in Table 8.70. Likewise, sequence duration is significantly longer in #CC than in C#C and in CC#, but significantly shorter in #CC than in CC#CC sequences as in the optimal model in Table 8.71.

Table 8.68 ICI count in back-front place order

Consonant Sequence	**Total *n***	**Not**		**Yes**	
		n	**Percentage**	***n***	**Percentage**
#CC	192	192	100.00	0	0.00
C#C	192	192	100.00	0	0.00
CC#	192	3	1.56	189	98.44
CC#CC	192	0	0.00	192	100.00
Total	768	387	50.39	381	49.61

Table 8.69 Acoustic measurements for stop/alveolar fricative sequences in back-front place order (mean_values)

Sequence Position	**ICI_duration**	**Sequence_duration**
#CC	NA	177.59
C#C	NA	126.60
CC#	57.63	232.99
CC#CC	62.83	229.63

On the other hand, ICIs do not occur in stop/alveolar fricative sequences in C#C or in #CC in back-front place order in Najdi Arabic; ICIs only occur in CC# and in CC#CC word positions (98% and 100% respectively) in back-front place order as in Table 8.68. The acoustic measurements are presented in Table 8.69. When running the model (with ICI duration as the dependent variable), it ignores C#C and #CC word positions since no ICIs occur in these two word positions. The model only considered CC# and CC#CC word positions, and it regards CC# as the reference level. Therefore, as in the optimal model in Table 8.72, the ICI is significantly shorter in CC# than in CC#CC sequences ($n=381, \beta=3.969e-02, SE=3.214e-03$, t-value$=12.35, p<0.001$). Accordingly, ICI duration is not a valid measure here; thus, sequence duration is considered as a measure to test Hypothesis (h) in stop/alveolar fricative sequences in back-front place order.

Regarding sequence duration, it is significantly longer in #CC than in C#C, but significantly shorter in #CC than in CC# and in CC#CC sequences as in the optimal model in Table 8.73.

To conclude, word-initial sequences exhibit lower degree of gestural overlap than elsewhere, excluding CC# (in back-front place order) and CC#CC sequences. Thus, Hypothesis (h) is supported in stop/alveolar fricative sequences if we exclude word positions, in which epenthetic vowels occurred (i.e., CC#CC in both place orders; and CC# in back-front place order). These findings, in addition to those reported for stop/stop sequences in Section 8.5.1, support the claim that intrusive vowels are variable in duration and can be influenced by surrounding consonants since they are the result of retiming between two existing consonantal gestures, unlike epenthetic vowels that are independent from surrounding consonants and they have a dedicated articulatory gesture.

FB Models:

Table 8.70 The optimal model of ICI_duration in stop/alveolar fricative sequences in front-back place order (with #CC position as the reference, n=424)

```
Formula: icilog ~ rate + sequence + (1 | speaker)
   Data: Cs_FB
Fixed effects:
               Estimate Std.Error         df tvalue Pr(>|t|)
(Intercept)    1.292538  0.005133 419.000000 251.81  <2e-16***
rateNormal     0.141857  0.005063 419.000000  28.02  <2e-16***
sequenceC#C   -0.437112  0.011179 419.000000 -39.10  <2e-16***
sequenceCC#   -0.151444  0.008000 419.000000 -18.93  <2e-16***
sequenceCC#CC  0.460037  0.005534 419.000000  83.13  <2e-16***
```

Table 8.71 The optimal model of sequence_duration in stop/alveolar fricative sequences in front-back place order (with #CC position as the reference, n=768)

```
Formula: wslog ~ rate + sequence + (1 | speaker)
   Data: Cs_FB
Fixed effects:
               Estimate Std.Error         df tvalue Pr(>|t|)
(Intercept)    2.185884  0.002387 196.493347 915.56  <2e-16***
rateNormal     0.149330  0.002060 747.999986  72.48  <2e-16***
sequenceC#C   -0.162238  0.002914 747.999986 -55.68  <2e-16***
sequenceCC#   -0.066297  0.002914 747.999986 -22.75  <2e-16***
sequenceCC#CC  0.079896  0.002914 747.999986  27.42  <2e-16***
```

BF Models:

Table 8.72 The optimal model of ICI_duration in stop/alveolar fricative sequences in back-front place order (with CC# position as the reference,n=381)

```
Formula: icilog ~ rate + sequence + (1 | speaker)
   Data: Cs_BF
Fixed effects:
               Estimate Std.Error      df tvalue Pr(>|t|)
(Intercept)   1.695e+00 2.805e-03 3.780e+02 604.01   <2e-16***
rateNormal    1.189e-01 3.214e-03 3.780e+02  36.98   <2e-16***
sequenceCC#CC 3.969e-02 3.214e-03 3.780e+02  12.35   <2e-16***
```

Table 8.73 The optimal model of sequence_duration in stop/alveolar fricative sequences in back-front place order (with #CC position as the reference, n=768)

```
Formula: wslog ~ rate + sequence + (1 | speaker)
   Data: Cs_BF
Fixed effects:
               Estimate Std.Error         df tvalue Pr(>|t|)
(Intercept)    2.171005  0.001954 763.000000 1110.91   <2e-16***
rateNormal     0.143980  0.001748 763.000000   82.37   <2e-16***
sequenceC#C   -0.146506  0.002472 763.000000  -59.27   <2e-16***
sequenceCC#    0.117930  0.002472 763.000000   47.71   <2e-16***
sequenceCC#CC  0.110451  0.002472 763.000000   44.68   <2e-16***
```

8.6 Interim discussion

This chapter presented the results concerning the types of vowel insertion and emphasis: Research Question 2 and the associated specific hypotheses (f), (g) and (h). The results of the common hypotheses (i) and (j), for two consonant sequences occurring at the word boundary in four consonant sequences (CC#CC), were presented too. The results of each sequence type (stop/stop or stop/alveolar fricative sequences) were presented separately for each hypothesis. The results of timing relations and common hypotheses for each sequence type were presented first, followed by the results of specific hypotheses for each sequence type.

Table 8.74 Summary of the impact of place order, by sequence type.(√) indicates that the impact is exhibited

	Stop/stop	**Stop/alveolar fricative**
CC#CC	X	X

Table 8.75 Summary of the impact of speech rate, by sequence type.(√) indicates that the impact is exhibited.

	Stop/stop		**Stop/alveolar fricative**	
	Front-back	**Back-front**	**Front-back**	**Back-front**
CC#CC	X	X	X	X

Table 8.76 Summary of the types of vowel insertion occurred in each word position, by place order

	Front-back	Back-front
C#C	Intrusive	Intrusive
#CC	Intrusive	Intrusive
CC#	Intrusive	Epenthetic
CC#CC	Epenthetic	Epenthetic

Table 8.77 Summary of the impact of emphasis (the impact of the state of the glottis of emphatic coronals), by sequence type, position and place order.(√) indicates that the impact is exhibited.

	Stop/stop		Stop/alveolar fricative	
	Front-back	**Back-front**	**Front-back**	**Back-front**
C#C	√	√	X	X
#CC	√	√	X	X
CC#	√	X	X	X
CC#CC	X	X	X	X

Table 8.78 Summary of the impact of the sequence position in the word, by place order and type of vowel insertion. These three positions are compared to #CC position. (√) indicates that the impact is exhibited

	Front-back	Type of vowel insertion	Back-front	Type of vowel insertion
C#C	√	Intrusive	√	Intrusive
CC#	√	Intrusive	X	Epenthetic
CC#CC	X	Epenthetic	X	Epenthetic

As in Tables 8.74 and 8.75, no significant differences were found between an emphatic context and the plain counterpart in the degree of gestural overlap in both sequence types in CC#CC word position. The impact of the place order and that of the speech rate were not exhibited in both sequence types, indicating that ***Hypotheses (i) and (j) are not supported in CC#CC*** position. These findings have been attributed to the type of vowel insertion. The ICIs in CC#CC exhibit the characteristics of epenthetic vowels, and therefore the place order effect and that of speech rate were not observed in these sequences.

Based on the results presented in Section 8.3, the types of vowel insertion occur in Najdi Arabic. As in Table, 8.76, intrusive vowels occur in #CC and C#C positions. Epenthetic vowels occur in CC#CC position. In CC# position, however, intrusive vowels occur in CC# sequences that obey the sonority sequencing (SSP), whereas epenthetic vowels occur in CC# sequences that violate the SSP. These findings support Hypothesis (f) for both sequence types. The question that aises here concerns the constrain that can determine the type of vowel insertion in CC# position: is it the SSP or the place order? As indicated earlier, CC# sequences that violate the SSP in word set C are /tb#/, /tˤb#/, /sb#/ and /sˤb#/, and they are all in back-front place order. The ICIs in those sequences exhibit the characteristics of epenthetic vowels (see Section 8.3). On the other hand, CC# sequences that obey the SSP in word set C are /bt#/, /btˤ#/, /bs#/ and /bsˤ#/, and they are all in front-back place order; the ICIs in those sequences exhibit the characteristics of intrusive vowels (see Section 8.3). As reported in Chapter 7, the ICI in /bz#/ sequence exhibits the characteristics of intrusive vowels although this sequence was expected to be broken up by an epenthetic vowel since it violates the SSP (see Section 4.7.2 in Chapter 4 for the SSP in Najdi Arabic); /bz#/ sequence is in front-back order. Likewise, the ICI in /zb#/ sequence exhibits the characteristics of epenthetic vowels although this sequence was not expected to be broken up by an epenthetic vowel since it obeys the SSP; /zb#/ sequence is in back-front order. Therefore, it appears that the place order is more influential than the SSP in determing the type of vowel insertion in CC# position. These observations will be discussed further in Chapter 9.

As in Table, 8.77, the impact of emphasis, particularly the impact of the less open glottis of the emphatic coronal /tˤ/, was observed in sequences where intrusive vowels occurred (i.e., CC# that obeys the SSP, #CC and in C#C). Emphasis impact was not observed in sequences where epenthetic vowels occurred (i.e., CC# that violates the SSP and in CC#CC). These findings ***support*** Hypothesis (g). This can attributed to the type of vowel insertion; intrusive vowels are variable in duration and voicing, and can be influenced by surrounding consonants, unlike epenthetic vowels that are independent from surrounding consonants in terms of duration and voicing. As made clear in Section 8.4.2, stop/alveolar fricative sequences (e.g., /bs/ ~ /bsˤ/) were not considered to test this hypothesis since there is no impact of emphasis (the role of the state of the glottis of emphatics) at all in these sequences in all word positions, as reported in Chapters 6 and 7 and also in Section 8.2.2.2 in this chapter.

Based on the results presented in Section 8.5, the pattern of gestural overlap and its interaction with word position varies as a function of the SSP. As in Table, 8.78, word-initial sequences were found to exhibit lower degree of gestural overlap than other word positions in sequences where intrusive vowels occurred (i.e., CC# that obeys the SSP, #CC and in C#C). However, word-initial sequences were ***not*** found to exhibit lower degree of gestural overlap than other positions where epenthetic vowels occurred (i.e., CC# that violates the SSP and in CC#CC). These findings are consistent for both sequence types, and these findings ***partially support*** Hypothesis (h). These findings have been attributed to the type of vowel insertion. These findings provide further evidence that intrusive vowels are variable in duration and they can be influenced by surrounding consonants since they are the result of retiming between two existing consonantal gestures, unlike epenthetic vowels that have their own gesture and are independent from the surrounding consonants (Hall, 2006). This hypothesis (h) is supported in sequences where intrusive vowels occur,but not in sequences where epenthetic vowels occur. All Hypotheses will be discussed further in Chapter 9.

Having presented the results of the current thesis in Chapters 6, 7 and 8, now we turn to discuss these findings and provide a conclusion of the thesis in Chapter 9.

9 Discussion and conclusion

9.1 Aims and goals of the thesis

This thesis acoustically investigates the impact of emphasis on the degree of gestural overlap in consonant sequences in Najdi Arabic. This thesis investigates the impact of two features of emphasis: the secondary articulation of the emphatic coronals /tˤ/, /sˤ/ and /ðˤ/, compared to the plain counterparts /t/, /s/ and /ð/, and the less open glottis involved during the production of the emphatic coronals /tˤ/ and /sˤ/, compared to the plain counterparts /t/ and /s/. A further aim of the thesis is to examine whether the two types of vowel insertion (intrusive and epenthetic vowels) occur in Najdi Arabic, and to examine whether emphasis impact is observed in intrusive vowels, epenthetic vowels or in both. To investigate these aims, various acoustic parameters were examined, including the hold phase (HP), frication, inter-consonantal interval (ICI) durations, Voice Onset Time (VOT), sequence durations and ICI voicing proportion. In addition to Context, the sequence position in the word (#CC, C#C, CC#, CC#CC), the order of place of articulation (front-back, back-front), the identity of the articulators (lingual/lingual, labial/lingual sequences), the speech rate (fast, normal) and gender (male, female) were all considered.

These aims are motivated based on the literature. It has been reported that the primary articulation can influence the degree of gestural overlap in consonant sequences. Lingual/lingual sequences (e.g., /gt/) have been reported to exhibit lower degree of gestural overlap than labial/lingual sequences (e.g., /bt/) cross-linguistically (e.g., Kühnert et al, 2006 for French; Alsubaie, 2014 for Najdi Arabic; Shitaw, 2014 for Tripolitanian Libyan Arabic; Zeroual et al, 2014 for Moroccan Arabic). This has been attributed to motor constraints. Both consonants in lingual/lingual sequences (such as /gt/) involve the tongue (tongue dorsum for /g/ and tongue tip for /t/), and therefore both tongue tip and tongue dorsum constrain the movement of each other since both are physiologically coupled. On the other hand, both consonants in labial/lingual sequences (such as /bt/) involve two independent articulators (lips for /b/ and tongue tip for /t/), and both do not constrain the movement of each other; each articulator can move freely to attain its target without the influence of the other. Accordingly, lingual/lingual sequences are reported to exhibit lower degree of gestural overlap than labial/lingual sequences. This thesis considered the emphatic coronals /tˤ/, /sˤ/ and /ðˤ/ which involve a secondary articulation involving the tongue back/root, in addition to the primary articulation involving the tongue tip, compared to the plain coronals /t/, /s/ and /ð/ which only involve the primary articulation (tongue tip). This secondary articulation adds more complexity (by adding a posterior movement of the tongue) to consonant sequences including an emphatic coronal, compared to sequences including the plain counterpart.

The second aim of the thesis (i.e., investigating the impact of the less open glottis of emphatic coronals on gestural overlap) is motivated by the findings in the literature concerning the impact of the state of the glottis on gestural overlap. It has been reported that voiced/voiced sequences exhibit greater degree of gestural overlap than voiced/voiceless sequences cross-linguistically (e.g., Bombian and Hoole, 2013; Pouplier, 2012 for German; Shitaw, 2013 for Tripolitanian Libyan Arabic; Alsubaie, 2014 for Najdi Arabic). This has been attributed to the state of the glottis. Both consonants in voiced/voiced sequences share the same state of the glottis, while the two consonants in voiced/voiceless sequences have different states of the glottis. Besides, it has been reported that the emphatic coronals /tˤ/ and /sˤ/ are produced with a less open glottis than the plain counterparts /t/ and /s/ (e.g., Watson and Heselwood, 2016 for San'ani Arabic; Heselwood et al, 2022 for Modern South Arabian Languages). Accordingly, it was examined whether this less open glottis would have an impact on gestural overlap in consonant sequences.

The third aim of the thesis (i.e., investigating the two types of vowel insertion and emphasis impact) is motivated by the findings in the literature concerning the two types of vowel insertion. It has been reported that the two types are observed in a number of languages including some Arabic varieties (e.g., Plug et al, 2019 for Tripolitanian Libyan Arabic; Al-Aqlobi, 2020 for Bisha Arabic and Makkah Arabic). Besides, it has been reported that intrusive vowels are the result of retiming between two existing consonantal gestures and they are influenced by surrounding consonants, unlike epenthetic vowels that have a dedicated articulatory gesture and they are independent from surrounding consonants in the sequence (Hall, 2006). In addition, it has been reported that emphasis can influence surrounding sounds (e.g., Almuhaimeed, 2021). Accordingly, it was investigated whether emphasis impact would be observed in intrusive vowels, epenthetic vowels or in both.

Having reiterated the main aims of the thesis, the remainder of this chapter will be devoted to the discussion of the findings of the current thesis, followed by a general conclusion. The discussion is divided according to the research questions and hypotheses. Accordingly, this chapter consists of six sections. Section 9.1 is an introductory section. Section 9.2 concerns the secondary articulation and gestural overlap. Section 9.3 concerns the state of the glottis and gestural overlap. Section 9.4 concerns the types of vowel insertion and emphasis. Section 9.5 concerns the common hypotheses that are relevant to the place order effect and that of speech rate on gestural overlap. In each section, the relevant results will be summarized, and it will be made clear whether the relevant hypotheses are supported or not with evidence from the thesis; then an answer to the relevant research question will be provided based on the findings of the thesis. The thesis ends with a general conclusion in Section 9.6 in which limitations and contributions of the thesis will be provided.

9.2 The secondary articulation of emphasis and gestural overlap

9.2.1 Summary of the results

The results in Chapter 6 concern Research Question 1**a** and the specific hypotheses (a) and (b), as restated below:

RQ1,a: Does the secondary articulation of emphatic coronals have an impact on the degree of gestural overlap in consonant sequences?

Hypothesis (a) lingual/lingual consonant sequences will exhibit a lower degree of gestural overlap than labial/lingual consonant sequences.

Hypothesis (b) lingual/lingual consonant sequences in an emphatic context will exhibit a lower degree of gestural overlap than lingual/lingual consonant sequences in the plain counterpart.

Table 9.1 Summary of the impact of the identity of articulators, by sequence type.(√) indicates that the impact is exhibited

	Stop/stop	Stop/alveolar fricative	Stop/dental fricative
The identity of articulators effect	√	√	√

Table 9.2 Summary of the impact of the secondary articulation of emphasis, by sequence type. (√) indicates that the impact is exhibited

	Stop/stop	Stop/alveolar fricative	Stop/dental fricative
The impact of the secondary articulation of emphasis	√	√	√

According to the results in Chapter 6 and the summary in Table 9.1, lingual/lingual sequences (/gt/, /tg/, /gs/, /sg/, /gð/, /ðg/) exhibit lower degree of gestural overlap than labial/lingual sequences (/bt/, /tb/, /bs/, /sb/, /bð/, /ðb/) across Context (emphatic, plain) in C#C position. This pattern of gestural overlap is generally characterized by a higher ICI count, longer ICI duration if it occurs, and/or longer sequence duration in lingual/lingual than in labial/lingual sequences. In addition, it has been found that lingual/lingual sequences in an emphatic context (/gtˤ/, /tˤg/, /gsˤ/, /sˤg/, /gðˤ/, /ðˤg/) exhibit lower degree of gestural overlap than lingual/lingual sequences in the plain counterpart (/gt/, /tg/, /gs/, /sg/, /gð/, /ðg/ respectively) in C#C position as in the summary Table 9.2. This pattern of gestural overlap, similar to the pattern observed above, is generally characterized by a higher ICI count, longer ICI duration, longer sequence duration and/or longer individual intervals (e.g., HP and frication) in lingual/lingual sequences in an emphatic context than in the same sequences in the plain counterpart.

9.2.1.1 Is Hypothesis (a) supported?

Based on the findings reported in Chapter 6 and the summary above, it can be concluded that Hypothesis (a) is ***supported***. Lingual/lingual sequences exhibit lower degree of gestural overlap than labial/lingual sequences in stop/stop (e.g., /gt/ vs /bt/), stop/alveolar fricative (e.g.,/gs/ vs /bs/) and in stop/dental fricative sequences (e.g., /gð/ vs /bð/ in C#C position. This lower degree of gestural overlap is characterized by a higher ICI count, longer ICI and sequence durations in lingual/lingual than in labial/lingual sequences. These results are in line with previous studies that examined the impact of the identity of articulators on gestural overlap (e.g., Hardcastle and Roach, 1979 for English; Kühnert et al., 2006 for French; Kochetov et al. 2007 for Russian; Alsubaie, 2014 for Najdi Arabic; Shitaw, 2014 for Tripolitanian Libyan Arabic; Zeroual et al, 2014 for Moroccan Arabic).

These findings are attributed to motor constraints, particularly the impact of the identity of articulators involved in the sequence. The primary articulators in lingual/lingual (such as tongue dorsum and tongue tip in /gt/) constrain the movement of each other in the sense that one articulator cannot attain its target until the other one is released, giving room for an ICI to occur, because both involve part of the same articulator, i.e. the tongue. For example, /gt/ and /tg/ sequences were compared to /bt/ and /tb/ sequences in C#C position in the current thesis. The results reveal that /gt/ and /tg/ are characterized by a higher ICI count and longer ICI duration than /bt/ and /tb/ sequences. For example, the ICI count percentage is about 88% in /gt/ and 89% in /tg/, whereas it is about 17% in /bt/ and 43% in /tb/ sequences. This indicates that the consonantal gestures are consistently apart in /gt/ and /tg/ (not overlapped), unlike the case in /bt/ and /tb/ in which the consonantal gestures are mostly overlapped. These patterns (higher ICI count or longer ICI duration) were not observed in /bt/ and /tb/ sequences because the two consonants in each sequence involve independent articulators: the lips for /b/ and tongue tip for /t/. Both the lips and tongue tip are independent from each other; they can attain their targets without interfering with each other. In labial/lingual sequences such as /bt/, C2 can attain its target before C1 is released because they do not constrain the movement of each other; each is free to attain its target without the influence of the other, unlike lingual/lingual sequences, such /gt/ in which C2 cannot attain its target before C1 release. While the tongue tip can move freely during C1 in /bt/, the anticipation of the tongue tip for /t/ is opposing the dorsal movement of the tongue for /g/ in /gt/. /bt/ involves non connected articulators while /gt/ involves two connected articulators.

Another example is the ICI duration in /bð/ and /gð/, which is around 10ms in /bð/ and around 19ms in /gð/. This indicates that the consonantal gestures in /gð/ are apart from each other further than the consonantal gestures in /bð/. The labial /b/ does not involve the tongue, so there is no constraint on the timing between /b/ and the coronal because they are different articulators whereas both the coronal and /g/ are parts of the tongue and the movement of one part constrains the movement of the other part. The tongue tip is more agile than the back of the tongue. Thus, when we are looking at the dorsal/coronal sequences (such as /gt/), it is the relative agility of the parts of the tongue, whereas when we are looking at the labial/coronal sequences (such as /bt/) we are looking at different articulators; they do not constrain each other. Sequence duration and/or individual intervals were generally longer in lingual/lingual than in labial/lingual sequences. These findings and such examples were consistent in all three sequence types (stop/stop, stop/alveolar fricative, stop/dental fricative sequences).

9.2.1.2 Is Hypothesis (b) supported?

Based on the results reported in Chapter 6 and the summary provided above, Hypothesis (b) is ***supported***. Lingual/lingual sequences exhibit lower degree of gestural overlap in an emphatic context than in the plain counterpart in stop/stop (e.g., /gt/ vs /gtˤ/), stop/alveolar fricative (e.g., /gs/ vs /gsˤ/) and in stop/dental fricative (e.g., /gð/ vs /gðˤ/ sequences in C#C position. This lower degree of gestural overlap is characterized by a higher ICI count, longer ICI duration, longer sequence duration and/or longer individual intervals in an emphatic context than in the plain counterpart in lingual/lingual sequences in Najdi Arabic. These findings are attributed to motor constraints, particularly the impact of the secondary articulation of emphasis. These findings are consistent with previous studies as indicated above (e.g., Hardcastle and Roach, 1979 for English; Kühnert et al., 2006 for French; Kochetov et al. 2007 for Russian; Alsubaie, 2014 for Najdi Arabic; Shitaw, 2014 for Tripolitanian Libyan Arabic; Zeroual et al, 2014 for Moroccan Arabic). These studies examined the role of the identity of articulators in general without considering emphasis,but all suggest the idea that the more physiologically coupled the articulators are, the lower the degree of gestural overlap will be observed. As explained in Section 9.2.1.1, lingual/lingual sequences exhibit lower degree of gestural overlap than labial/lingual sequences across context. The secondary articulation, which is involved in an emphatic context but not in the plain counterpart, however, adds more complexity in the sense that it adds a posterior movement of the tongue, to the sequences to be produced, particularly if an emphatic coronal occurs adjacent to a lingual consonant. For example, a comparison was made between the timing relations in /gt/ and those in /gtˤ/ sequences. The ICI count percentage is around 88% in /gt/ and 100% in /gtˤ/. A stronger evidence is based on the ICI duration which is around 20ms in /gt/ and around 31ms in /gtˤ/, indicating that the consonantal gestures in both sequences are apart from each other but they are further apart in /gtˤ/ than in /gt/, indicating lower degree of gestural overlap in /gtˤ/ than in /gt/. Sequence duration and/or individual intervals were generally longer in an emphatic context than in the plain counterpart in lingual/lingual sequences. These findings and such examples were consistent for all three sequence types. Although no ICIs occurred in /sg/ ~ /sˤg/ and in /ðg/ ~ /ðˤg/, the movement of the tongue back for /sˤ/ and /ðˤ/ seem to be constrained by the tongue dorsum movement for the following /g/. Although no ICIs occurred, sequence duration and individual intervals are still longer in an emphatic context than in the plain counterpart. For example, C1 frication is longer in duration in /ðˤg/ than in /ðg/ (96ms, 67ms respectively). Likewise, sequence duration is longer in /ðˤg/ than in /ðg/ (158ms, 123ms). All these indicate that lower degree of gestural overlap is exhibited in /ðˤg/ than in /ðg/.

Having a secondary articulation involving a movement of the tongue back in addition to the primary movement of the tongue tip, emphatic coronals seem slower than their plain counterparts. Plain coronals, on the other hand, involve only a movement of the tongue tip which is faster than the tongue back (Jun, 2004, Roon et al., 2021). When moving one part of the tongue, it will have an influence on how the other part is moving; they constrain each other. The tongue dorsum and the tongue back are connected articulators and they cannot achieve their targets simultaneously. Rather, they achieve their targets sequentially, as suggested by Kühnert et al (2006). After the tongue dorsum achieves the constriction of the dorsal /g/ in /gtˤ/ sequence, for instance, the tongue back needs time to achieve the secondary constriction of the emphatic /tˤ/. This time slot is reflected acoustically as a long ICI. On the other hand, when achieving the constriction of /g/ in /gt/ sequence, there is no need for the tongue back to move for another constriction during the production of the plain /t/; it is only the tongue tip that needs to move to achieve the coronal constriction. This time slot is reflected acoustically as a shorter ICI.

Having discussed the specific hypotheses of Research question 1**a**, now we turn to answer this question. Based on the discussion above, the answer is simply ***yes***. The secondary articulation of emphatic coronals (/tˤ/, /sˤ/ and /ðˤ/) has an impact on gestural overlap in consonant sequences in Najdi Arabic. Lingual/lingual sequences, including an emphatic coronal, exhibit lower degree of gestural overlap than lingual/lingual sequences, including the plain counterpart as discussed above. These findings contribute to our understanding of timing relations in consonant sequences, to our understanding of emphasis, and to the study of phonetics of Arabic. Previous studies on timing relations only examined the role of the primary articulation on gestural overlap. Now we know that not only the primary articulation, but also this thesis provides evidence that the secondary articulation of the emphatic coronals also has an impact on gestural overlap. Previous studies on emphasis focused on emphatic consonants as occurring in singletons. Now we have a clear view how emphatic consonants behave when occurring in a sequence, whether adjacent to a lingual or labial consonant. All of these contribute to the study of Arabic too.

9.3 The state of the glottis and gestural overlap

9.3.1 Summary of the results

The results in Chapter 7, concern Research Question 1**b** and the specific hypotheses (c), (d) and (e), as restated below:

RQ 1,b: Does the state of the glottis involved during the production of emphatic coronals play a role in the degree of gestural overlap in consonant sequences?

Hypothesis (c) voiced/voiced consonant sequences will exhibit a greater degree of gestural overlap than voiced/voiceless consonant sequences.

Hypothesis (d): voiced/emphatic /tˤ/ sequences (i.e., /btˤ/ and /tˤb/) will exhibit a greater degree of gestural overlap than voiced/plain /t/ sequences (i.e., /bt/ and /tb/), and accordingly /tˤ/ will behave similarly with the plain voiced counterpart /d/ in the degree of gestural overlap, compared to the plain voiceless counterpart /t/.

Hypothesis (e): voiced/emphatic /sˤ/ sequences (i.e., /bsˤ/ and /sˤb/) will exhibit a greater degree of gestural overlap than voiced/plain /s/ sequences (i.e., /bs/ and /sb/), and accordingly /sˤ/ will behave similarly with the plain voiced counterpart /z/ in the degree of gestural overlap, compared to the plain voiceless counterpart /s/.

The results of labial/coronal in Chapter 6 (i.e., /b#t/, /b#tˤ/,/t#b/, /tˤ#b/, /b#s/, /b#sˤ/,/s#b/, /sˤ#b/), and those of labial/coronal sequences in Chapter 8 (i.e., /Cb#tC/, /Cb#tˤC/,/Ct#bC/, /Ctˤ#bC/, /Cb#sC/, /Cb#sˤC/,/Cs#bC/, /Csˤ#bC/), also contribute to RQ1**b** and Hypotheses (d) and (e).

Table 9.3 Summary of the impact of the state of the glottis of voiced consonants, by sequence type and place order. (√) indicates that the impact is exhibited

	Front-back	**Back-front**
#CC	√	√
CC#	√	X

Table 9.4 Summary of the impact of the state of the glottis of emphatic coronals, by sequence type, position and place order. (√) indicates that the impact is exhibited

	Stop/stop		**Stop/alveolar fricative**	
	Front-back	**Back-front**	**Front-back**	**Back-front**
C#C	√	√	X	X
#CC	√	√	X	X
CC#	√	X	X	X
CC#CC	X	X	X	X

According to the results presented in Chapter 7 and the summary in Table 9.3, voiced/voiced sequences (e.g., /bd/, /bz/) exhibit greater degree of gestural overlap than voiced/voiceless sequences (e.g., /bt/, /bs/) in word-initial and word-final positions, apart from word-final sequences (CC#) in back-front place order. This pattern of gestural overlap is generally characterized by a lower ICI count, shorter ICI duration if it occurs, shorter sequence duration and/or shorter individual intervals in voiced/voiced than in voiced/voiceless sequences.

In addition, it has been found that voiced/emphatic /tˤ/ sequences (e.g., /btˤ/, /tˤb/) exhibit greater degree of gestural overlap than voiced/plain voiceless /t/ sequences (e.g., /bt/, /tb/) in word-initial and word-final positions (as reported in Chapter 7) and in C#C sequences (as reported in Chapter 6), but not in word-final sequences (CC# in back-front) nor in CC#CC position (as reported in Chapter 8) as in Table 9.4. This pattern of gestural overlap is generally characterized by a lower ICI count, shorter ICI duration, shorter sequence duration and/or shorter individual intervals in voiced/emphatic /tˤ/ than in voiced/plain voiceless /t/ sequences.

This pattern of gestural overlap, observed in sequences including the emphatic coronal /tˤ/, was not observed in sequences including the emphatic coronal /sˤ/ in all word positions as in

Table 9.4. No differences were found between sequences including /sˤ/ and sequences including the plain counterpart /s/ in ICI count, ICI duration, sequence duration or in individual intervals in all word positions (as reported in Chapters 6, 7 and 8).

9.3.1.1 Is Hypothesis (c) supported?

Based on the results reported in chapter 7 and the summary provided above, it can be concluded that Hypothesis (c) is ***partially*** supported. This hypothesis is supported *if* we exclude word-final sequences (CC# in back-front). Voiced/voiced sequences exhibit greater degree of gestural overlap than voiced/voiceless sequences in both stop/stop (e.g., /bd/ vs /bt/ and /btˤ/) and stop/alveolar fricative (e.g., /bz/ vs /bs/ and /bsˤ/). This greater degree of gestural overlap is characterized by a lower ICI count, shorter ICI duration, shorter sequence duration and/or shorter individual intervals in voiced/voiced than in voiced/voiceless sequences in Najdi Arabic. These findings are in agreement with the findings of previous studies (Chitoran et al, 2002 for Georgian; Hoole et al, 2009, Pouplier, 2012 for German; Bombian and Hoole, 2013 for German; Shitaw, 2013 for Tripolitanian Libyan Arabic; Alsubaie, 2014 for Najdi Arabic; Gibson et al, 2019 for Standard Peninsular Spanish). These findings are attributed to the role of the state of the glottis in gestural overlap. As suggested by a number of researchers including Browman and Goldstein (1992) and Hall (2017), voicing is the default activity of the glottis. More pressure build-up is expected during the production of a voiceless consonant than during the production of a voiced consonant. This pressure build-up may entail a delay between the consonantal gestures, giving room for an ICI to occur which may be long, and hence lower degree of gestural overlap is exhibited in voiced/voiceless than in voiced/voiced sequences since the pressure build-up is involved in voiced/voiceless but not in voiced/voiced sequences. For example, the timing relations in the voiced/voiced sequence, /#bz/, were compared to those in the voiced/voiceless sequences /#bs/ and /#bsˤ/ in the current thesis. The ICI count percentage is around 21% in /#bz/, 81% in /#bs/ and 78% in /#bsˤ/, indicating that the consonantal gestures are apart more consistently in both /#bs/ and /#bsˤ/ than in /#bz/. Another evidence is based on the ICI duration which is around 7ms in /#bz/ and 24ms in both /#bs/ and /#bsˤ/, indicating that the consonantal gestures are further apart in /#bs/ and /#bsˤ/ than in /#bz/, if apart, indicating greater degree of gestural overlap in /#bz/ than in /#bs/ and /#bsˤ/. Likewise, sequence duration and the individual interval (i.e., C2 frication) were reported to be shorter in /#bz/ than in both /#bs/ and /#bsˤ/ sequences; and all these measures indicate that /#bz/ exhibit greater degree of gestural overlap than both /#bs/ and /#bsˤ/. Similar observations were found in stop/stop sequences (e.g., /bd/ vs /bt/ and /btˤ/).

These findings have been attributed to the role of the state of the glottis on gestural overlap. For example, the ICI voicing proportion is higher in /#bz/ than in both /#bs/ and /#bsˤ/ (1, 0.66 and 0.67 respectively). Likewise, as another example, the ICI voicing proportion is higher in /#bd/ than in both /#bt/ and /#btˤ/ (1, 0.53 and 0.77 respectively). Such results indicate that both consonants share the same state of the glottis in /#bz/ and in /#bd/, and hence these sequences exhibit greater degree of gestural overlap; whereas both consonants, in /#bs/, /#bsˤ/, /#bt/ and /#btˤ/ sequences, have different states of the glottis, thus more pressure build-up is involved here, and hence these sequences exhibit lower degree of gestural overlap.

These patterns of gestural overlap (i.e., voiced/voiced sequences exhibit greater degree of gestural overlap than voiced/voiceless sequences), however, were not observed in word-final sequences (CC# in back-front place order). No differences were found between /db#/, /tb#/ and /tˤb#/ or between /zb#/, /sb#/ and /sˤb#/ sequences in all measures that were used to determine the degree of gestural overlap (i.e, ICI count, ICI duration, sequence duration and individual intervals), contra to the same sequences in a word-initial position (#CC). These findings are attributed to the type of vowel insertion observed in these sequences. It has been concluded that the ICI in these sequences (in CC# in back-front place order) exhibits the characteristics of epenthetic vowels, whereas the ICI in a word-initial position (#CC in both place orders) and in CC# (in front-back order) exhibits the characteristics of intrusive vowels, as will be discussed in Section 9.4. Therefore, Hypothesis (c) is supported in sequences, where intrusive vowels occurred, but not supported in sequences where epenthetic vowels occurred. These results support Hall's (2006) claim that intrusive vowels are variable in duration and can be influenced by surrounding consonants, unlike epenthetic vowels that are independent from surrounding consonants. These types of vowel insertion will be discussed further in Section 9.4.

The impact of the state of the glottis is constrained by ICI duration; it is observed in sequences where short ICIs occurred (intrusive vowels), but not in sequences where ICIs are mostly voiced and long (epenthetic vowels). This is in line with the findings of Ghummed (2015) and Plug et al (2019) that voicing assimilation was observed across short ICIs but not in long ICIs in Tripolitanian Libyan Arabic, supporting Hall's (2011) observation that epenthetic vowels block phonological processes, whereas intrusive vowels are transparent. This could be relevant to the 'relativized hypothesis' of Gafos et al. (2010); it is true that they based their hypothesis on the place order effect, but it could be used to interpret the state of the glottis impact. They suggest that the longer the ICI is, the less likely the place order effect is exhibited in the sequence. We can similarly conclude that the longer the ICI is, the less likely the state of the glottis effect is exhibited in the sequence. This is consistent with the findings discussed above, as epenthetic vowels are longer than intrusive vowels (as will be discussed further in Section 9.4), and the state of the glottis effect is not exhibited in epenthetic vowels, but it is observed in intrusive vowels.

9.3.1.2 Is Hypothesis (d) supported?

Based on the results reported in Chapters 6, 7 and 8, and the summary provided above, it can be concluded that Hypothesis (d) is ***partiall****y* supported. This hypothesis is conditioned by the sequence position in the word and place order. Voiced/emphatic /tˤ/ sequences (e.g., /btˤ/ and /tˤb/) exhibit greater degree of gestural overlap than voiced/plain /t/ sequences (e.g., /bt/ and /tb/) in CC# (in front-back), C#C and in #CC, but ***not*** in CC# (in back-front order) nor in CC#CC positions. This greater degree of gestural overlap is characterized by a lower ICI count, shorter ICI duration, shorter sequence duration and/or shorter individual intervals in voiced/emphatic /tˤ/ than in voiced/plain /t/ sequences in Najdi Arabic. These findings are attributed to the role of the state of the glottis in gestural overlap. These findings are in agreement with the findings of previous studies (Chitoran et al, 2002 for Georgian; Hoole et al, 2009, Pouplier, 2012 for German; Bombian and Hoole, 2013 for German; Shitaw, 2013 for Tripolitanian Libyan Arabic; Alsubaie, 2014 for Najdi Arabic; Gibson et al, 2019 for Standard Peninsular Spanish). These studies did not consider the emphatic coronal, /tˤ/, in which the state of the glottis is less open than the plain voiceless counterpart /t/; these studies, however, support the idea that if both consonants in a sequence are voiced (sharing the same state of the glottis), this sequence will exhibit greater degree of gestural overlap than sequences with mixed-voicing (voiced/voiceless) since they do not share the same state of the glottis. The emphatic coronal /tˤ/, as discussed in Chapter 3, is characterized by a less open glottis than the plain voiceless counterpart /t/. It is true that the state of the glottis involved in /tˤ/ is not as closed[100] as in the plain voiced counterpart /d/, but it is also not as wide open as in the plain voiceless /t/. The findings of the current thesis suggest that this less open glottis (in /tˤ/) can also play a role on gestural overlap, similar to state of the glottis of the plain voiced counterpart /d/. Sequences including the plain voiced /d/ exhibit greater degree of gestural overlap than both sequences including /tˤ/ and those including /t/, but sequences including the emphatic coronal /tˤ/ exhibit greater degree of gestural overlap than sequences including

[100] Using Watson and Heselwood (2016) terminology.

/t/. Accordingly, the emphatic /tˤ/ behaves similarly with the plain voiced /d/ in the degree of gestural overlap. Both sequences including /d/ (such as /#bd/) and sequences including /tˤ/ (such as /#btˤ/) exhibit greater degree of gestural overlap than sequences including the plain voiceless /t/ (such as /#bt/). This is in agreement with previous studies that concluded that /tˤ/ and /d/ pattern in the state of the glottis (e.g., Heselwood and Maghrabi, 2015; Watson and Heselwood, 2016).

For example, the timing relations in /#btˤ/, were compared to those in /#bt/ in the current thesis. The ICI count percentage is around 36% in /#btˤ/ and around 87% in /#bt/, indicating that the consonantal gestures are apart more consistently in /#bt/ than in /#btˤ/. Another evidence is based on the ICI duration which is around 21ms in /#btˤ/ and around 32ms in /#bt/, indicating that the consonantal gestures are further apart in the plain sequence /#bt/ than in the emphatic /#btˤ/, if apart, indicating greater degree of gestural overlap in /#btˤ/ than in /#bt/. As indicated above, these findings have been attributed to the role of the state of the glottis on gestural overlap. The ICI voicing proportion is, for example, higher in /#btˤ/ than in /#bt/ (0.77 and 0.53 respectively), indicating that the state of the glottis involved in /tˤ/ is less open than that in /t/; these findings support studies that found that /tˤ/ and /d/ pattern in the state of the glottis (e.g., Heselwood and Maghrabi, 2015; Watson and Heselwood, 2016). Such results indicate that both consonants in /#bt/ have different states of the glottis (closed/wide open, respectively). It is true that both consonants in /#btˤ/ still have different states of the glottis (closed/less open), and that is why /#btˤ/ still exhibits lower degree of gestural overlap than /#bd/ in which both consonants have the same state of the glottis (closed/closed), but the *less open* glottis (for /tˤ/) is closer to the *closed* glottis (for /d/), compared to the *wide open* glottis (for /t/). The difference between *closed* glottis and *wide open* glottis (as in /#bt/) is greater than the difference between *closed* glottis and *less open* glottis (as in /#btˤ/), and that is why /#btˤ/ exhibits greater degree of gestural overlap than /#bt/. The pressure build-up needed to produce the voiceless /t/ is not required to produce the emphatic /tˤ/ since the state of the glottis is *wide open* in /t/ and *less open* in /tˤ/. In /#btˤ/ sequence, for example, the state of the glottis starts with *closed* glottis for /b/ and then turns to *less open* for /tˤ/. The transition from *closed* to *less open* does not need a long time slot. In /#bt/, on the other hand, the glottis starts with *closed* glottis for /b/ and then turns to *wide-open* for /t/ This may need a longer time slot to occur. Accordingly, the laryngeal gesture of the emphatic /tˤ/ can be bound to the gesture of the oral stop /b/ constriction; /#btˤ/, for example, exhibits greater degree of gestural overlap than /#bt/. This indicates that the coordination of oral articulations could be influenced by the laryngeal specifications.

In short, /tˤ/ behaves similarly with the plain voiced /d/ in the degree of gestural overlap; both exhibit greater degree of gestural overlap than /t/. This is in line with Sibawayh's inclusion of /tˤ/ in the *majhūr* group in which /d/ is also included, while /t/ is included in the *mahmūs* group in which other sounds are voiceless. The above findings support Heselwood's (2020) conclusion that consonants in Arabic are best described as "breathed vs unbreathed" (following the observations of Sibawayh' *mahmūs* and *majhūr*) rather than "voiced vs voiceless". In this sense, /tˤ/ and /d/ are best described as unbreathed while /t/ is described as breathed in Najdi Arabic.

The impact of the less open glottis of /tˤ/ and these patterns of gestural overlap, however, were not observed in word-final sequences (CC# in back-front place order) or in CC#CC position. For example, no differences were found between /tb#/ and /tˤb#/ in all measures that were used to determine the degree of gestural overlap, contra to the same sequences in a word-initial position (/#tb/ and /#tˤb/). Likewise, no differences were found between /Cb#tC/ ~ /Cb#tˤC/ and between /Ct#bC/ ~ /Ctˤ#bC/ sequences in the degree of gestural overlap. Similar to Hypothesis (c), these findings are attributed to the type of the ICI observed in these sequences. The ICI in CC# (in back-front place order) and in CC#CC positions exhibits the characteristics of epenthetic vowels, whereas the ICI in other word positions (in CC# in front-back order, in #CC and in C#C positions) exhibits the characteristics of intrusive vowels, as will be discussed in Section 9.4. Therefore, Hypothesis (d) is supported in sequences, where intrusive vowels occurred,but not supported in sequences where epenthetic vowels occurred. These results support Hall's (2006) claim that intrusive vowels are variable in duration and can be influenced by surrounding consonants, unlike epenthetic vowels that are independent from surrounding consonants. These types of vowel insertion will be discussed further in Section 9.4.

As discussed in Section 9.2.1.2, when /tˤ/ occurs with another lingual in a sequence, as in /gtˤ/, this sequence exhibits lower overlap than the plain counterpart (/gt/), unlike /btˤ/ which exhibits greater overlap than /bt/. It seems that the impact of the identity of articulators is stronger than the impact of the state of the glottis; if the identity of articulators effect is active, that of the state of the glottis will not be operative. Sequences, where the impact of the less open glottis was operative, are all labial/lingual, and thus it was only the impact of the less open glottis that can act on gestural overlap in those sequences; no effect of the identity of articulators can compete with the effect of the less open glottis, unlike the case of lingual/lingual sequences.

Emphasis impact is constrained by ICI duration; it is observed in sequences where short ICIs occurred (intrusive vowels), but not in sequences where ICIs are mostly voiced and long (epenthetic vowels). This is in agreement with the findings of Ghummed (2015) and Plug et al (2019) that voicing assimilation was observed across short ICIs but not in long ICIs in Tripolitanian Libyan Arabic, supporting Hall's (2011) observation that epenthetic vowels block phonological processes, whereas intrusive vowels are transparent. This could be relevant to the 'relativized hypothesis' of Gafos et al. (2010); it is true that they based their hypothesis on the place order effect, but it could be used to interpret emphasis impact. They suggest that the longer the ICI is, the less likely the place order effect is exhibited in the sequence. We can similarly conclude that the longer the ICI is, the less likely emphasis impact is exhibited in the sequence. This is consistent with the findings discussed above, as epenthetic vowels are longer than intrusive vowels (as will be discussed further in Section 9.4), and emphasis impact is not exhibited in epenthetic vowels, but it is observed in intrusive vowels.

9.3.1.3 Is Hypothesis (e) supported?

Based on the results reported in Chapters 6, 7 and 8, and the summary provided above, it can be concluded that Hypothesis (e) is ***not*** supported. Voiced/emphatic /sˤ/ sequences (e.g., /bsˤ/ and /sˤb/) do not exhibit greater degree of gestural overlap than voiced/plain /s/ sequences (e.g., /bs/ and /sb/). This finding confirms that both the emphatic /sˤ/ and the plain voiceless /s/ have the same state of the glottis. This finding is unexpected; this is not in agreement with previous studies that concluded that the state of the glottis of the emphatic /sˤ/ is less open than that of the plain /s/ (e.g., Watson and Heselwood, 2016; Putten, 2019; Heselwood, 2020; Heselwood et al, 2022). The results of these studies are mostly based on Modern South Arabian languages or the Qura'nic Arabic. Very few studies examined the state of the glottis of the emphatic /sˤ/ in Arabic varieties. Hence, there was a need to examine the state of the glottis in an Arabic variety (i.e. Najdi Arabic) to establish whether the emphatic /sˤ/ is similar to the emphatic /tˤ/ in the state of the glottis in Arabic, just like the case in Modern South Arabian languages. The results of the current thesis reveal that the state of the glottis of the emphatic /sˤ/ is the same as that of the plain voiceless /s/, and accordingly the emphatic /sˤ/ is not similar to the emphatic /tˤ/ in the state of the glottis. For example, the timing relations in /#bsˤ/, were compared to those in /#bs/ in the current thesis. The ICI count percentage is around 78% in /#bsˤ/ and around 81% in /#bs/, indicating that the consonantal gestures are apart similarly in both sequences. Besides, the ICI duration is the same between the two sequences, 24ms. The sequence duration is also similar (187ms in /#bsˤ/ and 183ms in

/#bs/). The individual intervals were similar too. All these measures indicate that there is no difference between sequences including /sˤ/ and those including /s/ in the degree of gestural overlap.

These findings have been attributed to the role of the state of the glottis on gestural overlap. The finding, that no differences were found between sequences including /sˤ/ and sequences including /s/ in the degree of gestural overlap, indicates that the state of the glottis does not have any role here because both states of the glottis are the same in /sˤ/ and in /s/. The ICI voicing proportion is similar in both sequences in all word positions. The ICI voicing proportion is, for example, 0.67 in /#bsˤ/ and 0.66 in /#bs/. Accordingly, /sˤ/ behaves similarly with /s/ in the degree of gestural overlap, compared to /z/. Therefore, no evidence was found to support Hypothesis (e). Besides, the dental coronals /ð/ ~ /ðˤ/ were also examined in word set A to investigate the role of the secondary articulation on gestural overlap. No differences were found between /b#ðˤ/ ~ /b#ð/ and between /ðˤ#b/ ~ /ð#b/ sequences in the degree of gestural overlap because the state of the glottis is the same in /ðˤ/ and /ð/ (both are voiced). These results support the role of the state of the glottis on gestural overlap.

Having discussed the hypotheses of Research question 1**b**, now we turn to answer this question. Based on the above discussion, the answer is ***yes if*** we consider only the emphatic coronal /tˤ/. The state of the glottis involved during the production of the emphatic coronal /tˤ/ plays a role in gestural overlap in consonant sequences in Najdi Arabic. We have seen that voiced/voiced sequences and voiced/emphatic /tˤ/ sequences exhibit greater degree of gestural overlap than voiced/plain voiceless /t/ sequences. The state of the glottis of the emphatic coronal /sˤ/ turns out to be the same as that in the plain voiceless counterpart /s/, and therefore the emphatic /sˤ/ behaves similarly to the plain voiceless /s/ in the degree of gestural overlap, compared to the plain voiced /z/. These findings contribute to our understanding of timing relations in consonant sequences, to our understanding of emphasis, and to the study of phonetics of Arabic. Previous studies on timing relations only examined the role of the state of the glottis of voiced consonants on gestural overlap. Now we know that not only the state of the glottis of voiced consonants,but also this thesis provides evidence that the less open glottis of the emphatic coronal /tˤ/ also has an impact on gestural overlap. Previous studies on emphasis focused on the comparison between emphatic consonants and their plain counterparts as occurring in singletons. Now we have a clear view how emphatic consonants behave when occurring adjacent to a voiced consonant in a sequence, compared to their plain counterparts. All of these contribute to the study of Arabic too.

Having answered both Research Question1**a** (at the end of Section 9.2.1.2) and Research Question1**b** above, we now provide an answer to the first main Research Question **1** (whether there is an impact of emphasis on gestural overlap). The answer is ***yes***. We have seen that both features of emphasis has an impact on gestural overlap. We have seen that both the secondary articulation of emphatics and the less open glottis of the emphatic coronal /tˤ/ have an impact on gestural overlap, as discussed in Sections 9.2 and 9.3.

Having discussed the impact of emphasis (the secondary articulation and gestural overlap, and the less open glottis and gestural overlap) in Sections 9.2 and 9.3, now we turn to discuss gender effect as a social factor and emphasis impact in the following subsection.

9.3.1.4 Gender and emphasis impact

Gender was examined in the current thesis because it seems an influential social factor on emphasis, based on the findings of the literature (e.g., Alfraikh, 2015; Almuhaimeed, 2021). Although there was a tendency for the speech of males to exhibit more emphasis (particularly the impact of the secondary articulation) than that of females, the differences between males and females in relation to emphasis impact were not statistically significant. Accordingly, gender did not play any role in the emphatic-plain distinction. These results are neither consistent with Alfraikh (2015), who found that emphasis was more exhibited in the speech of males, nor with Almuhaimeed (2021) who found that emphasis was more exhibited in the speech of females in Najdi Arabic. Both studies collected data from a smaller number of speakers (4 speakers by Alfraikh, and 5 speakers by Almuhaimeed), compared to the current thesis that collected data from sixteen speakers (8 males and 8 females). Both Alfraikh and Almuhaimeed based their conclusion, regarding gender and its interaction with emphasis impact, on F2 lowering of adjacent vowels in an emphatic context. It is true that Almuhaimeed examined more parameters (than in Alfraikh's study), including the HP, frication, VOT and vowel duration and formants,but she did not find any differences in relation to emphasis between both genders in these parameters, except F2 lowering of the adjacent vowel /a/ which is greater in the speech of females than in that of males in an emphatic context. Now, based on the findings of the current thesis, we have a clearer view of gender behaviour in relation to emphasis in Najdi Arabic. Now we know that emphasis impact is observed in the speech of both males and females; no differences were found between them, based on data collected from sixteen speakers, and based on the findings of various acoustic parameters, including the HP, frication, sequence, VOT durations, in addition to ICI duration and voicing proportion (that were not considered in Almuhaimeed, 2021).

9.4 The types of inserted vowels and emphasis

9.4.1 Summary of the results

The results presented in Chapter 8 concern Research Question **2** and the specific hypotheses (f), (g) and (h), as restated below:

RQ2: If yes, is emphasis impact observed in intrusive vowels, epenthetic vowels, or in both?

Hypothesis (f) Intrusive vowels will occur in word-initial sequences (#CC), two-consonant sequences across the word boundary (C#C) and in word-final sequences (CC# that obey the sonority sequencing), whereas epenthetic vowels will occur in four-consonant sequences at the word boundary (CC#CC) and in word-final sequences (CC# that violate the sonority sequencing in Najdi Arabic).

Hypothesis (g) emphasis impact, if any, will be observed in intrusive vowels but not in epenthetic vowels.

Hypothesis (h) word-initial clusters will exhibit a lower degree of gestural overlap than word-final clusters and sequences across the word boundary.

Table 9.5 Summary of the types of vowel insertion occurred in each word position, by place order

	Front-back	Back-front
C#C	Intrusive	Intrusive
#CC	Intrusive	Intrusive
CC#	Intrusive	Epenthetic
CC#CC	Epenthetic	Epenthetic

Table 9.6 Summary of the impact of emphasis (the impact of the state of the glottis of emphatic coronals), by sequence type, position and place order . (√) indicates that the impact is exhibited.

	Stop/stop		**Stop/alveolar fricative**	
	Front-back	**Back-front**	**Front-back**	**Back-front**
C#C	√	√	X	X
#CC	√	√	X	X
CC#	√	X	X	X
CC#CC	X	X	X	X

Table 9.7 Summary of the impact of the sequence position in the word, by place order and type of vowel insertion. These three positions are compared to #CC position. (√) indicates that the impact is exhibited

	Front-back	**Type of vowel insertion**	**Back-front**	**Type of vowel insertion**
C#C	√	Intrusive	√	Intrusive
CC#	√	Intrusive	X	Epenthetic
CC#CC	X	Epenthetic	X	Epenthetic

According to the results presented in Chapter 8 and the summary in Table 9.5, the two types of vowel insertion occur in Najdi Arabic. The type varies as a function of the sequence position in the word, sonority sequencing (SSP) and place order. Intrusive vowels occur in word-final sequences (CC# that obey the SSP), in word-initial (#CC) and in C#C position. Epenthetic vowels, on the other hand, occur in word-final sequences (CC# that violate the SSP) and in CC#CC position. These patterns were found for both sequence types (stop/stop and stop/alveolar fricative). Duration of intrusive vowels was variable depending on surrounding consonants; they are characterised by shorter duration than epenthetic vowels. Also, voicing proportion of intrusive vowels was variable depending on the state of the glottis of surrounding consonants, whereas epenthetic vowels were mostly voiced regardless of the state of the glottis of surrounding consonants.

Besides, emphasis impact (the impact of the less open glottis of emphatic coronals) was examined in various word positions. The findings reveal that the state of the glottis during the production of the emphatic coronal /tˤ/ is less open than during the production of the plain counterpart /t/. This is generally characterised by higher ICI voicing proportion in sequences including /tˤ/ than in sequences including /t/. This impact is conditioned by position and the SSP. Sequences including /tˤ/ exhibit greater degree of gestural overlap than sequences including /t/ in CC# (that obey the SSP), in #CC and in C#C positions, but this impact was not exhibited in CC# (that violate the SSP) or in CC#CC positions as in Table 9.6. The results also reveal that the state of the glottis is the same in both /sˤ/ and /s/. The ICI voicing proportion is similar in both sequences including /sˤ/ and sequences including /s/; accordingly, there were no differences between both in the degree of gestural overlap. Thus, the less open glottis was only evident in the emphatic coronal /tˤ/, compared to /t/, but not in /sˤ/, compared to /s/.

In addition, the patterns of gestural overlap were found to vary as a function of the type of vowel insertion occurring in the sequence. Word-initial sequences were found to exhibit lower degree of gestural overlap than other word positions only in sequences where intrusive vowels occur (i.e., CC# that obey the SSP and in C#C position). However, word-initial sequences were

not found to exhibit lower degree of gestural overlap than other positions in sequences where epenthetic vowels occur (i.e., CC# that violate the SSP and in CC#CC position) as in Table 9.7.

9.4.1.1 Is Hypothesis (f) supported?

Based on the results presented in Chapter 8 and the summary provided above, it can be concluded that this hypothesis is ***supported, but*** it is not the sonority sequencing (SSP) that can determine the type of vowel insertion in a word-final position in Najdi Arabic (inconsistent with the conclusions of Alqahtani, 2014 and Alfaifi, 2019 who suggested that word-final sequences, violating the SSP, are broken up by an epenthetic vowel in Najdi Arabic); it is rather the place order as will be explained below. The finding, that the two types occurred in Najdi Arabic, is consistent with previous studies that found the two types in a number of languages (e.g., Ridouane and Fougeron, 2011 for Tashlhiyt; Kirby, 2014 for Khmer; Bellik, 2018 for Turkish; Heselwood et al, 2015, Plug et al, 2019 for Tripolitanian Libyan Arabic; Al-Aqlobi, 2020 for Bisha Arabic and Makkah Arabic). Intrusive vowles occurred in word-initial and in C#C sequences, in line with Plug et al (2019) and Alaqlobi (2020), while epenthetic vowels occurred in CC#CC position, in line with plug et al (2019). In a word-final position, however, both types occurred. Intrusive vowels occurred in CC# in front-back order, while epenthetic vowels occurred in CC# in back-front order. Intrusive vowels are generally characterised by shorter ICI and lower ICI voicing proportion than epenthetic vowels. For example, the ICI in /bt/ sequences was examined in various word positions. The findings reveal that the ICI is shorter and the ICI voicing proportion is lower in /bt/ sequence when occurring in #CC (32ms, 0.53 respectively), C#C (18ms, 0.62) and CC# (21ms, 0.59) positions than when occurring in CC#CC position (63ms, 0.94). In /tb/ sequence, however, the ICI is shorter and the ICI voicing proportion is lower in /tb/ sequence when occurring in C#C (15ms, 0.44, respectively) and in #CC (37ms, 0.5) than when occurring in CC# that violate the SSP (66ms, 0.92) and in CC#CC position (63ms, 0.9). The findings reveal that intrusive vowels are generally shorter and variable in duration and voicing, depending on surrounding consonants, while epenthetic vowels are longer and mostly voiced regardless of surrounding consonants.

Sequences that violate the SSP in CC# position (in word set C) include /tb#/, /tˤb#/, /sb#/ and /sˤb#/, and all are in back-front order. There is, however, another sequence that was examined in word set B (/bz#/), and it violates the SSP in Najdi Arabic,but the ICI occurring in this sequence exhibits the characteristics of intrusive vowels. The ICI in /bz#/ is as short as in /#bz/, as occurring word-initially, (6ms and 10ms respectively), as reported in Chapter 7, although this sequence (/bz#/) was expected to be broken up by an epenthetic vowel since it violates the SSP in Najdi Arabic (as explained in Chapter 4, Section 4.7.2). Besides, there are sequences that were examined in word set B (/db#/, /zb#/), and they obey the SSP in Najdi Arabic; thus the ICI occurring in these sequences was expected to exhibit the characteristics of intrusive vowels. The ICI in these two sequences, however, exhibits the characteristics of epenthetic vowels. The ICI duration in /db#/ is 62ms, compared to the ICI in /#db/ which is 24ms (as reported in Chapter 7). Likewise, the ICIs occurred in /zb#/ and its duration is 62ms, compared to /#zb/ in which no ICIs occurred (as reported in Chapter 7). To sum up, the ICIs in sequences that are in front-back order occurring word-finally (i.e., /bt#/, /btˤ#/, /bd#/, /bs#/, /bsˤ#/ and /bz#/) exhibit the characteristics of intrusive vowels; whereas the ICIs in sequences that are in back-front order occurring word-finally (i.e., /tb#/, /tˤb#/, /db#/, /sb#/, /sˤb#/ and /zb#/) exhibit the characteristics of epenthetic vowels, regardless of the SSP of the sequence. These findings indicate that the place order is more influential than the SSP in determining the type of vowel insertion in word-final sequences in Najdi Arabic. These findings are in agreement with Alfaifi's (2019) observation that back-front sequences tend to be broken up by an epenthetic vowel in a word-final position in Najdi Arabic. Alfaifi did not verify this observation; he did not do any statistical analysis to validate this observation since it was not an aim of his study. This thesis, however, provides evidence, backed up by statistical analysis, that supports Alfaifi's observation. Having said that, it seems that the sonority sequencing cannot provide a full account for the structure of word-final sequences in Najdi Arabic; non-sonority factors (i.e., place order) can better account for word-final sequences in Najdi Arabic.

The finding that epenthetic vowels occur in CC# sequences (in back-front) is not expected; what was expected is that they occur *only* if CC# sequences violate the SSP regardless of place order. This may be attributed to the characteristics of epenthetic vowels, which repair a structure that is marked (Hall, 2006). It is true that sequences, violating the SSP, are considered marked, but CC# back-front sequences may be marked too. It should be noted that the ICI in /bz#/ sequence, as indicated above, exhibits the characteristics of intrusive vowels although this sequence violates the SSP in Najdi Arabic. It seems that back-front sequences in CC# position are more marked than sequences that violate the SSP in the same position. This interpretation, however, needs further research to have a clearer view; the relation between markedness, the SSP and place order and how they interact with vowel epenthesis needs further investigation.

Arguably, the occurrence of epenthetic vowels in a four-consonant sequence at the word boundary (CC#CC), is not surprising. As indicated earlier, epenthetic vowels repair illicit syllable structures. Najdi Arabic allows up to two consonants in a sequence (Alqahtani, 2014). Therefore, inserting an epenthetic vowel at the word boundary in CC#CC sequences is the only way to break up a four consonant sequences without generating another prohibited CCC sequence. Besides, following Kiparsky's (2003) and Watson's (2007) classification of Arabic varieties, the site of an epenthetic vowel at the word boundary in CC#CC sequences could be an extension of CV-dialects epenthesis pattern in CCvC sequence in Najdi Arabic, where *v* is an epenthetic vowel.

Regarding the occurrence of intrusive vowels in other positions (CC# in front-back, C#C and #CC positions), this could be interpreted as aerodynamic consequence of the tendency in Arabic varieties, in general, to avoid overlapping obstruents, particularly stop closures (Shitaw, 2014); this may be to maximise perceptual recoverability (i.e, the availability of acoustic cues to phoneme identity) (Wright, 1996; Chitoran, 1999, Chitoran et al., 2002).

These results, discussed above, fit with Hall's (2006) distinction between epenthetic and intrusive vowels; intrusive vowels are variable in duration and in voicing, and can be influenced by surrounding consonants, unlike epenthetic vowels that are mostly voiced and longer regardless of surrounding consonants. As in the example given above, the ICI duration and voicing proportion in /tb/ were variable in C#C (15ms, 0.44, respectively) and in #CC (37ms, 0.5), whereas the ICI was longer and mostly voiced in CC# (66ms, 0.92) and in CC#CC (63ms, 0.9). In positions, where the ICI duration and voicing were variable, intrusive vowels occurred; whereas in positions, where the ICI was longer and mostly voiced, epenthetic vowels occurred. The findings also supports Hall's claim that intrusive vowels "are likely to be optional, have a highly variable duration" (Hall, 2006, p. 391), as we have seen that ICI count was generally low in sequences where intrusive vowels occurred, and the ICI duration which was variable according to surrounding consonants, unlike epenthetic. For example, as discussed in Section 9.3.1., the ICI count was lower (i.e., ICIs occur less often) in voiced/voiced than in voiced/voiceless sequences; it was also lower in voiced/emphatic /tˤ/ than in voiced/plain /t/ sequences. Likewise, the ICI duration was variable according to surrounding consonants; it was shorter in voiced/voiced than in voiced/voiceless; it was also shorter in voiced/emphatic /tˤ/ sequences than in voiced/plain /t/ sequences. These findings contribute to the study of consonant sequences in Arabic and to the study of vowel epenthesis.

9.4.1.2 Is Hypothesis (g) supported?

Based on the results presented in Chapters 6, 7 and 8 and the summary provided above, it can be concluded that this hypothesis is ***supported***. Emphasis impact (impact of the less open glottis of /tˤ/) is exhibited in intrusive vowels but not in epenthetic vowels. Sequences including /tˤ/ exhibit greater degree of gestural overlap than sequences including /t/ in #CC and C#C positions, but not in CC#CC position. In a word-final position, this impact and pattern of gestural overlap is exhibited in CC# in front-back (/btˤ#/ vs /bt#/), while it is not exhibited in CC# in back-front (/tˤb#/ vs /tb#/). In short, emphasis impact was exhibited in sequences where intrusive vowels occurred, while it was not exhibited in sequences where epenthetic vowels occurred. These findings are in line with Plug et al (2019) and Ghummed (2015) who found that voicing assimilation was exhibited in ICIs that exhibit the characteristics of intrusive vowels, whereas voicing assimilation was blocked by ICIs that exhibit the characteristics of epenthetic vowels in Tripolitanian Libyan Arabic.

These findings are attributed to the type of vowel insertion. The finding that emphasis impact is observed in intrusive but not in epenthetic vowels supports Hall's (2006) claim that intrusive vowels do not form a syllable nucleus, while epenthetic vowels do; intrusive vowels are the result of retiming between two existing gestures, are variable in duration and voicing and can be influenced by surrounding consonants, unlike epenthetic vowels that have their own gesture and are independent from surrounding consonants. Therefore, emphasis impact was observed in intrusive but not in epenthetic vowels. It is true that emphasis can influence formants of adjacent lexical vowels (F2 lowering) as discussed in Chapter 3, but it *does not* influence the duration or voicing of lexical vowels (Almuhaimeed, 2021 for Najdi Arabic). This thesis examined duration and voicing proportion, but not formants. Epenthetic vowels are different from lexical vowels (Hall, 2013).

For example, the ICI in /b#tˤ/ sequence is shorter in duration (5ms) and higher in voicing proportion (0.81) than the ICI in /b#t/ (18ms, 0.62respectively). The ICI duration and voicing proportion, in addition to other measures (sequence duration and individual intervals), all indicate that /b#tˤ/ exhibits greater degree of gestural overlap than /b#t/. This impact of the less open glottis of /tˤ/ and these patterns of gestural overlap were found in other sequences where intrusive vowels occurred (/#btˤ/, /btˤ#/, /#tˤb/ and /tˤ#b/), but not in other sequences where epenthetic vowels occurred (/tˤb#/, /Cb#tˤC/ or /Ctˤ#bC/). As shown above, the results reveal that the state of the glottis is the same in both /sˤ/ and /s/, and hence no differences were found between sequences including /sˤ/ and those including /s/ in the degree of gestural overlap. Therefore, only the findings for stop/stop sequences are considered to test Hypothesis (g).

Emphasis impact is constrained by ICI duration; it is observed in sequences where short ICIs occurred (intrusive vowels),but not in sequences where ICIs are mostly voiced and long (epenthetic vowels). This is in agreement with the findings of Ghummed (2015) and Plug et al (2019) that voicing assimilation was observed across short ICIs but not in long ICIs in Tripolitanian Libyan Arabic, supporting Hall's (2011) observation that epenthetic vowels block phonological processes, whereas intrusive vowels are transparent. This could be relevant to the 'relativized hypothesis' of Gafos et al. (2010); it is true that they based their hypothesis on the place order effect, but it could be used to interpret emphasis impact. They suggest that the longer the ICI is, the less likely the place order effect is exhibited in the sequence. We can similarly conclude that the longer the ICI is, the less likely emphasis impact is exhibited in the sequence. This is consistent with the findings discussed above, as epenthetic vowels are longer than intrusive vowels, and emphasis impact is not exhibited in epenthetic vowels,but it is observed in intrusive vowels.

9.4.1.3 Is Hypothesis (h) supported?

Based on the results reported in chapters 6, 7 and 8 and the summary provided above, it can be concluded that Hypothesis (h) is ***partially*** supported. This hypothesis is supported if we exclude sequences where epenthetic vowels occurred. Word-initial sequences exhibit lower degree of gestural overlap than word-final (CC# in front-back order) and C#C sequences, where intrusive vowels occur. However, word-initial sequences ***do not*** exhibit lower degree of gestural overlap than CC# (in back-front) or in CC#CC sequences, where epenthetic vowels occur. The finding that word-initial sequences exhibit lower degree of gestural overlap than other word positions is in agreement with previous research (e.g., Hardcastle, 1985; Byrd, 1996 for English; Wright, 1996 for Tsou; Chitoran, 1999 for Georgian). For example, /#bt/ was found to exhibit lower degree of gestural overlap than /b#t/ and /bt#/ sequences, which is characterised by higher ICI count (87% in /#bt/, 16% in /b#t/, 72% in /bt#/), longer ICI duration (32ms in /#bt/, 18ms in /b#t/, 21ms in /bt#/) and longer sequence duration (167ms in /#bt/, 137ms in /b#t/, 135ms in /bt#/) in a word-initial position. In these sequences, intrusive vowels occurred. On the other hand, /#tb/ has a shorter ICI duration than /tb#/ or /Ct#bC/ sequences (37ms, 66ms, 63ms respectively), shorter sequence duration (154ms, 177ms, 177ms), and same ICI count (100%) in a word-initial position. In these sequences, epenthetic vowels occurred. Similar patterns of gestural overlap were found in stop/alveolar sequences, supporting the hypothesis that word-initial sequences exhibit lower degree of gestural overlap than word-final sequences (in front-back) and C#C sequences. The finding that word-initial sequences exhibit lower degree of gestural overlap than other positions is attributed to perceptual recoverability because greater overlap in initial position would threaten the perceptual recoverability of obstruents. For example, the release is the only acoustic cue for the stop (Kühnert et al., 2006). Thus, word-initial sequences tend to be less overlapped. Perceptibility is crucial in initial position (Marslen-Wilson, 1987, Chitoran et al., 2002) for the lexical accessibility of the word. The finding, that /tˤ/ was more prone to exhibit greater overlap than /t/ word initially (as indicated in Section 9.4.1.2), can be attributed to the acoustic cue for the emphatic /tˤ/ which is in the vowel formants. It is well documented that the second formant of the vowel adjacent to an emphatic coronal is lowered, unlike /t/ for which the only acoustic cue is the release. This is true for Najdi Arabic (Alarifi, 2010; Alhammad, 2014; Alfraikh, 2015; Almuhaimeed, 2021). This is supported by Jongman et al's (2011) perception study on Jordanian Arabic; they concluded that emphasis can be perceived from the formants of the adjacent vowels. This finding motivates further research to investigate the formants of adjacent vowels in these sequences.

The finding, that the sequence position effect is ***not*** exhibited in sequences where epenthetic vowels occur, is attributed to the type of vowel insertion. Epenthetic vowels have their own gesture and are independent from surrounding consonants in terms of duration and voicing; they are typically longer and mostly voiced regardless of surrounding consonants (Hall, 2006). Intrusive vowels, in contrast, are the result of retiming between two consonantal gestures, and do not have a gesture and are influenced by surrounding consonants.

Similar to emphasis impact, discussed in Section 9.4.1.2, sequence position effect is constrained by ICI duration; it is observed in sequences where short ICIs occurred (intrusive vowels),but not in sequences where ICIs are mostly voiced and long (epenthetic vowels). This could be relevant to the 'relativized hypothesis' of Gafos et al. (2010); it is true that they based their hypothesis on the place order effect,but it could be used to interpret position effect. They suggest that the longer the ICI is, the less likely the place order effect is exhibited in the sequence. We can similarly conclude that the longer the ICI is, the less likely position effect is exhibited in the sequence. This is consistent with the findings discussed above, as epenthetic vowels are longer than intrusive vowels, and position effect is not exhibited in epenthetic vowels, but it is in intrusive vowels.

Having discussed the specific hypotheses of Research question **2**, now we turn to answer this question. Based on the discussion above, the answer is simply ***yes***. Emphasis impact (impact of the less open glottis of /tˤ/) is exhibited in intrusive vowels but not in epenthetic vowels. We have seen that sequences including /tˤ/ exhibit greater degree of gestural overlap than sequences including /t/ in positions where intrusive vowels occurred, but not in sequences where epenthetic vowels occurred. These findings contribute to our understanding of timing relations in consonant sequences, to our understanding of emphasis, and to the study of phonetics of Arabic. These findings also support Hall's (2006) and Plug et al's (2019) observations about intrusive vowels (that are variable in duration and voicing, and are influenced by surrounding consonants) and about epenthetic vowels (that are independent from surrounding consonants in terms of duration and voicing). This thesis provides further evidence, based on emphasis impact, as a diagnostic of the types of vowel insertion. Thus, these findings also contribute to the study of consonant sequences in Arabic and to the study of vowel epenthesis.

9.5 Common Hypotheses

9.5.1 Summary of the results

The common hypotheses, as restated below, were examined in all word sets:

> **Hypothesis (i)** back-front consonant sequences will exhibit a lower degree of gestural overlap than front-back consonant sequences.
>
> **Hypothesis (j)** consonant sequences at a fast speech rate will exhibit a greater degree of gestural overlap than sequences at a normal speech rate.

Table 9.8 Summary of the impact of place order, by sequence type and position. (√) indicates that the impact is exhibited.

	Stop/stop	Stop/alveolar fricative	Stop/dental fricative
C#C	(inconsistent)[101]	√ (only in lingual/lingual)	√ (only in lingual/lingual)
#CC	√	X	Not examined in these positions
CC#	√	√	
CC#CC	X	X	

[101] Some measures reveal that the place order effect is exhibited in labial/lingual only, and some other measures reveal that the place order effect is exhibited in lingual/lingual sequences only.

Table 9.9 Summary of the impact of speech rate, by sequence type, position and place order. (√) indicates that the impact is exhibited. NA = no ICIs occurred

	Stop/stop		**Stop/alveolar fricative**		**Stop/dental fricative**	
	Front-back	**Back-front**	**Front-back**	**Back-front**	**Front-back**	**Back-front**
C#C	√	√	√ (if C1 is a stop), NA (if C1 is a fricative)		√ (if C1 is a stop), NA (if C1 is a fricative)	
#CC	√	√	√	NA	Not examined in these positions	
CC#	√	X	√	X		
CC#CC	X	X	X	X		

According to the results presented in Chapters 6, 7 and 8 and as in Table 9.8, back-front sequences exhibit lower degree of gestural overlap than front-back sequences in CC#, but not in CC#CC positions for both stop/stop and stop/alveolar fricative sequences. In C#C position, the place order effect was only exhibited in lingual/lingual sequences in both stop/fricative sequences. For stop/stop sequences, the effect was inconsistent; while the place order effect on ICI count was exhibited only in labial/lingual, the place order effect on sequence duration was only exhibited in lingual/lingual sequences in C#C position. In #CC position, the place order effect was exhibited in stop/stop but not in stop/alveolar fricative sequences. The place order effect is generally characterized by higher ICI count and longer ICI and sequence durations in back-front than in front-back sequences in Najdi Arabic.

As in Table 9.9, sequences at fast speech rate exhibit greater degree of gestural overlap than sequences at normal rate in CC# (in front-back), #CC and in C#C positions, but not in CC# (in back-front) or in CC#CC positions. Exceptions to this pattern are #CC in back-front stop/alveolar fricative sequences and C#C (if C1 is a fricative) in both stop/fricative sequences, in which no ICIs occurred. The speech rate effect is characterised by lower ICI count at fast than at normal rate.

9.5.1.1 Is Hypothesis (i) supported?

Based on the results presented in Chapters 6, 7 and 8 and the summary above, Hypothesis (i) is ***partially*** supported. The place order effect varies as a function of word position, sequence type and the identity of articulators. Back-front sequences exhibit lower degree of gestural overlap than front-back sequences in CC#, but not in CC#CC positions. In C#C position, the place order effect was only exhibited in lingual/lingual in stop/fricative sequences, while the place order effect was not consistent for stop/stop sequences. In #CC position, the place order effect was exhibited in stop/stop but not in stop/alveolar fricative sequences.

The finding that back-front sequences exhibit lower degree of gestural overlap than front-back sequences is in agreement with previous studies (e.g., Byrd, 1996 for English; Chitoran et al, 2002 for Georgian; Kochetov et al, 2007 for Korean; Wright, 1996 for Tsou; Zeroual et al, 2014 for Moroccan Arabic; Ghummed, 2015 for Tripolitanian Libyan Arabic; Alsubaie, 2014 for Najdi Arabic). The finding that back-front sequences exhibit lower degree of gestural overlap than front-back sequences is attributed to perceptual recoverability because greater overlap would threaten the perceptual recoverability of obstruents. For example, the release is the only acoustic cue for the stop (Kühnert et al., 2006). In back-front order, if the gesture of C1 in C1C2 sequence is overlapped (and thus not released) with that of C2, perceptual recoverability of C1 would be at stake, and thus no or low degree of gestural overlap is needed to maximise the availability of acoustic cues to phoneme identity (Wright, 1996; Chitoran, 1999, Chitoran et al., 2002). In back-front order, the constriction of C1 is posterior to that of C2, contra to front-back sequences in which the constriction of C1 is anterior to that of C2. For example, stop/stop sequences in back-front order such as /tb/, occurring in #CC or CC#, exhibit a higher ICI count than those in front-back (e.g., /bt/) sequences (87% and 40%, respectively), indicating that the consonantal gestures are more consistently apart in back-front than in front-back sequences. Likewise, back-front sequences (e.g., /tb/) exhibit a longer sequence duration than those in front-back (e.g., /bt/) (163ms and 132ms respectively). All these measures indicate that back-front sequences exhibit lower degree of gestural overlap than front-back sequences. The constriction of the coronal /t/ in /tb/ is posterior to that of /b/, and if the tongue tip gesture of /t/ is overlapped with the labial gesture of /b/, the only acoustic cue for /t/ (i.e., release) would be absent, and hence perceptual recoverability would be at stake. Therefore, a back-front sequence, such as /tb/ exhibits lower degree of gestural overlap than a front-back sequence such as /bt/.

As pointed out in Section 9.4.1.3, /tˤ/ was more prone to exhibit greater overlap than /t/ word initially in both orders (e.g., /#tˤb/ vs /#tb/ in back-front, and both sequences are followed by a vowel); this finding can be attributed to the additional acoustic cue for the emphatic /tˤ/ which is in the vowel formants. The second formant of the vowel adjacent to an emphatic coronal was reported to be lowered, unlike the plain /t/ for which the only acoustic cue is the release (Alarifi, 2010; Alhammad, 2014; Alfraikh, 2015; Almuhaimeed, 2021 for Najdi Arabic). Jongman et al (2011), in their perception study on Jordanian Arabic, concluded that emphasis can be perceived from the formants of the adjacent vowels. Further research is suggested to investigate the formants of adjacent vowels in these sequences.

In CC#CC position, the place order effect was not exhibited in both sequence types. This is attributed to the type of vowel insertion, which is an epenthetic vowel in this position. Since epenthetic vowels are independent from surrounding consonants in terms of duration and voicing, the place order effect was not operative, and this supports Hall's (2006) observations about epenthetic vowels. This is also relevant to the 'relativized hypothesis' of Gafos et al. (2010) who suggest that the longer the ICI is, the less likely the place order effect is exhibited in the sequence. This is consistent with the findings discussed above, the ICIs are longer in CC#CC than in other positions (apart from CC# in back-front order which will be discussed below). For example, the ICI in /tb/ is longer when occurring at the word boundary in CC#CC and in CC# than in C#C or in #CC positions (63ms, 66ms, 15ms and 37ms respectively). Similar conclusion was reported by Plug et al (2019) who found that the place order effect was not exhibited in positions where long ICIs occurred (at the word boundary in CC#CC).

The place order effect in CC# position can be attributed to the type of vowel insertion. Epenthetic vowels occur in CC# sequences that are in back-front order, while intrusive vowels occur in CC# that are in front-back order, as explained in Section 9.4.1.1. Hence, the ICI is longer in back-front than in front-back sequences in CC# position in both stop/stop and stop/alveolar fricative sequences, indicating lower degree of gestural overlap in back-front than in front-back sequences in CC# position. For example, the ICI duration is longer in /tb#/ (back-front) than in /bt#/ (front-back) (66ms and 21ms, respectively).

In C#C position, for stop/stop sequences, the place order effect on ICI count was exhibited only in labial/lingual, while the place order effect on sequence duration was only exhibited in lingual/lingual sequences. These results are inconsistent and are perhaps difficult to explain although both measures suggest that back-front exhibit lower degree of gestural overlap than front-back sequences, but these results can be attributed to the identity of articulators, which are independent in labial/lingual but constrain the movement of each other in lingual/lingual sequences. This, however, needs further research considering both the identity of articulators and place order in various word positions to have a clear view of the relation between both variables in various word positions.

For both stop/fricative sequences, the place order effect was only exhibited in lingual/lingual sequences in C#C position. This could be due to the identity of articulators; in lingual/lingual sequences, lower degree of gestural overlap was exhibited in general, and the place order can be more operative here since the articulators constrain the movement of each other, compared to labial/lingual sequences in which articulators are independent from each other. This, however, needs further research to have a clearer view of the relation between the identity of articulators and place order in various word positions. Besides, ICIs do not occur in sequences where C1 is a fricative in C#C position. For example, ICIs do not occur in /s#b/ and /sˤ#b/ back-front sequences, whereas ICIs occur in /b#s/ and /b#sˤ/ front-back sequences; this may explain why the place order effect was *not* exhibited in labial/lingual sequences in both stop/fricative sequences in C#C position. On the other hand, ICIs do not occur in sequences, such as /s#g/ and /sˤ#g/ front-back sequences, whereas ICIs occur in /g#s/ and /g#sˤ/ back-front sequences; this may explain why the place order effect was only exhibited in lingual/lingual sequences in both stop/fricative sequences; also sequence duration was longer in /g#s/ and /g#sˤ/ (back-front) than in /s#g/ and /sˤ#g/ (front-back) sequences. Likewise, ICIs do not occur in sequences where C1 is a fricative in #CC position. Hence, ICIs do not occur in /#sb/, /#sˤb/ and /#zb/ back-front sequences, whereas ICIs occur in /#bs/, /#bsˤ/ and /#bz/ front-back sequences; this explains why the place order effect was not exhibited in #CC position in stop/alveolar fricative sequences. The finding that ICIs do not occur if C1 is a fricative in #CC and in C#C can be attributed to C1 identity. C1 in /#bs/, for example, is the stop /b/, and ICIs are prone to occur if C1 is a stop in the sequence because there is a release in stops, unlike C1 in /#sb/ which is a fricative, and ICIs occur less often because there is no a release after a fricative. This interpretation is, however, ***not*** operative in marked sequences where epenthetic vowels are likely to occur such as /sb#/.

In general, the results of the place order effect vary as a function of word position, sequence type and the identity of articulators. Further research is suggested to have clearer view of the relation between the identity of articulators and place order in gestural overlap in various word positions.

9.5.1.2 Is Hypothesis (j) supported?

Based on the results presented in Chapters 6, 7 and 8 and the summary above, Hypothesis (j) is ***partially*** supported. The speech rate effect is constrained by the sequence type, word position, and place order. The speech rate effect is characterised by lower ICI count/occurrence at fast than at normal rate. For stop/stop sequences, greater degree of gestural overlap was exhibited at fast rate than at normal rate in CC# (in front-back), #CC and in C#C positions,but not in CC# (in back-front) or in CC#CC positions. Positions where the speech rate effect was exhibited, intrusive vowels occurred; whereas positions where the speech rate effect was ***not*** operative, epenthetic vowels occurred.

For stop/alveolar fricative sequences, greater degree of gestural overlap was exhibited at fast rate than at normal rate only in front-back sequences, whether occurring word-initially or word-finally. Speech rate effect was ***not*** exhibited in CC#CC or in back-front sequences, whether occurring word-initially or word-finally. In C#C, speech rate effect was exhibited only if C1 is a stop, but not if a fricative. No ICIs occurred in #CC (in back-front) or in C#C (if C1 is a fricative) in this sequence type. This can be attributed to C1 identity. C1 in /#bs/ or /g#s/, for example, is the stop /b/ or /g/, and ICIs are prone to occur if C1 is a stop in the sequence because there is a release in stops, unlike C1 in /#sb/ or /s#g/ which is a fricative, and ICIs occur less often because there is no a release after a fricative. This explains why the the speech rate effect was *not* exhibited in #CC (back-front) or in C#C (where C1 is a fricative) in stop/alveolar fricative sequences, since the measure that is used to examine the speech rate effect is ICI count/occurrence in this thesis. This interpretation is not operative in marked sequences where epenthetic vowels are likely to occur such as /sb#/, as indicated above. Likewise, no ICIs occurred in C#C position (where C1 is a fricative) in stop/dental fricative sequences for the same reason explained above, and this similarly explains why the the speech rate effect was not exhibited in this sequence in stop/dental fricative sequences too.

Based on the above discussion, the speech rate effect was applicable only in sequences where ICIs occurred. In these sequences, the speech rate effect was observed in ICIs that exhibit the characteristics of intrusive vowels, but not in ICIs that exhibit the characteristics of epenthetic vowels. Accordingly, Hypothesis (j) is supported in sequences where intrusive vowels occurred,but not in sequences where epenthetic vowels occurred. These findings support Hall's (2006) observation that intrusive vowels may disappear at fast rate, unlike epenthetic vowels that are not influenced by speech rate.

The finding, that greater degree of gestural overlap was exhibited at fast than at normal speech rate, is in line with previous studies (e.g., Hardcastle, 1985; Zsiga, 1994; Byrd and Tan, 1996 for English; Gafos, 2002 for Moroccan Arabic; Shitaw, 2014 for Tripolitania Libyan Arabic). This finding indicates that gestures come close to each other in fast rate, resulting in greater overlap, and are further apart in normal rate, resulting in lower overlap (Huinck et al., 2004; Byrd and Tan, 1996). The finding, that speech rate effect was ***not*** exhibited in CC# (in back-front) or in CC#CC positions, is attributed to the type of vowel insertion which is an epenthetic vowel in these sequences. These findings support Hall's (2006) observation that intrusive vowels may disappear at fast rate, unlike epenthetic vowels that are not influenced by speech rate.

Similar to the effect of emphasis, position, and place order, discussed above, the speech rate effect is constrained by ICI duration; it is observed in sequences where short ICIs occurred (intrusive vowels), but not in sequences where ICIs are mostly voiced and long (epenthetic vowels). This could be relevant to the 'relativized hypothesis' of Gafos et al. (2010); it is true that they based their hypothesis on the place order effect, but it could be used to interpret speech rate effect. They suggest that the longer the ICI is, the less likely the place order effect is exhibited in the sequence. We can similarly conclude that the longer the ICI is, the less likely speech rate effect is exhibited in the sequence. This is consistent with the findings discussed above, as epenthetic vowels are longer than intrusive vowels, and speech rate effect is not exhibited in epenthetic vowels, but it is in intrusive vowels.

9.6 General conclusion, contributions, limitations and suggestions for future research

The main aim of the thesis is to acoustically investigate the impact of emphasis on the degree of gestural overlap in consonant sequences in Najdi Arabic. The thesis sought to answer three main research questions. The first research question concerns whether the secondary articulation of the three emphatic coronals (/tˤ/, /sˤ/ and /ðˤ/) has an impact on gestural overlap. The second question concerns whether the less open glottis involved during the production of the two emphatic coronals (/tˤ/ and /sˤ/) has an impact on gestural overlap. The third question concerns whether the two types of vowel insertion are exhibited in Najdi Arabic, and whether emphasis impact is observed in intrusive vowels, epenthetic vowels or in both. Accordingly, the results of the current thesis were presented in three consecutive chapters (6, 7 and 8).

The results reveal that there is an impact of the secondary articulation of emphasis on gestural overlap in consonant sequences in Najdi Arabic. Lingual/lingual sequences in an emphatic context, such as /gtˤ/, /gsˤ/ and /gðˤ/, exhibit lower degree of gestural overlap than lingual/lingual sequences in the plain counterpart, such as /gt/, /gs/ and /gð/. This impact is generally characterized by a higher ICI count, longer ICI, longer sequence and/or individual intervals in an emphatic context than in the plain counterpart. These findings have been attributed to motor constraints.

The results also reveal that there is an impact of the less open glottis involved during the production of the emphatic coronal /tˤ/ on gestural overlap in Najdi Arabic. Voiced/emphatic /tˤ/ sequences, such as /btˤ/ in C#C, #CC and in CC# word positions, exhibit greater degree of gestural overlap than voiced/plain /t/ sequences, such as /bt/ in C#C, #CC and in CC# word positions. This impact is generally characterized by a lower ICI count, shorter ICI, shorter sequence and/or individual intervals in an emphatic context than in the plain counterpart. These findings have been attributed to the role of the state of the glottis in gestural overlap.

Besides, the results reveal that both types of vowel insertion occur in Najdi Arabic. Intrusive vowels occur in #CC and in C#C word positions. Epenthetic vowels occur in CC#CC word position. In a word-final position, intrusive vowels occur in CC# (in front-back place order), while epenthetic vowels occur in CC# (in back-front order). Intrusive vowels were generally shorter and variable in duration and their voicing proportion is constrained by the state of the glottis of the surrounding consonants, unlike epenthetic vowels that were generally longer in duration and mostly voiced regardless of surrounding consonants. These findings are consistent with the observation of Hall (2006) and Plug et al (2019) about intrusive and epenthetic vowels. Emphasis impact was observed in intrusive vowels, but not in epenthetic vowels. This finding has been attributed to variability of intrusive vowels in duration and voicing, depending on the surrounding consonants since they are a result of retiming between two existing consonantal gestures, unlike epenthetic vowels that have their own articulatory gesture and are independent from the surrounding consonants.

This thesis contributes to our understanding of timing relations in consonant sequences and to our understanding of emphasis. It also contributes to the study of phonetics of Arabic, particularly Najdi Arabic. Previous research on timing relations in consonant sequences did not examine the impact of emphasis. Only the impact of the primary articulation on gestural overlap was examined in previous research. Before this thesis, we only knew that the primary articulation can influence gestural overlap, but we did not know whether the secondary articulation of the emphatic coronals can have an impact on gestural overlap. Now, after this thesis, we can confirm that not only the primary articulation affects gestural overlap, but also there is evidence to conclude that the secondary articulation of the emphatic coronals has an impact on gestural overlap. These conclusions contribute to our understanding of timing relations in consonant sequences and to our understanding of emphasis. Most previous studies on emphasis either examined emphatic consonants as singleton, or examined emphasis spread (mainly emphasis effect on the formants of adjacent vowels),but not examined the behaviour of an emphatic consonant when occurring with another consonant in a sequences. This thesis, however, examined emphatic consonants as occurring in a sequence, and it also examined a number of acoustic parameters, including the ICI duration and voicing proportion. In particular, this thesis examined the degree of gestural overlap in consonant sequences in an emphatic context. Now we have a clear view how emphatic consonants behave when occurring adjacent to another consonant in a sequence, compared to their plain counterparts. These aims were not examined in previous research on emphasis or timing relations in consonant sequences.

Besides, before this thesis, we only knew that the state of the glottis involved during the production of voiced consonants can influence gestural overlap, but we did not know whether the less open glottis during the production of the emphatic coronal /tˤ/ can have an impact on gestural overlap or not. Now, after this thesis, we can confirm that not only the state of the glottis of voiced consonants can affect gestural overlap, but also there is evidence to conclude that the less open glottis of the emphatic coronal /tˤ/ has an impact on gestural overlap. Also, before this thesis we did not have a clear view of the state of the glottis during the production of the emphatic coronal /sˤ/ in Arabic varieties. Now, after this thesis, we have a clearer view of the state of the glottis of /sˤ/, which is the same as that of the plain counterpart /s/, unlike the case in Modern South Arabian Languages in which the emphatic /sˤ/ is characterised by a less open glottis than the plain counterpart /s/.

Furthermore, before this thesis, we did not know whether the two types of vowel insertion (intrusive and epenthetic vowels) occur in Najdi Arabic. Now after this thesis, we can conclude that there is evidence that the two types of vowel insertion occur in Najdi Arabic. Also, before the thesis, we did not know whether emphasis impact would be observed in intrusive vowels or in epenthetic vowels. Now, after this thesis, we can confirm that there is evidence to conclude that emphasis impact is observed in intrusive vowels, but not in epenthetic vowels.

In addition, before this thesis, we knew that gender can interact with emphasis in various varieties of Arabic. However, we did not have a clear view of gender interaction with emphasis in Najdi Arabic; the only two studies (Alfraikh, 2015; Almuhaimeed, 2021) that considered gender reported contradictory results. Now, after this thesis, we have a clearer view of gender behaviour in relation to emphasis; now we know that emphasis impact is observed in the speech of both males and females; no differences were found between them, based on data collected from sixteen speakers (8 males and 8 females), and based on the findings of a number of acoustic parameters, including the hold phase, frication, ICI, sequence, VOT durations, and ICI voicing proportion.

Moreover, the speech rate was not examined in previous studies on timing relations in Najdi Arabic, therefore we did not have a clear view of the speech rate effect on consonant sequences in Najdi Arabic. Now, after this thesis, we have a clear view of the speech rate effect on consonant sequences in Najdi Arabic. Likewise, the place order effect was only examined in word-initial sequences in Najdi Arabic. This thesis examined the place order effect in various word positions. Although further research is suggested to investigate the relation between the identity of articulators and place order in various word positions, but after this thesis, we at least have a view of the patterns of the place order effect in various word positions (#CC, C#C, CC# and CC#CC) in Najdi Arabic. Finally, before this thesis, the degree of gestural overlap in consonant sequences was only examined in word-initial sequences in Najdi Arabic. Now, after this thesis, we have a clear view of the patterns of gestural overlap in various word positions (#CC, C#C, CC# and CC#CC) in Najdi Arabic (position effect).

All of the observations, discussed above, contribute to the study of the phonetics of Arabic, particularly Najdi Arabic, in addition to our understanding of timing relations and emphasis. They also contribute to the study of consonant sequences in Arabic and to the study of vowel epenthesis; this thesis provides further evidence, based on emphasis impact, as a diagnostic of the types of vowel insertion.

As explained in Chapter 2, this thesis followed an acoustic approach, similar to relevant studies (e.g., Alsubaie, 2014; Plug et al, 2019); and in line with studies in the framework of Articulatory Phonology, it can be assumed that we can draw conclusions about gestural overlap from acoustic records. Most studies adopting Articulatory Phonology used instruments to track the articulatory movements. Such instruments were not used in the current thesis due to the high cost of using them, as explained in Chapter 2. Since the results of this thesis were based on an acoustic analysis, there is a need to use instruments, such as EPG, ultrasound or MRI, by which the movements of the articulators involved in the sequence are directly detected. The tongue movement, for example, can be directly detected using EPG. Besides, using Laryngography can detect the state of the glottis during the production of the sequence more clearly, so that the state of the glottis account proposed for the patterns observed in this thesis can be verified by using such an instrument.

Lingual/lingual sequences were only considered at the word boundary. As explained in Chapter 5, dorsal/coronal sequences are not frequently occurring word-initially or word-finally according to the Najdi Arabic lexicon. Since the pairs to be examined need to be carefully designed to be closely matched as possible, these sequences were examined as occurring across a word boundary (C#C). Examining such sequences word-initially or word-finally, in another variety, can help find out whether the same pattern observed in C#C position in Najdi Arabic would be also observed in another variety and in other word positions. The patterning between /tˤ/ and /d/ was examined in word-initial and word-final sequences. Examining this patterning relationship in other word positions would provide a more comprehensive view of the patterning relationship between /tˤ/ and /d/ in timing relations. This thesis considered voicing proportions of only the ICI. Considering voicing proportions of the HP and frication would provide a clearer view of the state of the glottis of the emphatic coronals. Also, the adjacent vowel duration and formants would give a more comprehensive view of the impact of emphasis.

10 References

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11 Appendices

11.1 Appendix A

<u>Consent form</u>

UNIVERSITY OF LEEDS

Consent to take part in *An Acoustic Investigation of Emphasis Impact on Consonant Sequences in 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 details of the researcher: Mr Khalid Alsubaie Email: ml13khta@leeds.ac.uk Tel: UK (00447532622272), KSA (00966504151376)	
I understand that my recordings and personal information will be kept strictly confidential. I give permission for members of the research team to have access to my anonymised data. 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 agree for the data collected from me to be used in 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 [or person taking consent]	
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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<u>**Information sheet**</u>

An Acoustic Investigation of Emphasis Impact on Consonant Sequences in Arabic

Participant information sheet

You are being invited to take part in a research project. Before you decide it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Please ask if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part.

Purpose of the research

This study aims to investigate phonetic aspects of particular sound sequences in Arabic.

Why have I been chosen?

You have been chosen because you are a native speaker of Najdi Arabic which is the variety under investigation in this research.

What do I have to do? What will happen to me if I take part?

You will be asked to read some sentences in normal and fast speech rates. This will be recorded to be later analysed using a computer software. The session will last for about one hour maximally.

What are the possible disadvantages and risks of taking part?

We do not foresee any disadvantages or risks to you taking part in this project.

What are the possible benefits of taking part?

While there are no immediate benefits for those people taking part in this project, your participation will help shed more light on Najdi dialect and will hopefully contribute to future research.

Do I have to take part?

It is up to you to decide whether or not to take part. If you do decide to take part you will be given this information sheet to keep and be asked to sign a consent form. You can still withdraw at any time.

Will my taking part in this project be kept confidential? What will happen to the results of the research project?

Your participation will be kept confidential. Your name will not be used at any time on any written or spoken data records you provide and your participation in the project will remain anonymous.

If you have any questions, please do not hesitate to contact me. My contact details are given below:

Researcher: Khalid Alsubaie

Email: ml13khta@leeds.ac.uk

Tel: UK (00447532622272), KSA (00966504151376)

Supervisor: Dr Leendert Plug

Email: l.plug@leeds.ac.uk

School of Languages, Cultures and Societies

University of Leeds

LS2 9JT

Office: B21, Michael Sadler Building

Date:

Thank you for taking the time to read this information sheet.

11.2 Appendix B (Optimal Models)

```
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

11.2.1 Results of Chapter 6 (The secondary articulation of emphasis and gestural overlap)

11.2.1.1 Stop/stop consonant sequences

11.2.1.1.1 b#t vs b#$t^ʕ$

11.2.1.1.1.1 C1_HP_(log)_n=22

```
Formula: c1hplog ~ rate + Context + (1 | speaker)
   Data: At_lab_FB
Fixed effects:
             Estimate Std.Error       df tvalue Pr(>|t|)
(Intercept)   1.53895   0.02354 19.00000  65.364  <2e-16***
rateNormal    0.12350   0.01985 19.00000   6.221 5.64e-06***
ContextPlain  0.16691   0.01530 19.00000  10.910 1.27e-09***
```

11.2.1.1.1.2 ICI_(log)_n=22

```
Formula: icilog ~ rate + Context + (1 | speaker)
   Data: At_lab_FB
Fixed effects:
             Estimate Std.Error       df tvalue Pr(>|t|)
(Intercept)   0.61018   0.09945 15.98335   6.135 1.44e-05***
rateNormal    0.12505   0.08304 14.53457   1.506    0.154
ContextPlain  0.53678   0.06302 14.05514   8.518 6.36e-07***
```

11.2.1.1.1.3 C2_HP_(log)_n=22

```
Formula: c2hplog ~ rate + Context + (1 | speaker)
   Data: At_lab_FB
Fixed effects:
             Estimate Std.Error       df tvalue Pr(>|t|)
(Intercept)   1.58499   0.03347 19.00000  47.349  <2e-16***
rateNormal    0.13966   0.02823 19.00000   4.948 8.94e-05***
ContextPlain -0.04627   0.02175 19.00000  -2.127   0.0467*
```

11.2.1.1.1.4 VOT_(log)_n=192

```
Formula: VOTlog ~ rate + Context + (1 | speaker)
   Data: At_lab_FB
Fixed effects:
              Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)  1.281e+00 5.108e-03 7.864e+01 250.72   <2e-16***
rateNormal   1.427e-01 5.598e-03 1.740e+02  25.49   <2e-16***
ContextPlain 2.240e-01 5.598e-03 1.740e+02  40.02   <2e-16***
```

11.2.1.1.1.5 Sequence_duration_(log)_n=192

```
Formula: wslog ~ rate + Context + (1 | speaker)
   Data: At_lab_FB
Fixed effects:
              Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)  1.959e+00 4.879e-03 1.890e+02 401.50   <2e-16***
rateNormal   1.260e-01 5.634e-03 1.890e+02  22.36   <2e-16***
ContextPlain 1.107e-01 5.634e-03 1.890e+02  19.64   <2e-16***
```

11.2.1.1.1.6 ICI_Voicing_Proportion_n=22

```
Formula: ici_voicing ~ Context + (1 | speaker)
   Data: At_lab_FB
Fixed effects:
             Estimate Std.Error       df tvalue Pr(>|t|)
(Intercept)   0.80783   0.02659 20.00000 30.377 <2e-16***
ContextPlain -0.19102   0.03118 20.00000 -6.126 5.5e-06***
```

11.2.1.1.2 t#b vs tˤ#b

11.2.1.1.2.1 C1_HP_(log)_n=69

```
Formula: c1hplog ~ rate + (1 | speaker)
   Data: At_lab_BF
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 1.625636  0.008615 67.000000 188.71  <2e-16***
rateNormal  0.150518  0.010551 67.000000  14.27  <2e-16***
```

11.2.1.1.2.1 ICI_(log)_n=69

```
Formula: icilog ~ rate + Context + (1 | speaker)
   Data: At_lab_BF
Fixed effects:
             Estimate Std.Error       df tvalue Pr(>|t|)
(Intercept)   0.63810   0.02984 66.00000  21.38  <2e-16***
rateNormal    0.17497   0.02907 66.00000   6.02 8.57e-08***
ContextPlain  0.43425   0.02790 66.00000  15.56  <2e-16***
```

11.2.1.1.2.1 C2_HP_(log)_n=69

```
Formula: c2hplog ~ rate + (1 | speaker)
   Data: At_lab_BF
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 1.719359  0.009773 67.000000 175.92  <2e-16***
rateNormal  0.137561  0.011970 67.000000  11.49  <2e-16***
```

11.2.1.1.2.1 Sequence_duration_(log)_n=192

```
Formula: wslog ~ rate + Context + (1 | speaker)
   Data: At_lab_BF
Fixed effects:
              Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)  1.932e+00 5.669e-03 9.820e+01 340.77  <2e-16***
rateNormal   1.611e-01 6.517e-03 1.740e+02  24.72  <2e-16***
ContextPlain 9.798e-02 6.517e-03 1.740e+02  15.03  <2e-16***
```

11.2.1.1.2.1 ICI_Voicing_Proportion_n=69

```
Formula: ici_voicing ~ Context + (1 | speaker)
   Data: At_lab_BF
Fixed effects:
              Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)   0.669548  0.008026 50.815961  83.42  <2e-16***
ContextPlain -0.226919  0.010297 58.788525 -22.04  <2e-16***
```

11.2.1.1.3 g#t vs g#tˁ

11.2.1.1.3.1 C1_HP_(log)_n=180

```
Formula: c1hplog ~ rate + (1 | speaker)
   Data: At_dor_BF
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 1.646e+00  4.291e-03 1.770e+02  383.5   <2e-16 ***
rateNormal  1.397e-01  5.921e-03 1.770e+02   23.6   <2e-16 ***
```

11.2.1.1.3.1 ICI_(log)_n=180

```
Formula: icilog ~ rate + Context + Context * gender + (1 | speaker)
   Data: At_dor_BF
Fixed effects:
                         Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)               1.38508   0.01286 174.00000 107.669  <2e-16***
rateNormal                0.13997   0.01186 174.00000  11.801  <2e-16***
ContextPlain             -0.14913   0.01720 174.00000  -8.671 2.93e-15***
genderMale                0.05896   0.01614 174.00000   3.652 0.000344***
ContextPlain:genderMale  -0.07255   0.02376 174.00000  -3.054 0.002617**
```

FURTHER: n=94, n=86

```
Formula: icilog ~ rate + Context + (1 | speaker)
   Data: At_dor_BF_Male
Fixed effects:
             Estimate Std.Error       df tvalue Pr(>|t|)
(Intercept)   1.45786   0.01304 90.00000 111.786  <2e-16***
rateNormal    0.11231   0.01523 90.00000   7.375 7.77e-11***
ContextPlain -0.22076   0.01523 90.00000 -14.496  <2e-16***
```

```
Formula: icilog ~ rate + Context + (1 | speaker)
   Data: At_dor_BF_Female
Fixed effects:
             Estimate Std.Error       df tvalue Pr(>|t|)
(Intercept)   1.36998   0.01492 82.99989  91.815  <2e-16***
rateNormal    0.17016   0.01792 82.99999   9.493 6.74e-15***
ContextPlain -0.15151   0.01800 83.00000  -8.416 9.63e-13***
```

11.2.1.1.3.1 C2_HP_(log)_n=180

```
Formula: c2hplog ~ rate + Context + (1 | speaker)
   Data: At_dor_BF
Fixed effects:
              Estimate Std.Error         df tvalue Pr(>|t|)
(Intercept)   1.635742  0.004802 176.000000 340.61   <2e-16***
rateNormal    0.172464  0.005685 176.000000  30.34   <2e-16***
ContextPlain -0.116134  0.005693 176.000000 -20.40   <2e-16***
```

11.2.1.1.3.1 VOT_(log)_n=192

```
Formula: VOTlog ~ rate + Context + (1 | speaker)
   Data: At_dor_BF
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)  1.239e+00 7.044e-03 1.890e+02 175.88   <2e-16***
rateNormal   1.586e-01 8.134e-03 1.890e+02  19.50   <2e-16***
ContextPlain 2.388e-01 8.134e-03 1.890e+02  29.35   <2e-16***
```

11.2.1.1.3.1 Sequence_duration_(log)_n=192

```
Formula: wslog ~ rate + Context + (1 | speaker)
   Data: At_dor_BF
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)  2.127163  0.002790 189.000000 762.35  <2e-16***
rateNormal   0.151380  0.003222 189.000000  46.98  <2e-16***
ContextPlain -0.047220 0.003222 189.000000 -14.66  <2e-16***
```

11.2.1.1.3.1 ICI_ Voicing_Proportion_n=180

None of the independent variables was significant

11.2.1.1.4 t#g vs tˤ#g

11.2.1.1.4.1 C1_HP_(log)_n=181

```
Formula: c1hplog ~ rate + (1 | speaker)
   Data: At_dor_FB
Fixed effects:
            Estimate  Std.Error        df tvalue Pr(>|t|)
(Intercept) 1.629e+00 5.097e-03 1.790e+02 319.66   <2e-16***
rateNormal  1.832e-01 6.999e-03 1.790e+02  26.17   <2e-16***
```

11.2.1.1.4.1 ICI_(log)_n=181

```
Formula: icilog ~ rate + Context + Context * gender + (1 | speaker)
   Data: At_dor_FB
Fixed effects:
                        Estimate Std.Error       df  tvalue Pr(>|t|)
(Intercept)              1.33843   0.01307 176.00000 102.434  <2e-16***
rateNormal               0.14896   0.01200 176.00000  12.411  <2e-16***
ContextPlain            -0.09326   0.01701 176.00000  -5.482 1.44e-07***
genderMale               0.11720   0.01641 176.00000   7.140 2.36e-11***
ContextPlain:genderMale -0.12660   0.02395 176.00000  -5.285 3.69e-07***
```

<u>FURTHER:</u> n=91, n=90

```
Formula: icilog ~ rate + Context + (1 | speaker)
   Data: At_dor_FB_Male
Fixed effects:
            Estimate Std.Error       df tvalue Pr(>|t|)
(Intercept)  1.44031   0.01585 27.96159  90.85  <2e-16***
rateNormal   0.17960   0.01669 81.25563  10.76  <2e-16***
ContextPlain -0.22153  0.01669 81.25563 -13.28  <2e-16***

Formula: icilog ~ rate + Context + (1 | speaker)
   Data: At_dor_FB_Female
Fixed effects:
            Estimate Std.Error       df tvalue Pr(>|t|)
(Intercept)  1.35403   0.01370 87.00000 98.851  <2e-16***
rateNormal   0.11776   0.01621 87.00000  7.266 1.50e-10***
ContextPlain -0.09103  0.01621 87.00000 -5.617 2.29e-07***
```

11.2.1.1.4.1 C2_HP_(log)_n=181

```
Formula: c2hplog ~ rate + Context + (1 | speaker)
   Data: At_dor_FB
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)  1.672944  0.005448 178.000000 307.05  <2e-16***
rateNormal   0.180192  0.006432 178.000000  28.02  <2e-16***
ContextPlain -0.104722 0.006432 178.000000 -16.28  <2e-16***
```

11.2.1.1.4.1 Sequence_duration_(log)_n=192

```
Formula: wslog ~ rate + Context + Context * gender + (1 | speaker)
   Data: At_dor_FB
Fixed effects:
                       Estimate Std.Error         df tvalue Pr(>|t|)
(Intercept)            2.056407  0.005024  42.467909 409.278  <2e-16***
rateNormal             0.172278  0.003847 173.000000  44.785  <2e-16***
ContextPlain          -0.066275  0.005440 173.000000 -12.182  <2e-16***
genderMale             0.028077  0.006564  31.770652   4.277 0.000162***
ContextPlain:genderMale -0.027526 0.007694 173.000000  -3.578 0.000450***
```

FURTHER: n=96, n=96

```
Formula: wslog ~ rate + Context + (1 | speaker)
   Data: At_dor_FB_Male
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)  2.082024  0.006335 18.649891  328.66   <2e-16***
rateNormal   0.177199  0.005652 86.000000   31.35   <2e-16***
ContextPlain -0.093800  0.005652 86.000000  -16.60   <2e-16***

Formula: wslog ~ rate + Context + (1 | speaker)
   Data: At_dor_FB_Female
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)  2.058867  0.004436 93.000000  464.10   <2e-16***
rateNormal   0.167357  0.005123 93.000000   32.67   <2e-16***
ContextPlain -0.066275  0.005123 93.000000  -12.94   <2e-16***
```

11.2.1.1.4.1 ICI_Voicing_Proportion_n=181

None of the independent variables was significant

11.2.1.2 Stop/alveolar fricative sequences

11.2.1.2.1 b#s vs b#sˁ

11.2.1.2.1.1 C1_HP_(log)_n=192

```
Formula: c1hplog ~ rate + (1 | speaker)
   Data: As_lab_FB
Fixed effects:
           Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 1.602e+00  7.684e-03 2.144e+01  208.51   <2e-16***
rateNormal  1.561e-01  6.241e-03 1.750e+02   25.02   <2e-16***
```

11.2.1.2.1.1 ICI_(log)_n=24

```
Formula: icilog ~ rate + (1 | speaker)
   Data: As_lab_FB
Fixed effects:
           Estimate Std.Error       df tvalue Pr(>|t|)
(Intercept)  0.76631   0.04249 22.00000  18.037 1.14e-14***
rateNormal   0.26068   0.04906 22.00000   5.314 2.47e-05***
```

11.2.1.2.1.2 C2_Frication_(log)_n=192

```
Formula: c2friclog ~ rate + (1 | speaker)
   Data: As_lab_FB
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 1.706e+00  8.756e-03 2.154e+01  194.82   <2e-16***
rateNormal  1.956e-01  7.155e-03 1.750e+02   27.35   <2e-16***
```

11.2.1.2.1.1 Sequence_duration_(log)_n=192

```
Formula: wslog ~ rate + (1 | speaker)
   Data: As_lab_FB
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 2.021e+00  4.365e-03 3.452e+01     463   <2e-16***
rateNormal  1.546e-01  5.156e-03 1.750e+02      30   <2e-16***
```

11.2.1.2.1.1 ICI_Voicing_Proportion_n=24

None of the independent variables was significant

11.2.1.2.2 s#b vs sˤ#b

11.2.1.2.2.1 C1_Frication(log)_n=192

```
Formula: c1friclog ~ rate + (1 | speaker)
   Data: As_lab_BF
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)   1.78366   0.00396 190.00000  450.4   <2e-16***
rateNormal    0.12210   0.00560 190.00000   21.8   <2e-16***
```

11.2.1.2.2.2 C2_HP_(log)_n=192

```
Formula: c2hplog ~ rate + (1 | speaker)
   Data: As_lab_BF
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 1.668e+00  5.364e-03 1.900e+02  310.93   <2e-16***
rateNormal  1.389e-01  7.586e-03 1.900e+02   18.31   <2e-16***
```

11.2.1.2.2.3 Sequence_duration_(log)_n=192

```
Formula: wslog ~ rate + (1 | speaker)
   Data: As_lab_BF
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 2.032e+00  3.343e-03 1.900e+02   607.9   <2e-16***
rateNormal  1.290e-01  4.727e-03 1.900e+02    27.3   <2e-16***
```

11.2.1.2.3 g#s vs g#sˤ

11.2.1.2.3.1 C1_HP_(log)_n=192

```
Formula: c1hplog ~ rate + Context + (1 | speaker)
   Data: As_dor_BF
Fixed effects:
              Estimate Std.Error         df tvalue Pr(>|t|)
(Intercept)   1.685867  0.005203  73.314852 324.04   <2e-16***
rateNormal    0.165876  0.005609 173.999994  29.57   <2e-16***
ContextPlain -0.097510  0.005609 173.999994 -17.39   <2e-16***
```

11.2.1.2.3.1 ICI_(log)_n=154

```
Formula: icilog ~ rate + Context + (1 | speaker)
   Data: As_dor_BF
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)   1.36737   0.00927 151.00000  147.51   <2e-16***
rateNormal    0.12744   0.01080 151.00000   11.80   <2e-16***
ContextPlain -0.18499   0.01078 151.00000  -17.16   <2e-16***
```

11.2.1.2.3.1 C2_Frication_(log)_n=192

```
Formula: c2friclog ~ rate + Context + (1 | speaker)
   Data: As_dor_BF
Fixed effects:
              Estimate Std.Error         df tvalue Pr(>|t|)
(Intercept)   1.911935  0.003671  63.964968 520.77   <2e-16***
rateNormal    0.116203  0.003825 174.000000  30.38   <2e-16***
ContextPlain -0.093869  0.003825 174.000000 -24.54   <2e-16***
```

11.2.1.2.3.1 Sequence_duration_(log)_n=192

```
Formula: wslog ~ rate + Context + (1 | speaker)
   Data: As_dor_BF
Fixed effects:
              Estimate Std.Error         df tvalue Pr(>|t|)
(Intercept)   2.187862  0.002846 189.000000 768.86   <2e-16***
rateNormal    0.130870  0.003286 189.000000  39.83   <2e-16***
ContextPlain -0.086314  0.003286 189.000000 -26.27   <2e-16***
```

11.2.1.2.3.1 ICI_Voicing_Proportion_n=154

None of the independent variables was significant

11.2.1.2.4 s#g vs $s^{ʕ}$#g

11.2.1.2.4.1 C1_Frication_(log)_n=192

```
Formula: c1friclog ~ rate + Context + Context:rate + (1 | speaker)
   Data: As_dor_FB
Fixed effects:
                         Estimate Std.Error         df  tvalue Pr(>|t|)
(Intercept)              1.964415  0.005475 188.000000 358.784   <2e-16***
rateNormal               0.120675  0.007743 188.000000  15.585   <2e-16***
ContextPlain            -0.108475  0.007743 188.000000 -14.009   <2e-16***
rateNormal:ContextPlain -0.024064  0.010950 188.000000  -2.198   0.0292*
```

<u>FURTHER:</u> n=96, n=96

```
Formula: c1friclog ~ Context + (1 | speaker)
   Data: As_dor_FB_Normal
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)  2.085089  0.005205 94.000000  400.6   <2e-16***
ContextPlain -0.132539  0.007361 94.000000  -18.0   <2e-16***
```

```
Formula: c1friclog ~ Context + (1 | speaker)
   Data: As_dor_FB_Fast
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)  1.964415  0.005732 94.000000 342.69   <2e-16***
ContextPlain -0.108475  0.008107 94.000000 -13.38   <2e-16***
```

11.2.1.2.4.2 C2_HP_(log)_n=192

```
Formula: c2hplog ~ rate + Context + (1 | speaker)
   Data: As_dor_FB
Fixed effects:
               Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)    1.754412  0.007633 189.000000  229.85   <2e-16***
rateNormal     0.089707  0.008814 189.000000   10.18   <2e-16***
ContextPlain  -0.113235  0.008814 189.000000  -12.85   <2e-16***
```

11.2.1.2.4.1 Sequence_duration_(log)_n=192

```
Formula: wslog ~ rate + Context + (1 | speaker)
   Data: As_dor_FB
Fixed effects:
               Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)    2.177736  0.004441 189.000000  490.38   <2e-16***
rateNormal     0.101319  0.005128 189.000000   19.76   <2e-16***
ContextPlain  -0.117089  0.005128 189.000000  -22.83   <2e-16***
```

11.2.1.3 Stop/dental fricative sequences

11.2.1.3.1 b#ð vs b#ðˤ

11.2.1.3.1.1 C1_HP_(log)_n=170

```
Formula: c1hplog ~ rate + (1 | speaker)
   Data: AD_lab_FB
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 1.545e+00  8.300e-03 2.181e+01  186.20   <2e-16***
rateNormal  2.015e-01  7.293e-03 1.574e+02   27.64   <2e-16***
```

11.2.1.3.1.1 ICI_(log)_n=25

```
Formula: icilog ~ rate + (1 | speaker)
   Data: AD_lab_FB
Fixed effects:
            Estimate Std.Error       df tvalue Pr(>|t|)
(Intercept)  0.80532   0.06564 23.00000  12.270 1.42e-11***
rateNormal   0.29407   0.07735 23.00000   3.802 0.000919***
```

11.2.1.3.1.1 C2_Frication_(log)_n=170

```
Formula: c2friclog ~ rate + (1 | speaker)
   Data: AD_lab_FB
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 1.626e+00  9.230e-03 1.795e+01  176.22   <2e-16***
rateNormal  1.711e-01  5.677e-03 1.553e+02   30.14   <2e-16***
```

11.2.1.3.1.1 Sequence_duration_(log)_n=192

```
Formula: wslog ~ rate + (1 | speaker)
   Data: AD_lab_FB
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 1.934e+00  3.341e-03 1.900e+02  578.86   <2e-16***
rateNormal  1.780e-01  4.725e-03 1.900e+02   37.67   <2e-16***
```

11.2.1.3.1.1 ICI_Voicing_Proportion_n=25

None of the independent variables was significant

11.2.1.3.2 ð#b vs ðˤ#b

11.2.1.3.2.1 C1_Frication_(log)_n=192

```
Formula: c1friclog ~ rate + (1 | speaker)
   Data: AD_lab_BF
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 1.677e+00  5.459e-03 4.125e+01  307.25   <2e-16***
rateNormal  1.249e-01  6.982e-03 1.750e+02   17.89   <2e-16***
```

11.2.1.3.2.2 C2_HP_(log)_n=192

```
Formula: c2hplog ~ rate + (1 | speaker)
   Data: AD_lab_BF
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 1.676e+00  5.149e-03 5.337e+01  325.57   <2e-16***
rateNormal  8.822e-02  7.206e-03 1.750e+02   12.24   <2e-16***
```

11.2.1.3.2.1 Sequence_duration_(log)_n=192

```
Formula: wslog ~ rate + (1 | speaker)
   Data: AD_lab_BF
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 1.979e+00  3.797e-03 4.645e+01  521.25   <2e-16***
rateNormal  1.068e-01  5.077e-03 1.750e+02   21.03   <2e-16***
```

11.2.1.3.3 g#ð vs g#ðˤ

11.2.1.3.3.1 C1_HP_(log)_n=186

```
Formula: c1hplog ~ rate + Context + (1 | speaker)
   Data: AD_dor_BF
Fixed effects:
              Estimate Std.Error         df tvalue Pr(>|t|)
(Intercept)   1.660803  0.008493  42.929054  195.56   <2e-16***
rateNormal    0.196122  0.007736 168.667040   25.35   <2e-16***
ContextPlain -0.144148  0.007735 168.709505  -18.64   <2e-16***
```

11.2.1.3.3.1 ICI_(log)_n=167

```
Formula: icilog ~ rate + Context + (1 | speaker)
   Data: AD_dor_BF
Fixed effects:
             Estimate Std.Error        df  tvalue Pr(>|t|)
(Intercept)   1.41786   0.01225  77.17057 115.714  <2e-16***
rateNormal    0.12411   0.01362 151.50007   9.114 4.46e-16***
ContextPlain -0.22012   0.01354 150.26129 -16.255  <2e-16***
```

11.2.1.3.3.1 C2_Frication_(log)_n=186

```
Formula: c2friclog ~ rate + (1 | speaker)
   Data: AD_dor_BF
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 1.688e+00  6.219e-03 2.608e+01  271.48   <2e-16***
rateNormal  1.569e-01  5.974e-03 1.696e+02   26.27   <2e-16***
```

11.2.1.3.3.1 Sequence_duration_(log)_n=192

```
Formula: wslog ~ rate + Context + (1 | speaker)
   Data: AD_dor_BF
Fixed effects:
              Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)   2.095773  0.005963  39.958919 351.44   <2e-16***
rateNormal    0.150302  0.005324 174.000000  28.23   <2e-16***
ContextPlain -0.066151  0.005324 174.000000 -12.42   <2e-16***
```

11.2.1.3.3.1 ICI_Voicing_Proportion_n=167

None of the independent variables was significant

11.2.1.3.4 ð#g vs ðˤ#g

11.2.1.3.4.1 C1_Frication_(log)_n=192

```
Formula: c1friclog ~ rate + Context + (1 | speaker)
   Data: AD_dor_FB
Fixed effects:
              Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)   1.933739  0.005881  75.273907 328.80   <2e-16***
rateNormal    0.095286  0.006380 173.999952  14.94   <2e-16***
ContextPlain -0.160014  0.006380 173.999952 -25.08   <2e-16***
```

11.2.1.3.4.2 C2_HP_(log)_n=192

```
Formula: c2hplog ~ rate + (1 | speaker)
   Data: AD_dor_FB
Fixed effects:
             Estimate Std.Error       df tvalue Pr(>|t|)
(Intercept) 1.726e+00  5.187e-03 1.900e+02 332.81   <2e-16***
rateNormal  8.016e-02  7.335e-03 1.900e+02  10.93   <2e-16***
```

11.2.1.3.4.1 Sequence_duration_(log)_n=192

```
Formula: wslog ~ rate + Context + (1 | speaker)
   Data: AD_dor_FB
Fixed effects:
              Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)   2.150918  0.004278  84.922177 502.74   <2e-16***
rateNormal    0.088708  0.004770 173.999998  18.60   <2e-16***
ContextPlain -0.105682  0.004770 173.999998 -22.16   <2e-16***
```

11.2.2 Results of Chapter 7 (The state of the glottis and gestural overlap)

11.2.2.1 Stop/stop consonant sequences

11.2.2.1.1 #bt ~ #btˤ ~ #bd (word-initial)

11.2.2.1.1.1 /d/_reference:

11.2.2.1.1.2 C1_HP_(log)_n=139

```
Formula: c1hplog ~ rate + (1 | speaker)
   Data: Bini_plos_FB
Fixed effects:
             Estimate Std.Error       df tvalue Pr(>|t|)
(Intercept) 1.642e+00  5.287e-03 1.370e+02 310.54   <2e-16***
rateNormal  1.743e-01  6.801e-03 1.370e+02  25.62   <2e-16***
```

11.2.2.1.1.1 ICI_(log)_n=139

```
Formula: icilog ~ rate + Context + (1 | speaker)
   Data: Bini_plos_FB
Fixed effects:
                       Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)             1.06662   0.01562 135.00000   68.28  <2e-16***
rateNormal              0.11475   0.01069 135.00000   10.74  <2e-16***
ContextEmphatic         0.19335   0.01721 135.00000   11.24  <2e-16***
ContextPlain_Voiceless  0.37806   0.01532 135.00000   24.68  <2e-16***
```

11.2.2.1.1.2 C2_HP_(log)_n=139

```
Formula: c2hplog ~ rate + Context + (1 | speaker)
   Data: Bini_plos_FB
Fixed effects:
                        Estimate Std.Error         df tvalue Pr(>|t|)
(Intercept)             1.572397  0.008468 136.000000 185.691  <2e-16***
rateNormal              0.245384  0.005792 136.000000  42.363  <2e-16***
ContextEmphatic         0.054689  0.029355 136.000000   1.863  0.06462 .
ContextPlain_Voiceless -0.070294  0.008305 136.000000  -8.464 3.81e-14***
```

11.2.2.1.1.1 Sequence_duration_(log)_n=288

```
Formula: wslog ~ rate + Context + (1 | speaker)
   Data: Bini_plos_FB
Fixed effects:
                       Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)           1.954e+00  8.191e-03 2.840e+02 238.59   <2e-16***
rateNormal            1.786e-01  8.191e-03 2.840e+02  21.81   <2e-16***
ContextEmphatic       1.064e-01  1.003e-02 2.840e+02  10.60   <2e-16***
ContextPlain_Voiceless 1.634e-01 1.003e-02 2.840e+02  16.28   <2e-16***
```

11.2.2.1.1.1 ICI_Voicing_Proportion_n=139

```
Formula: ici_voicing ~ Context + (1 | speaker)
   Data: Bini_plos_FB
Fixed effects:
                       Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)             1.00000   0.01043 136.00000  95.89  <2e-16***
ContextEmphatic        -0.23074   0.01307 136.00000 -17.65  <2e-16***
ContextPlain_Voiceless -0.46929   0.01160 136.00000 -40.44  <2e-16***
```

11.2.2.1.1.2 /tˤ/_Reference:

11.2.2.1.1.1 C1_HP_(log)_n=139

```
Formula: c1hplog ~ rate + (1 | speaker)
   Data: Bini_plos_FB
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 1.642e+00 5.287e-03 1.370e+02 310.54   <2e-16***
rateNormal  1.743e-01 6.801e-03 1.370e+02  25.62   <2e-16***
```

11.2.2.1.1.1 ICI_(log)_n=139

```
Formula: icilog ~ rate + Context + (1 | speaker)
   Data: Bini_plos_FB
Fixed effects:
                       Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)             1.25998   0.01235 135.00000 102.00  <2e-16***
rateNormal              0.11475   0.01069 135.00000  10.74  <2e-16***
ContextPlain_Voiced    -0.19335   0.01721 135.00000 -11.24  <2e-16***
ContextPlain_Voiceless  0.18471   0.01235 135.00000  14.95  <2e-16***
```

11.2.2.1.1.1 C2_HP_(log)_n=139

```
Formula: c2hplog ~ rate + Context + (1 | speaker)
   Data: Bini_plos_FB
Fixed effects:
                         Estimate Std.Error         df tvalue Pr(>|t|)
(Intercept)              1.627086  0.006696 135.000000 242.996  <2e-16***
rateNormal               0.245384  0.005792 135.000000  42.363  <2e-16***
ContextPlain_Voiced     -0.054689  0.009328 135.000000  -5.863 3.32e-08***
ContextPlain_Voiceless  -0.124983  0.006697 135.000000 -18.663  <2e-16***
```

11.2.2.1.1.1 VOT_(log)_n=192

```
Formula: VOTlog ~ rate + Context + (1 | speaker)
   Data: Bini_plos_FB
Fixed effects:
                        Estimate Std. Error        df t value Pr(>|t|)
(Intercept)            1.229e+00  6.054e-03 9.509e+01  202.97   <2e-16***
rateNormal             1.862e-01  6.912e-03 1.740e+02   26.94   <2e-16***
ContextPlain_Voiceless 2.261e-01  6.912e-03 1.740e+02   32.70   <2e-16***
```

11.2.2.1.1.1 Sequence_duration_(log)_n=288

```
Formula: wslog ~ rate + Context + (1 | speaker)
   Data: Bini_plos_FB
Fixed effects:
                         Estimate Std.Error         df tvalue Pr(>|t|)
(Intercept)              2.060554  0.008191 284.000000 251.571  <2e-16***
rateNormal               0.178639  0.008191 284.000000  21.810  <2e-16***
ContextPlain_Voiced     -0.106358  0.010032 284.000000 -10.602  <2e-16***
ContextPlain_Voiceless   0.056999  0.010032 284.000000   5.682  3.3e-08***
```

11.2.2.1.1.1 ICI_Voicing_Proportion_n=139

```
Formula: ici_voicing ~ Context + (1 | speaker)
   Data: Bini_plos_FB
Fixed effects:
                         Estimate Std.Error         df tvalue Pr(>|t|)
(Intercept)              0.769263  0.007883 136.000000   97.58   <2e-16***
ContextPlain_Voiced      0.230737  0.013073 136.000000   17.65   <2e-16***
ContextPlain_Voiceless  -0.238549  0.009383 136.000000  -25.42   <2e-16***
```

11.2.2.1.2 bt# ~ btˤ# ~ bd# (word-final)

11.2.2.1.2.1 /d/_Reference:

11.2.2.1.2.2 C1_HP_(log)_n=96

```
Formula: c1hplog ~ rate + (1 | speaker)
   Data: Bfin_plos_FB
Fixed effects:
            Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 1.740444  0.006642 94.000000 262.06   <2e-16***
rateNormal  0.133394  0.008198 94.000000  16.27   <2e-16***
```

11.2.2.1.2.1 ICI_(log)_n=96

```
Formula: icilog ~ rate + Context + (1 | speaker)
   Data: Bfin_plos_FB
Fixed effects:
                       Estimate Std.Error       df tvalue Pr(>|t|)
(Intercept)             0.64481   0.03195 92.00000 20.182  <2e-16***
rateNormal              0.12949   0.01690 92.00000  7.661 1.81e-11***
ContextEmphatic         0.36153   0.03307 92.00000 10.933  <2e-16***
ContextPlain_Voiceless  0.60406   0.02935 92.00000 20.579  <2e-16***
```

11.2.2.1.2.1 C2_HP_(log)_n=96

```
Formula: c2hplog ~ rate + (1 | speaker)
   Data: Bfin_plos_FB
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 1.509313  0.007767 94.000000 194.33   <2e-16***
rateNormal  0.198878  0.009588 94.000000  20.74   <2e-16***
```

11.2.2.1.2.1 Sequence_duration_(log)_n=288

```
Formula: wslog ~ rate + Context + (1 | speaker)
   Data: Bfin_plos_FB
Fixed effects:
                        Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)            1.949e+00 4.177e-03 2.840e+02 466.45   <2e-16***
rateNormal             1.310e-01 4.177e-03 2.840e+02  31.36   <2e-16***
ContextEmphatic        8.391e-02 5.116e-03 2.840e+02  16.40   <2e-16***
ContextPlain_Voiceless 1.119e-01 5.116e-03 2.840e+02  21.87   <2e-16***
```

11.2.2.1.2.1 ICI_Voicing_Proportion_n=96

```
Formula: ici_voicing ~ Context + (1 | speaker)
   Data: Bfin_plos_FB
Fixed effects:
                       Estimate Std.Error       df  tvalue Pr(>|t|)
(Intercept)             0.98130   0.01754 93.00000  55.962  <2e-16***
ContextEmphatic        -0.21006   0.02107 93.00000  -9.967  2.4e-16***
ContextPlain_Voiceless -0.38818   0.01851 93.00000 -20.972  <2e-16***
```

11.2.2.1.2.2 /tˤ/_Reference:

11.2.2.1.2.1 C1_HP_(log)_n=96

```
Formula: c1hplog ~ rate + (1 | speaker)
   Data: Bfin_plos_FB
Fixed effects:
            Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 1.740444  0.006642 94.000000 262.06   <2e-16***
rateNormal  0.133394  0.008198 94.000000  16.27   <2e-16***
```

11.2.2.1.2.1 ICI_(log)_n=96

```
Formula: icilog ~ rate + Context + Context * gender + (1 | speaker)
   Data: Bfin_plos_FB
Fixed effects:
                                  Estimate Std.Error       df  tvalue Pr(>|t|)
(Intercept)                        1.07135   0.02097 89.00000  51.090  <2e-16***
rateNormal                         0.13113   0.01269 89.00000  10.334  <2e-16***
ContextPlain_Voiced               -0.43074   0.03485 89.00000 -12.360  <2e-16***
ContextPlain_Voiceless             0.12321   0.02173 89.00000   5.671 1.74e-07***
genderMale                        -0.13221   0.02714 89.00000  -4.872 4.77e-06***
ContextPlain_Voiced:genderMale     0.13732   0.07599 89.00000   1.807  0.07414
ContextPlain_Voiceless:genderMale  0.23040   0.03045 89.00000   7.567 3.34e-11***
```

FURTHER: n=51, n=45

```
Formula: icilog ~ rate + Context + (1 | speaker)
   Data: Bfin_plos_FB_Male
Fixed effects:
                        Estimate Std.Error       df tvalue Pr(>|t|)
(Intercept)              0.92714   0.02248 47.00000  41.235  <2e-16***
rateNormal               0.14914   0.01737 47.00000   8.586 3.45e-11***
ContextPlain_Voiced     -0.29942   0.03522 47.00000  -8.501 4.60e-11***
ContextPlain_Voiceless   0.35471   0.02146 47.00000  16.529  <2e-16***
```

```
Formula: icilog ~ rate + Context + (1 | speaker)
   Data: Bfin_plos_FB_Female
Fixed effects:
                        Estimate Std.Error       df tvalue Pr(>|t|)
(Intercept)              1.08536   0.02238 41.00000  48.507  <2e-16***
rateNormal               0.11013   0.01827 41.00000   6.028 3.95e-07***
ContextPlain_Voiced     -0.42374   0.03438 41.00000 -12.324 2.27e-15***
ContextPlain_Voiceless   0.12233   0.02126 41.00000   5.754 9.68e-07***
```

11.2.2.1.2.1 C2_HP_(log)_n=96

```
Formula: c2hplog ~ rate + (1 | speaker)
   Data: Bfin_plos_FB
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 1.509313  0.007767 94.000000 194.33   <2e-16***
rateNormal  0.198878  0.009588 94.000000  20.74   <2e-16***
```

11.2.2.1.2.1 Sequence_duration_(log)_n=288

```
Formula: wslog ~ rate + (1 | speaker)
   Data: Bfin_plos_FB
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 2.014e+00  4.947e-03 2.860e+02 407.12   <2e-16***
rateNormal  1.310e-01  6.995e-03 2.860e+02  18.73   <2e-16***
```

11.2.2.1.2.1 ICI_Voicing_Proportion_n=96

```
Formula: ici_voicing ~ Context + (1 | speaker)
   Data: Bfin_plos_FB
Fixed effects:
                        Estimate Std.Error       df tvalue Pr(>|t|)
(Intercept)              0.77124   0.01169 93.00000  65.975  <2e-16***
ContextPlain_Voiced      0.21006   0.02107 93.00000   9.967  2.4e-16***
ContextPlain_Voiceless  -0.17813   0.01311 93.00000 -13.590  <2e-16***
```

11.2.2.1.3 #tb ~ #tˤb ~ #db (word-initial)

11.2.2.1.3.1 /d/_Reference:

11.2.2.1.3.2 C1_HP_(log)_n=216

```
Formula: c1hplog ~ rate + (1 | speaker)
   Data: Bini_plos_BF
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 1.670e+00  3.567e-03 2.140e+02 468.10   <2e-16***
rateNormal  2.133e-01  4.805e-03 2.140e+02  44.39   <2e-16***
```

11.2.2.1.3.1 ICI_(log)_n=216

```
Formula: icilog ~ rate + Context + (1 | speaker)
   Data: Bini_plos_BF
Fixed effects:
                        Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)              1.30114   0.01464 212.00000 88.860  <2e-16***
rateNormal               0.12108   0.01086 212.00000 11.147  <2e-16***
ContextEmphatic          0.04449   0.02410 212.00000  1.846  0.06629
ContextPlain_Voiceless   0.19828   0.01535 212.00000 12.917  <2e-16***
```

11.2.2.1.3.1 C2_HP_(log)_n=216

```
Formula: c2hplog ~ rate + (1 | speaker)
   Data: Bini_plos_BF
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 1.663e+00  3.258e-03 2.140e+02  510.56   <2e-16***
rateNormal  2.073e-01  4.389e-03 2.140e+02   47.22   <2e-16***
```

11.2.2.1.3.1 Sequence_duration_(log)_n=288

```
Formula: wslog ~ rate + Context + (1 | speaker)
   Data: Bini_plos_BF
Fixed effects:
                        Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)            2.069e+00  3.766e-03 1.443e+02 549.426  <2e-16***
rateNormal             1.682e-01  3.708e-03 2.690e+02  45.361  <2e-16***
ContextEmphatic        2.444e-02  4.541e-03 2.690e+02   5.383 1.60e-07***
ContextPlain_Voiceless 2.615e-02  4.541e-03 2.690e+02   5.759 2.31e-08***
```

11.2.2.1.3.1 ICI_Voicing_Proportion_n=216

```
Formula: ici_voicing ~ Context + (1 | speaker)
   Data: Bini_plos_BF
Fixed effects:
                        Estimate Std.Error         df tvalue Pr(>|t|)
(Intercept)             0.990478  0.006188 213.000000 160.07   <2e-16***
ContextEmphatic        -0.309990  0.007440 213.000000 -41.66   <2e-16***
ContextPlain_Voiceless -0.493446  0.007283 213.000000 -67.75   <2e-16***
```

11.2.2.1.3.2 /tˤ/_Reference:

11.2.2.1.3.1 C1_HP_(log)_n=216

```
Formula: c1hplog ~ rate + (1 | speaker)
   Data: Bini_plos_BF
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 1.670e+00  3.567e-03 2.140e+02  468.10   <2e-16***
rateNormal  2.133e-01  4.805e-03 2.140e+02   44.39   <2e-16***
```

11.2.2.1.3.1 ICI_(log)_n=216

```
Formula: icilog ~ rate + Context + (1 | speaker)
   Data: Bini_plos_BF
Fixed effects:
                        Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)              1.34563   0.01071 212.00000 125.638  <2e-16***
rateNormal               0.12108   0.01086 212.00000  11.147  <2e-16***
ContextPlain_Voiced     -0.04449   0.02410 212.00000  -1.846  0.06629 .
ContextPlain_Voiceless   0.15379   0.01188 212.00000  12.950  <2e-16***
```

11.2.2.1.3.1 C2_HP_(log)_n=216

```
Formula: c2hplog ~ rate + (1 | speaker)
   Data: Bini_plos_BF
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 1.663e+00  3.258e-03 2.140e+02  510.56   <2e-16***
rateNormal  2.073e-01  4.389e-03 2.140e+02   47.22   <2e-16***
```

11.2.2.1.3.1 Sequence_duration_(log)_n=288

```
Formula: wslog ~ rate + (1 | speaker)
   Data: Bini_plos_BF
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 2.086e+00  2.805e-03 2.860e+02  743.6   <2e-16***
rateNormal  1.682e-01  3.967e-03 2.860e+02   42.4   <2e-16***
```

11.2.2.1.3.1 ICI_Voicing_Proportion_n=216

```
Formula: ici_voicing ~ Context + (1 | speaker)
   Data: Bini_plos_BF
Fixed effects:
                         Estimate Std.Error         df tvalue Pr(>|t|)
(Intercept)              0.680488  0.004131 213.000000 164.71   <2e-16***
ContextPlain_Voiced      0.309990  0.007440 213.000000  41.66   <2e-16***
ContextPlain_Voiceless  -0.183456  0.005641 213.000000 -32.52   <2e-16***
```

11.2.2.1.4 tb# ~ tˤb# ~ db# (word-final)

11.2.2.1.4.1 /d/_Reference:

11.2.2.1.4.2 C1_HP_(log)_n=286

```
Formula: c1hplog ~ rate + (1 | speaker)
   Data: Bfin_plos_BF
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 1.568e+00  3.977e-03 5.533e+01  394.19   <2e-16***
rateNormal  2.346e-01  5.551e-03 2.691e+02   42.26   <2e-16***
```

11.2.2.1.4.1 ICI_(log)_n=286

```
Formula: icilog ~ rate + (1 | speaker)
   Data: Bfin_plos_BF
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 1.741e+00  3.040e-03 2.840e+02  572.70   <2e-16***
rateNormal  1.098e-01  4.285e-03 2.840e+02   25.62   <2e-16***
```

11.2.2.1.4.1 C2_HP_(log)_n=286

```
Formula: c2hplog ~ rate + (1 | speaker)
   Data: Bfin_plos_BF
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 1.679e+00  2.453e-03 2.840e+02  684.38   <2e-16***
rateNormal  2.069e-01  3.457e-03 2.840e+02   59.85   <2e-16***
```

11.2.2.1.4.1 Sequence_duration_(log)_n=288

```
Formula: wslog ~ rate + (1 | speaker)
   Data: Bfin_plos_BF
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 2.146e+00  1.776e-03 4.961e+01 1208.21   <2e-16***
rateNormal  1.793e-01  2.412e-03 2.710e+02   74.34   <2e-16***
```

11.2.2.1.4.1 ICI_Voicing_Proportion_n=286

None of the independent variables was significant

11.2.2.1.4.2 /tˤ/_Reference:

11.2.2.1.4.1 C1_HP_(log)_n=286

```
Formula: c1hplog ~ rate + (1 | speaker)
   Data: Bfin_plos_BF
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 1.568e+00  3.977e-03 5.533e+01  394.19   <2e-16***
rateNormal  2.346e-01  5.551e-03 2.691e+02   42.26   <2e-16***
```

11.2.2.1.4.1 ICI_(log)_n=286

```
Formula: icilog ~ rate + (1 | speaker)
   Data: Bfin_plos_BF
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 1.741e+00  3.040e-03 2.840e+02  572.70   <2e-16***
rateNormal  1.098e-01  4.285e-03 2.840e+02   25.62   <2e-16***
```

11.2.2.1.4.1 C2_HP_(log)_n=286

```
Formula: c2hplog ~ rate + (1 | speaker)
   Data: Bfin_plos_BF
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 1.679e+00  2.453e-03 2.840e+02  684.38   <2e-16***
rateNormal  2.069e-01  3.457e-03 2.840e+02   59.85   <2e-16***
```

11.2.2.1.4.1 Sequence_duration_(log)_n=288

```
Formula: wslog ~ rate + (1 | speaker)
   Data: Bfin_plos_BF
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 2.146e+00  1.776e-03 4.961e+01 1208.21   <2e-16***
rateNormal  1.793e-01  2.412e-03 2.710e+02   74.34   <2e-16***
```

11.2.2.1.4.1 ICI_Voicing_Proportion_n=286

None of the independent variables was significant

11.2.2.2 Stop/alveolar fricative sequences

11.2.2.2.1 #bs ~ #bsˤ ~ #bz (word-initial)

11.2.2.2.1.1 /z/_Reference:

11.2.2.2.1.2 C1_HP_(log)_n=288

```
Formula: c1hplog ~ rate + (1 | speaker)
   Data: Bini_fric_alv_FB
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 1.587e+00  4.499e-03 3.142e+01  352.70   <2e-16***
rateNormal  2.405e-01  5.034e-03 2.710e+02   47.77   <2e-16***
```

11.2.2.2.1.1 ICI_(log)_n=174

```
Formula: icilog ~ rate + Context + (1 | speaker)
   Data: Bini_fric_alv_FB
Fixed effects:
                         Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)             6.987e-01  1.519e-02 1.656e+02   46.00   <2e-16***
rateNormal              1.544e-01  9.718e-03 1.592e+02   15.89   <2e-16***
ContextEmphatic         5.801e-01  1.541e-02 1.617e+02   37.65   <2e-16***
ContextPlain_Voiceless 5.921e-01  1.536e-02 1.635e+02   38.56   <2e-16***
```

11.2.2.2.1.1 C2_Frication_(log)_n=288

```
Formula: c2friclog ~ rate + Context + (1 | speaker)
   Data: Bini_fric_alv_FB
Fixed effects:
                         Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)             1.859e+00  4.342e-03 5.146e+01  428.19   <2e-16***
rateNormal              1.490e-01  3.444e-03 2.690e+02   43.28   <2e-16***
ContextEmphatic         1.019e-01  4.218e-03 2.690e+02   24.17   <2e-16***
ContextPlain_Voiceless 8.542e-02  4.218e-03 2.690e+02   20.25   <2e-16***
```

11.2.2.2.1.1 Sequence_duration_(log)_n=288

```
Formula: wslog ~ rate + Context + (1 | speaker)
   Data: Bini_fric_alv_FB
Fixed effects:
                         Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)             2.072e+00  3.415e-03 1.113e+02  606.57   <2e-16***
rateNormal              1.515e-01  3.224e-03 2.690e+02   47.00   <2e-16***
ContextEmphatic         1.178e-01  3.949e-03 2.690e+02   29.84   <2e-16***
ContextPlain_Voiceless 1.085e-01  3.949e-03 2.690e+02   27.47   <2e-16***
```

11.2.2.2.1.1 ICI_Voicing_Proportion_n=174

```
Formula: ici_voicing ~ Context + (1 | speaker)
   Data: Bini_fric_alv_FB
Fixed effects:
                        Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)              0.99864   0.01148 145.52776   86.97   <2e-16***
ContextEmphatic         -0.32855   0.01245 160.44550  -26.40   <2e-16***
ContextPlain_Voiceless  -0.34206   0.01242 162.02217  -27.54   <2e-16***
```

11.2.2.2.1.2 /sˤ/_Reference:

11.2.2.2.1.1 C1_HP_(log)_n=288

```
Formula: c1hplog ~ rate + (1 | speaker)
   Data: Bini_fric_alv_FB
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 1.587e+00  4.499e-03 3.142e+01  352.70   <2e-16***
rateNormal  2.405e-01  5.034e-03 2.710e+02   47.77   <2e-16***
```

11.2.2.2.1.1 ICI_(log)_n=174

```
Formula: icilog ~ rate + (1 | speaker)
   Data: Bini_fric_alv_FB
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)   1.22365   0.02467 172.00000  49.593  <2e-16***
rateNormal    0.13892   0.03146 172.00000   4.415 1.78e-05***
```

11.2.2.2.1.1 C2_Frication_(log)_n=288

```
Formula: c2friclog ~ rate + (1 | speaker)
   Data: Bini_fric_alv_FB
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 1.922e+00  4.536e-03 2.860e+02  423.65   <2e-16***
rateNormal  1.490e-01  6.415e-03 2.860e+02   23.23   <2e-16***
```

11.2.2.2.1.1 Sequence_duration_(log)_n=288

```
Formula: wslog ~ rate + (1 | speaker)
   Data: Bini_fric_alv_FB
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 2.147e+00  5.029e-03 2.860e+02  426.93   <2e-16***
rateNormal  1.515e-01  7.112e-03 2.860e+02   21.31   <2e-16***
```

11.2.2.2.1.1 ICI_Voicing_Proportion_n=174

None of the independent variables was significant

11.2.2.2.2 bs# ~ bsˤ# ~ bz# (word-final)

11.2.2.2.2.1 /z/_Reference:

11.2.2.2.2.2 C1_HP_(log)_n=284

```
Formula: c1hplog ~ rate + (1 | speaker)
   Data: Bfin_fric_alv_FB
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 1.550e+00  6.602e-03 2.053e+01  234.72   <2e-16***
rateNormal  2.391e-01  5.053e-03 2.672e+02   47.32   <2e-16***
```

11.2.2.2.2.1 ICI_(log)_n=63

```
Formula: icilog ~ rate + Context + (1 | speaker)
   Data: Bfin_fric_alv_FB
Fixed effects:
                      Estimate Std.Error       df tvalue Pr(>|t|)
(Intercept)            0.79905   0.03325 59.00000 24.030  <2e-16***
rateNormal             0.24013   0.02235 59.00000 10.744 1.63e-15***
ContextEmphatic        0.25458   0.03300 59.00000  7.714 1.67e-10***
ContextPlain_Voiceless 0.29044   0.03237 59.00000  8.972 1.27e-12***
```

11.2.2.2.2.1 C2_Frication_(log)_n=284

```
Formula: c2friclog ~ rate + Context + (1 | speaker)
   Data: Bfin_fric_alv_FB
Fixed effects:
                        Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)            1.748e+00  5.554e-03 4.730e+01 314.70   <2e-16***
rateNormal             1.438e-01  4.250e-03 2.653e+02  33.84   <2e-16***
ContextEmphatic        1.537e-01  5.225e-03 2.653e+02  29.42   <2e-16***
ContextPlain_Voiceless 1.409e-01  5.225e-03 2.653e+02  26.97   <2e-16***
```

11.2.2.2.2.1 Sequence_duration_(log)_n=288

```
Formula: wslog ~ rate + Context + (1 | speaker)
   Data: Bfin_fric_alv_FB
Fixed effects:
                        Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)            2.035e+00  3.957e-03 1.165e+02 514.28   <2e-16***
rateNormal             1.240e-01  3.765e-03 2.690e+02  32.95   <2e-16***
ContextEmphatic        9.920e-02  4.611e-03 2.690e+02  21.51   <2e-16***
ContextPlain_Voiceless 9.524e-02  4.611e-03 2.690e+02  20.65   <2e-16***
```

11.2.2.2.2.1 ICI_Voicing_Proportion_n=63

```
Formula: ici_voicing ~ Context + (1 | speaker)
   Data: Bfin_fric_alv_FB
Fixed effects:
                       Estimate Std.Error       df tvalue Pr(>|t|)
(Intercept)             0.97431   0.01453 60.00000  67.07   <2e-16***
ContextEmphatic        -0.43742   0.01669 60.00000 -26.21   <2e-16***
ContextPlain_Voiceless -0.38227   0.01635 60.00000 -23.38   <2e-16***
```

11.2.2.2.2 /sˤ/_Reference:

11.2.2.2.2.1 C1_HP_(log)_n=284

```
Formula: c1hplog ~ rate + (1 | speaker)
   Data: Bfin_fric_alv_FB
Fixed effects:
            Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 1.550e+00 6.602e-03 2.053e+01 234.72   <2e-16***
rateNormal  2.391e-01 5.053e-03 2.672e+02  47.32   <2e-16***
```

11.2.2.2.2.1 ICI_(log)_n=63

```
Formula: icilog ~ rate + (1 | speaker)
   Data: Bfin_fric_alv_FB
Fixed effects:
            Estimate Std.Error       df tvalue Pr(>|t|)
(Intercept)  1.04571   0.02833 61.00000 36.911  <2e-16***
rateNormal   0.22964   0.03390 61.00000  6.774 5.66e-09***
```

11.2.2.2.2.1 C2_Frication_(log)_n=284

```
Formula: c2friclog ~ rate + (1 | speaker)
   Data: Bfin_fric_alv_FB
Fixed effects:
            Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 1.847e+00 6.623e-03 2.820e+02 278.85   <2e-16***
rateNormal  1.452e-01 9.400e-03 2.820e+02  15.45   <2e-16***
```

11.2.2.2.2.1 Sequence_duration_(log)_n=288

```
Formula: wslog ~ rate + (1 | speaker)
   Data: Bfin_fric_alv_FB
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 2.100e+00  4.680e-03 2.860e+02  448.71   <2e-16***
rateNormal  1.240e-01  6.618e-03 2.860e+02   18.74   <2e-16***
```

11.2.2.2.2.1 ICI_Voicing_Proportion_n=63

None of the independent variables was significant

11.2.2.2.3 #sb ~ #s^{ʕ}b ~ #zb (word-initial)

11.2.2.2.3.1 /z/_Reference:

11.2.2.2.3.2 C1_Frication_(log)_n=288

```
Formula: c1friclog ~ rate + Context + (1 | speaker)
   Data: Bini_fric_alv_BF
Fixed effects:
                         Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)             1.802e+00  3.429e-03 2.840e+02  525.38   <2e-16***
rateNormal              1.495e-01  3.429e-03 2.840e+02   43.59   <2e-16***
ContextEmphatic         1.117e-01  4.200e-03 2.840e+02   26.61   <2e-16***
ContextPlain_Voiceless 1.151e-01  4.200e-03 2.840e+02   27.40   <2e-16***
```

11.2.2.2.3.3 C2_HP_(log)_n=288

```
Formula: c2hplog ~ rate + Context + (1 | speaker)
   Data: Bini_fric_alv_BF
Fixed effects:
                         Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)             1.671e+00  3.604e-03 1.528e+02  463.60   <2e-16***
rateNormal              1.706e-01  3.579e-03 2.690e+02   47.67   <2e-16***
ContextEmphatic         1.295e-01  4.384e-03 2.690e+02   29.53   <2e-16***
ContextPlain_Voiceless 1.335e-01  4.384e-03 2.690e+02   30.46   <2e-16***
```

11.2.2.2.3.1 Sequence_duration_(log)_n=288

```
Formula: wslog ~ rate + Context + (1 | speaker)
   Data: Bini_fric_alv_BF
Fixed effects:
                         Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept)             2.043e+00  2.624e-03 2.840e+02  778.48   <2e-16***
rateNormal              1.587e-01  2.624e-03 2.840e+02   60.48   <2e-16***
ContextEmphatic         1.193e-01  3.214e-03 2.840e+02   37.11   <2e-16***
ContextPlain_Voiceless 1.228e-01  3.214e-03 2.840e+02   38.21   <2e-16***
```

11.2.2.2.3.2 /s^ʕ/_Reference:

11.2.2.2.3.1 C1_Frication_(log)_n=288

```
Formula: c1friclog ~ rate + (1 | speaker)
   Data: Bini_fric_alv_BF
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 1.877e+00  5.083e-03 2.860e+02  369.28   <2e-16***
rateNormal  1.495e-01  7.189e-03 2.860e+02   20.79   <2e-16***
```

11.2.2.2.3.1 C2_HP_(log)_n=288

```
Formula: c2hplog ~ rate + (1 | speaker)
   Data: Bini_fric_alv_BF
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 1.758e+00  5.768e-03 2.860e+02  304.82   <2e-16***
rateNormal  1.706e-01  8.158e-03 2.860e+02   20.92   <2e-16***
```

11.2.2.2.3.1 Sequence_duration_(log)_n=288

```
Formula: wslog ~ rate + (1 | speaker)
   Data: Bini_fric_alv_BF
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 2.123e+00  5.118e-03 2.860e+02  414.87   <2e-16***
rateNormal  1.587e-01  7.238e-03 2.860e+02   21.92   <2e-16***
```

11.2.2.2.4 sb# ~ sˤb# ~ zb# (word-final)

11.2.2.2.4.1 /z/_Reference:

11.2.2.2.4.2 C1_Frication_(log)_n=288

```
Formula: c1friclog ~ rate + (1 | speaker)
   Data: Bfin_fric_alv_BF
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 1.923e+00  3.616e-03 5.941e+01  531.81   <2e-16***
rateNormal  1.333e-01  5.021e-03 2.642e+02   26.54   <2e-16***
```

11.2.2.2.4.3 ICI_(log)_n=280

```
Formula: icilog ~ rate + (1 | speaker)
   Data: Bfin_fric_alv_BF
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 1.705e+00  3.183e-03 2.780e+02  535.65   <2e-16***
rateNormal  1.190e-01  4.438e-03 2.780e+02   26.82   <2e-16***
```

11.2.2.2.4.4 C2_HP_(log)_n=288

```
Formula: c2hplog ~ rate + (1 | speaker)
   Data: Bfin_fric_alv_BF
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 1.765e+00  3.280e-03 4.056e+01  538.16   <2e-16***
rateNormal  1.829e-01  4.042e-03 2.636e+02   45.24   <2e-16***
```

11.2.2.2.4.1 Sequence_duration_(log)_n=288

```
Formula: wslog ~ rate + (1 | speaker)
   Data: Bfin_fric_alv_BF
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 2.285e+00  1.868e-03 4.030e+01 1223.17   <2e-16***
rateNormal  1.458e-01  2.355e-03 2.710e+02   61.93   <2e-16***
```

11.2.2.2.4.1 ICI_Voicing_Proportion_n=280

None of the independent variables was significant

11.2.2.2.4.2 /sˤ/_Reference:

11.2.2.2.4.1 C1_Frication_(log)_n=288

```
Formula: c1friclog ~ rate + (1 | speaker)
   Data: Bfin_fric_alv_BF
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 1.923e+00  3.616e-03 5.941e+01  531.81   <2e-16***
rateNormal  1.333e-01  5.021e-03 2.642e+02   26.54   <2e-16***
```

11.2.2.2.4.1 ICI_(log)_n=280

```
Formula: icilog ~ rate + (1 | speaker)
   Data: Bfin_fric_alv_BF
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 1.705e+00  3.183e-03 2.780e+02  535.65   <2e-16***
rateNormal  1.190e-01  4.438e-03 2.780e+02   26.82   <2e-16***
```

11.2.2.2.4.1 C2_HP_(log)_n=288

```
Formula: c2hplog ~ rate + (1 | speaker)
   Data: Bfin_fric_alv_BF
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 1.765e+00  3.280e-03 4.056e+01  538.16   <2e-16***
rateNormal  1.829e-01  4.042e-03 2.636e+02   45.24   <2e-16***
```

11.2.2.2.4.1 Sequence_duration_(log)_n=288

```
Formula: wslog ~ rate + (1 | speaker)
   Data: Bfin_fric_alv_BF
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 2.285e+00  1.868e-03 4.030e+01 1223.17   <2e-16***
rateNormal  1.458e-01  2.355e-03 2.710e+02   61.93   <2e-16***
```

11.2.2.2.4.1 ICI_Voicing_Proportion_n=280

None of the independent variables was significant

11.2.3 Results of Chapter 8 (The types of inserted vowels and emphasis)

11.2.3.1 Stop/stop consonant sequences

11.2.3.1.1 Cb#tC vs Cb#tˤC

11.2.3.1.1.1 C1_HP_(log)_n=192

```
Formula: c1hplog ~ rate + (1 | speaker)
   Data: Ct4_FB
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 1.618e+00  4.109e-03 1.900e+02  393.69   <2e-16***
rateNormal  2.352e-01  5.811e-03 1.900e+02   40.47   <2e-16***
```

11.2.3.1.1.1 ICI_(log)_n=192

```
Formula: icilog ~ rate + (1 | speaker)
   Data: Ct4_FB
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 1.752e+00  3.052e-03 1.900e+02  573.93   <2e-16***
rateNormal  9.896e-02  4.316e-03 1.900e+02   22.93   <2e-16***
```

11.2.3.1.1.1 C2_HP_(log)_n=192

```
Formula: c2hplog ~ rate + (1 | speaker)
   Data: Ct4_FB
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 1.593e+00  4.613e-03 1.900e+02  345.44   <2e-16***
rateNormal  2.488e-01  6.523e-03 1.900e+02   38.14   <2e-16***
```

11.2.3.1.1.1 Sequence_duration_(log)_n=192

```
Formula: wslog ~ rate + (1 | speaker)
   Data: Ct4_FB
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 2.139e+00  2.103e-03 1.900e+02 1017.19   <2e-16***
rateNormal  1.878e-01  2.973e-03 1.900e+02   63.16   <2e-16***
```

11.2.3.1.1.1 ICI_Voicing_Proportion_n=192

None of the independent variables was significant

11.2.3.1.2 Ct#bC vs Ctˤ#bC

11.2.3.1.2.1 C1_HP_(log)_n=192

```
Formula: c1hplog ~ rate + (1 | speaker)
   Data: Ct4_BF
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 1.538e+00  4.512e-03 1.900e+02  340.92   <2e-16***
rateNormal  2.723e-01  6.381e-03 1.900e+02   42.68   <2e-16***
```

11.2.3.1.2.1 ICI_(log)_n=192

```
Formula: icilog ~ rate + (1 | speaker)
   Data: Ct4_BF
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 1.727e+00  3.055e-03 1.900e+02  565.37   <2e-16***
rateNormal  1.118e-01  4.320e-03 1.900e+02   25.87   <2e-16***
```

11.2.3.1.2.1 C2_HP_(log)_n=192

```
Formula: c2hplog ~ rate + (1 | speaker)
   Data: Ct4_BF
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 1.703e+00  2.892e-03 1.900e+02  588.85   <2e-16***
rateNormal  2.032e-01  4.090e-03 1.900e+02   49.69   <2e-16***
```

11.2.3.1.2.1 Sequence_duration_(log)_n=192

```
Formula: wslog ~ rate + (1 | speaker)
   Data: Ct4_BF
Fixed effects:
             Estimate Std.Error       df tvalue Pr(>|t|)
(Intercept) 2.142e+00  1.760e-03 5.082e+01  1217.3   <2e-16***
rateNormal  1.894e-01  2.425e-03 1.750e+02    78.1   <2e-16***
```

11.2.3.1.2.1 ICI_Voicing_Proportion_n=192

None of the independent variables was significant

11.2.3.2 Stop/alveolar fricative consonant sequences

11.2.3.2.1 Cb#sC vs Cb#sˤC

11.2.3.2.1.1 C1_HP_(log)_n=192

```
Formula: c1hplog ~ rate + (1 | speaker)
   Data: Cs4_FB
Fixed effects:
             Estimate Std.Error       df tvalue Pr(>|t|)
(Intercept) 1.629e+00  3.760e-03 1.900e+02  433.19   <2e-16***
rateNormal  2.366e-01  5.317e-03 1.900e+02   44.49   <2e-16***
```

11.2.3.2.1.1 ICI_(log)_n=192

```
Formula: icilog ~ rate + (1 | speaker)
   Data: Cs4_FB
Fixed effects:
             Estimate Std.Error       df tvalue Pr(>|t|)
(Intercept) 1.765e+00  2.377e-03 1.900e+02   742.5   <2e-16***
rateNormal  1.173e-01  3.362e-03 1.900e+02    34.9   <2e-16***
```

11.2.3.2.1.1 C2_Frication_(log)_n=192

```
Formula: c2friclog ~ rate + (1 | speaker)
   Data: Cs4_FB
Fixed effects:
             Estimate Std.Error       df tvalue Pr(>|t|)
(Intercept) 1.904e+00  3.904e-03 3.953e+01  487.76   <2e-16***
rateNormal  1.548e-01  4.907e-03 1.750e+02   31.55   <2e-16***
```

11.2.3.2.1.1 Sequence_duration_(log)_n=192

```
Formula: wslog ~ rate + (1 | speaker)
   Data: Cs4_FB
Fixed effects:
             Estimate Std.Error       df tvalue Pr(>|t|)
(Intercept) 2.258e+00  2.005e-03 5.495e+01 1126.63   <2e-16***
rateNormal  1.641e-01  2.828e-03 1.750e+02   58.04   <2e-16***
```

11.2.3.2.1.1 ICI_Voicing_Proportion_n=192

None of the independent variables was significant

11.2.3.2.2 Cs#bC vs Csˤ#bC

11.2.3.2.2.1 C1_Frication_(log)_n=192

```
Formula: c1friclog ~ rate + (1 | speaker)
   Data: Cs4_BF
Fixed effects:
             Estimate Std.Error       df tvalue Pr(>|t|)
(Intercept) 1.863e+00  3.607e-03 1.900e+02  516.58   <2e-16***
rateNormal  1.679e-01  5.101e-03 1.900e+02   32.92   <2e-16***
```

11.2.3.2.2.2 ICI_(log)_n=192

```
Formula: icilog ~ rate + (1 | speaker)
   Data: Cs4_BF
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 1.736e+00  2.596e-03 1.900e+02  668.75   <2e-16***
rateNormal  1.150e-01  3.672e-03 1.900e+02   31.32   <2e-16***
```

11.2.3.2.2.3 C2_HP_(log)_n=192

```
Formula: c2hplog ~ rate + (1 | speaker)
   Data: Cs4_BF
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 1.780e+00  4.451e-03 1.900e+02  399.96   <2e-16***
rateNormal  1.815e-01  6.295e-03 1.900e+02   28.84   <2e-16***
```

11.2.3.2.2.1 Sequence_duration_(log)_n=192

```
Formula: wslog ~ rate + (1 | speaker)
   Data: Cs4_BF
Fixed effects:
             Estimate Std.Error        df tvalue Pr(>|t|)
(Intercept) 2.275e+00  2.063e-03 1.900e+02 1102.52   <2e-16***
rateNormal  1.577e-01  2.918e-03 1.900e+02   54.06   <2e-16***
```

11.2.3.2.2.1 ICI_Voicing_Proportion_n=192

None of the independent variables was significant