Gestural Phasing of Tongue-back and Tongue-tip Articulations in Tripolitanian Libyan Arabic Stop Clusters

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1. Abstract

This paper adopts the framework of Articulatory Phonology to explore the timing patterns of two-stop clusters in Tripolitanian Libyan Arabic (TLA), a colloquial form of Arabic used in everyday spoken communication in Tripoli. By means of electropalatography (EPG) and acoustic analysis, the influence of syllable position and speaking rate on the inter-gestural coordination of the clusters /gt/, /gd/, /kt/, and /kd/ is investigated. The data were collected from one male speaker of TLA who repeated the target words in a carrier sentence three times, and in two speaking rates: normal and fast. The results provide evidence that syllable-initial (onset) clusters are coordinated differently from syllable-final (coda) clusters. The coordination pattern in syllable-initial clusters is characterised by an overlap between the gestures of the first consonant (C1) and the second consonant (C2) in the cluster. This is the result of the simultaneous closure of the tongue-body (TB) gesture, and the following tongue-tip (TT) gesture. Another coordination pattern in onset clusters allows a short delay between the release of C1 and forming the closure of C2. This coordination is marked by a short inter-consonantal interval (ICI) 5-15 ms in duration, between the two articulatory closures. On the other hand, the coordination pattern in syllable-final clusters is distinguished by a longer ICI separating the two consonantal gestures. The syllable-final ICI emerges as a result of the long delay between the release of C1 and forming the closure of C2. The duration of this ICI is between 30-50 ms. As speaking rate is increased, the duration of syllable-initial clusters decreases. However, the coordination pattern remains stable in /gt/, /gd/ and /kt/, but more gestural overlap between the two consonantal gestures is observed in /kd/. In coda clusters, the increase in speaking rate results in a decrease in duration of C1 and C2, some reduction in the percentage of contact, particularly in the velar region and finally, a tighter coordination between the two gestures. This leads to the decrease in the duration of the ICI in syllable-final clusters.

2. Introduction:

The objective of the current study is to investigate how two-stop clusters in Tripolitanian Libyan Arabic (henceforth TLA) are coordinated. It also aims to investigate how this coordination is influenced by two factors: syllable position (syllable-initial, henceforth SI, clusters vs. syllable-final, henceforth SF, clusters) and speaking rate (Normal vs. fast)

A considerable amount of literature has focused on studying the inter-gestural coordination in consonant clusters in different languages, and has examined the factors that influence this coordination. For example, Catford (1977:200) points out that in a sequence of two stops, it is normal that the closure of the second stop is formed before the release of the first. It has been said that the coordination of gestures is influenced by many factors such as syllable position (Browman and Goldstein 1988:140), place of articulation (Byrd 1996:240, Chitoran et al 2002:34), speaking rate (Byrd 1996:160), and stress patterns (Tilsen 2011:657).

Syllable position is one of the main factors that plays a role in the way consonantal gestures are organised. SI clusters have been described as having different spatial and temporal characteristics distinguishing them from SF clusters (Browman and Goldstein 1988). Onset clusters have greater spatial displacement and exhibit stability compared to coda clusters (Pouplier and Marin 2008). SI clusters are also said to exhibit the c-center organisation in which consonantal gestures are organised globally with the vowel gesture (Browman and Goldstein 1988; Byrd 1996). The consonants in a complex onset are coupled with the vowel in an in-phase relation (Browman and Goldstein 2000) and are in a competitive mode with each other to avoid the two consonantal closures being synchronous and to secure the perceptual recoverability of C1 by releasing it (Goldstein et al 2007). The c-center for SI clusters has been confirmed for a number of languages, including English (Byrd 1996; Marin and Pouplier 2010), Italian (Hermes et al 2008), Romanian (Marin 2013), and French (Kühnert et al 2006).

Coda clusters, on the other hand, are said to be organised locally, not forming a global organisation with the preceding vowel, in an anti-phase relation with the vowel, and they are not in a competitive mode with each other (Browman and Goldstein 2000). Coda clusters are also described as showing reduction in magnitude: duration (henceforth Dur) and percentage of contact (Byrd 1996:210). Figure 1.1 shows the timing patterns of SI and SF consonant clusters as proposed by the C-center hypothesis.

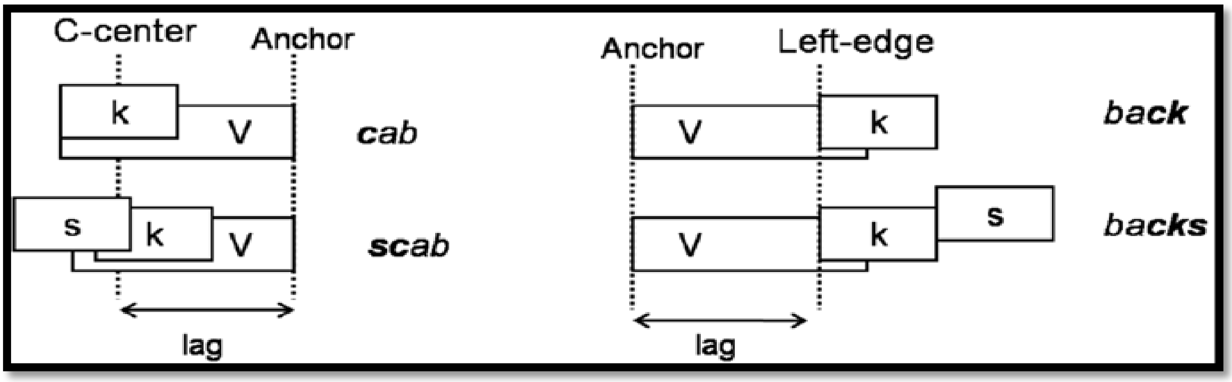


Figure 2.1: The organisation of complex onset and codas in English, as proposed by the C-center (from Marin and Pouplier: 2010).

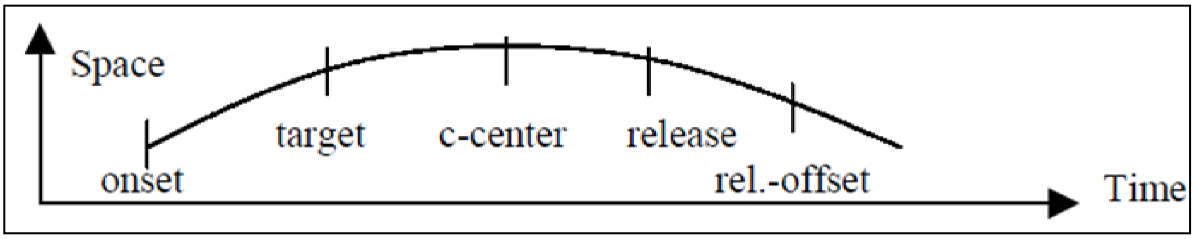
Krakow (1999) states that the reason lies in the way these syllables are articulated in different positions. While syllables in initial position exhibit tighter constrictions and stability, a number of studies reported that there is some weakening in the constriction or loss of the stop completely in syllables occurring in final position, (Manuel & Vatikiotis-Bateson 1988, and Kent & Read 1992).

A large body of literature has also reported the influence of speaking rate on intergestural coordination. For example, using electromyographic (EMG) data, Gay (1981) reported a decrease in segment duration and an increase in the velocity of articulators in fast speaking rate. The increase in speaking rate also results in target undershoot where articulators fail to reach their targets due to restrictions on their speed, particularly in fast speaking rate (Lindblom 1963). One of the most important influences of speaking rate on inter-gestural coordination is the increase in the amount of gestural overlap reported in many studies such as Byrd and Tan (1996), although some studies claim that the relative timing of some gestures remains stable despite the change in speaking rate (Kent and Netsell 1971; Kent and Moll 1975). The contradictory results of the relationship between the increase in speaking rate and target undershoot could be related to variability between speakers (Flege 1988).

Unlike English which only allows stop clusters in SF (e.g. *apt*) because traditional accounts do not require them in onsets (See Heselwood 2007 for an alternative view), TLA allows up to two stop consonants in SI and in SF position. Despite the amount of literature published on articulatory timing in different languages, and how it is influenced by factors such as syllable position and speaking rate, in reviewing the literature, only a few acoustic studies investigating TLA were found (e.g Ahmed 2008, Kriba 2009) ,and there was no study that used EPG to explore articulatory timing in TLA. The aim of this paper is to investigate the inter-gestural coordination patterns of two-stop clusters in TLA.

3. Methodology:

Articulatory Phonology as proposed by Browman and Goldstein (1986, 1988, 1989 and 1990a, 1990b, 1992) and Gafos (2002) is the framework adopted in this study. In Articulatory Phonology a gesture is "a spatio-temporal unit, consisting of the attainment of some constriction at some location in the vocal tract" (Gafos 2002:270). An articulatory gesture has the following landmarks: onset, target, c-center, release and release offset (Gafos 2002). Figure 2.1 shows the landmarks of a gesture.



3.1: Spatio and temporal realizations of a gesture (from Benus et al (2004)

The onset refers to the onset of movement of the articulator towards a target. The articulator then achieves its target for some time before the release starts. The mid-point between attaining the target and starting the release is called the c-center. This is when the articulator reaches the maximum contact. The release offset marks the end of the gesture.

In the case of oral stops, these landmarks adequately fit in constrictions formed at the lips, the TT with the alveolar ridge and the TB with the velum. In consonant clusters, the timing of release of the first stop (C1) and achieving the target constriction of the second (C2) determines the pattern of coordination, i.e. whether there is an overlap, synchronicity or a delay between the two gestures.

EPG is used to record the duration and percentage of contact between the tongue and the palate. Figure 2.2 shows the EPG plate used in this study.

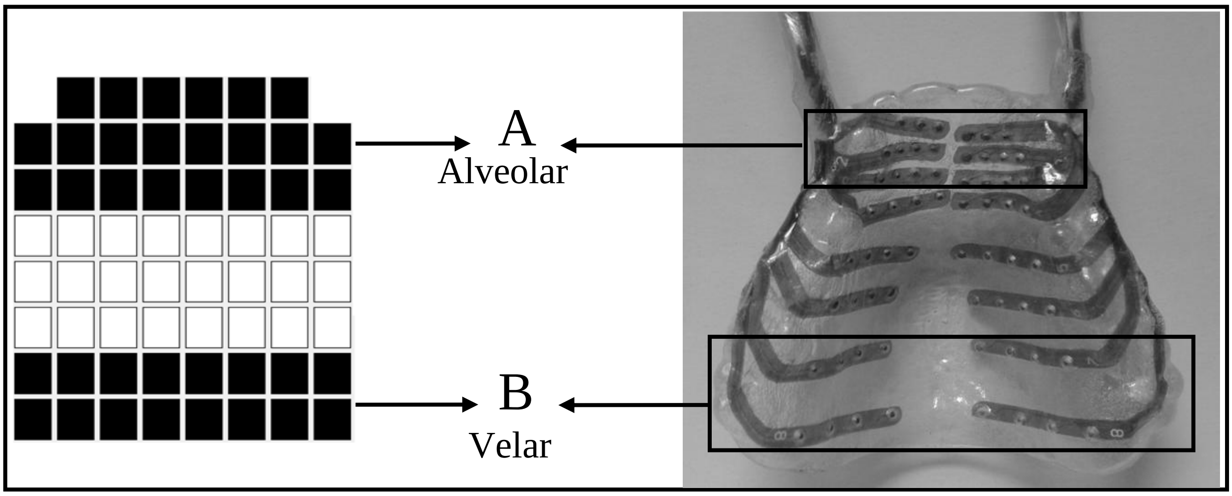


Figure 3.2: EPG plate (right) with computer generated display (left) showing a complete closure at the alveolar region (A) and a complete closure at the velar region (B). Black square record tongue contact and white squares mean no contact.

The custom made artificial palate is known as "the articulate palate". It is very thin and fits against the speaker's hard palate. The palate contains 62 electrodes distributed equally on both sides. The electrodes are arranged in eight rows with each row containing eight electrodes, except for the front row which contains only six electrodes. Starting from the front, the first three rows (1-3) measure the alveolar region contact, the next three rows (4-6) measure the palatal region contact, and the last two rows (7-8) measure the velar region contact (Articulate Assistant user guide 2003-2007: 31). The plate is connected to a 'mutiplexer' which is connected to EPG serial interface SPI V.2.0 with a palate scanner EPG3.V2. The scanner is then plugged into a PC. To analyse the recording, the software 'Articulate Assistant' is used. This software displays place and time of the tongue contacts with the palate. Every frame of 10 ms intervals shows real time articulatory events aligned with a spectrogram and waveform display. The tongue-palate contact patterns can be analysed and presented in tables and graphs. Despite not providing any information about the behaviour of the tongue when it is not in contact, EPG is a very suitable and convenient tool for this investigation.

4. Data

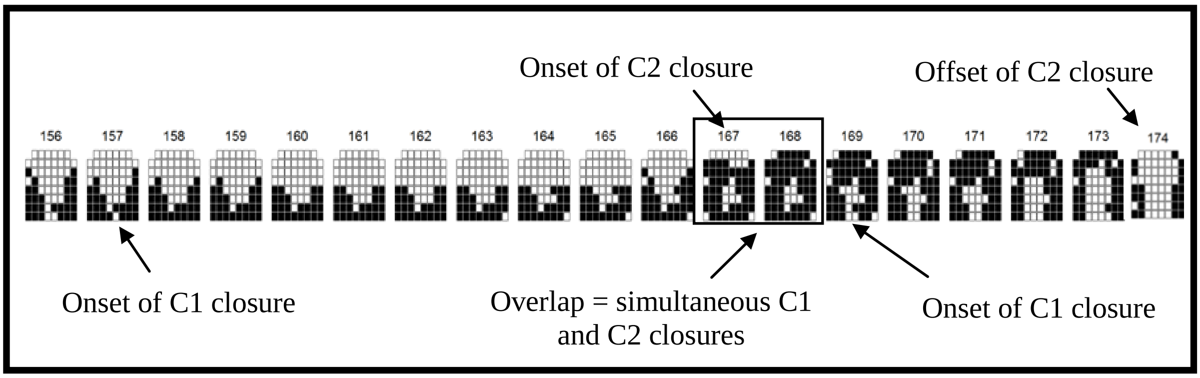
Data (cf. Table 3.1) were collected from one male native speaker of TLA. The target words were embedded in the carrier sentence /matgu:li:ʃ _______ halba/ "don't say_______too much". The target words are frequently used in TLA, apart from /nakd/ which could be related to /nakad/ in Standard Arabic. These words were repeated 3 times each, and in two speaking rates: Normal and fast. Clusters containing /b/ were excluded from this study, because bilabial closure is not captured by the EPG.

	Syllable-initial		Syllable-final	
Cluster	Word	Gloss	Word	Gloss
/gt/	/gtal/	"he killed"	/wagt/	"time"
/gd/	/gdar/	"he was able"	/ ʕagd/	"tying"
/kt/	/ktab/	"he wrote"	/nakt/	"unpacking"
/kd/	/kdab/	"he lied"	/nakd/	"boring"

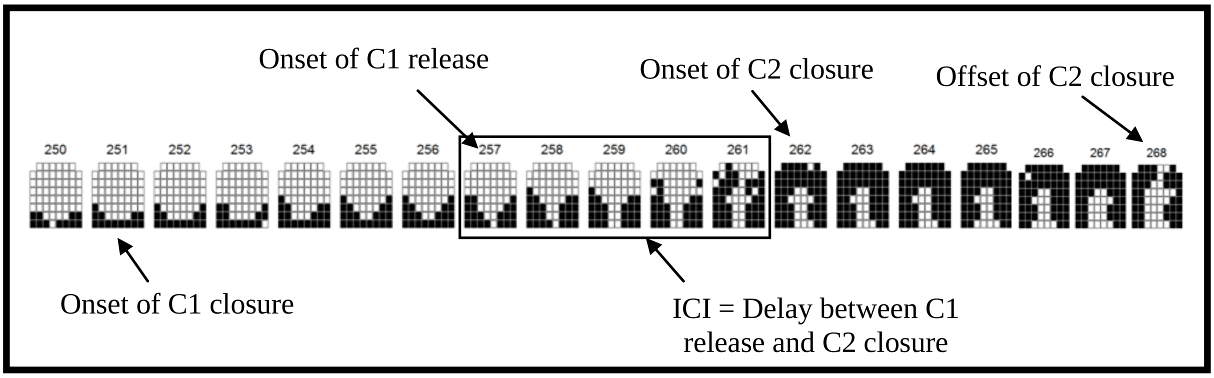
4.1: Stimuli in IPA phonemic transcription with glosses

To facilitate the acoustic analysis, the target words were placed between two words, the first one ends with a fricative and the second one starts with a fricative. Because TLA allows up to two consonants in SI and in SF, more than two can occur across word boundary. In this case, it is more likely that an insertion will take place. The long vowel /i:/ preceding the target word helps to eliminate vowel insertion before the target cluster. The sentences were printed on 10x20 cm cards.

All clusters in SI position were followed by the open vowel /a/. Using this particular vowel helps to minimise the interference with the trajectory of the consonantal gestures (Chitoran et al 2002:11), and to control the contextual effect of the vowel environment (Dixit and Flege 1991). For each cluster, four EPG measurements were made. These are onset and offset of closure for C1, onset and offset of closure For C2, the amount of overlap between the closure of C1 and C2, and finally, the amount of delay between the release of C1 and forming the closure of C2. It is worth noting that C1 and C2 refer to the first and second member in a cluster, regardless of syllable position The onset of closure of C1 or C2 was measured from the first frame in which the TB or the TT gesture reached the target and formed a complete closure. It is worth mentioning that the percentage of contact, despite a closure formed, is rarely 100% in the velar region. This means, in most cases, only the last row will have a complete seal. The offset of closure of C1 or C2 is marked by the first frame where the closure seal at the alveolar or velar region is broken. The amount of overlap was measured by how many frames there are in which there is a simultaneous closure of C1 and C2 at the alveolar and velar regions. Figure 3.1 shows the EPG measurements taken when there is an overlap between the two closures



4.1: EPG frames showing a simultaneous overlap between a TB gesture and a following TT gesture



4.2: EPG printouts showing a delay (ICI) between the release of a TB gesture and forming a closure by a TT gesture. The ICI lasts between frames 257-261inclusive.

More frames with a simultaneous constriction indicate more overlap between the two closures. Finally, the delay was defined as the frame(s) between the release of C1 and forming the closure for C2. Figure 3.2 shows the measurements when there is a delay between these two closures. The open juncture frames are characterised by having no complete alveolar or velar seal. An increase in the number of these frames reflects a lesser degree of overlap between the two closures. It is worth mentioning that the measurement of the duration is of the hold phase only. i.e. excludes the duration of VOT in SI clusters and the release of C2 in SF clusters.

5. Results:

Results are divided into two sections. In the first sections, the durational results and the coordination patterns are presented. The second section shows the results of the influence of speaking rate on the duration and the coordination pattern

5.1 Results of the influence of syllable position:

The duration of SI clusters and the duration of SF clusters in normal speaking rate is shown in tables 5.1 and table 5.2 respectively. For ease of comparison, measurements in fast speaking rate are inserted between two brackets.

Word	No. of Syllable per second	Dur of C1	Dur. of Overlap/ ICI	Dur of C2	Overall Dur of cluster	Std. Deviation	Percentage of decrease in Dur in fast rate
/gtal/	4.7[6.0]	110[95]	-20[-25]	97 [75]	187[145]	17[8]	[22%]
/gdar/	4.3[6.0]	104[89]	-10[-15]	85[65]	179[139]	15[6]	[22%]
/ktab/	4.5[6.0]	95[67]	-20[-20]	98 [75]	173[122]	14[7]	[29%]
/kdab/	4.8[6.0]	103[65]	10[-20]	65 [72]	178[129]	13[8]	[28%]
Average	4.5[6.0]	103[82]	-15[-20]	86 [72]	179[136]	13[9]	[24%]

5.1: Average number of syllables per second, duration of C1 and C2, and the amount of overlap (in minus) or ICI in SI clusters produced in normal speaking rate. The results of fast speaking rate and percentage of decrease are between brackets.

Word	No of Syllables per second	Dur of C1	Dur of overlap/ ICI	Dur of C2	Overall Dur of cluster	Std. Deviation	Percentage of decrease in Dur in fast rate
/wagt/	4.4[6.6]	65 [55]	50 [8]	60 [60]	175[123]	6[4]	[34%]
/ ʕagd/	4.5[7.2]	80 [60]	30 [8]	70 [60]	180[128]	5[14]	[38%]
/nakt/	4.9[7.2]	90[68]	30[15]	80 [49]	200[132]	3[6]	[33%]
/nakd/	5.0[7.2]	90[63]	30[15]	85[56]	201[134]	8[6]	[32%]
Average	4.7[7.0]	81[62]	35[12]	74[56]	189[130]	6[8]	[34%]

5.2: Average number of syllables per second, Duration of C1, ICI and C2 in SF clusters. The results of fast speaking rate is between brackets.

The average duration of SI clusters is 179 ms. Apart from /kt/, C1 seems to always be longer in duration. The average overlap duration is 15 ms. Some clusters exhibited more overlap (e.g /gt/ and /kt/) compared to zero overlap in /kd/. In this particular clusters, the average duration of ICI is 10 ms. In SF clusters, the average duration of the target clusters is 189 ms. There was no overlap between the two closures in SF clusters. The average duration of ICI is between 30 ms in /gd/, /kt/ and /kd/ is 50 ms in /gt/ with an average of 35 ms. Despite the fact that the duration of SF clusters is always longer than SI clusters, when the duration of the ICI is subtracted, SI clusters, apart from /kt/, are always longer.

Regarding the pattern of coordination, in SI position, the two closures, apart from /kd/, are overlapped. This is the result of forming the closure of C2 before the release of C1. This pattern of coordination led to the masking of the C1 release. The simultaneous overlap between the velar and alveolar closure lasted between 10 ms in /gd/ and 20 ms in /gt/ and /kt/. When there is overlap, the two gestures are very cohesive and exhibit high percentage of contact, particularly at the alveolar region. Figure 4.1 shows the pattern of intergestural coordination of /gt/ in SI position. When there is no overlap between the two consonantal gestures, as in the coordination of /kd/ in /kdab/, the pattern is characterised by a short delay between the release of C1 and forming the closure for C2. Despite the release of C1, the two gestures are have high percentage of contact, tightly coordinated that they allowed only the release of C1.

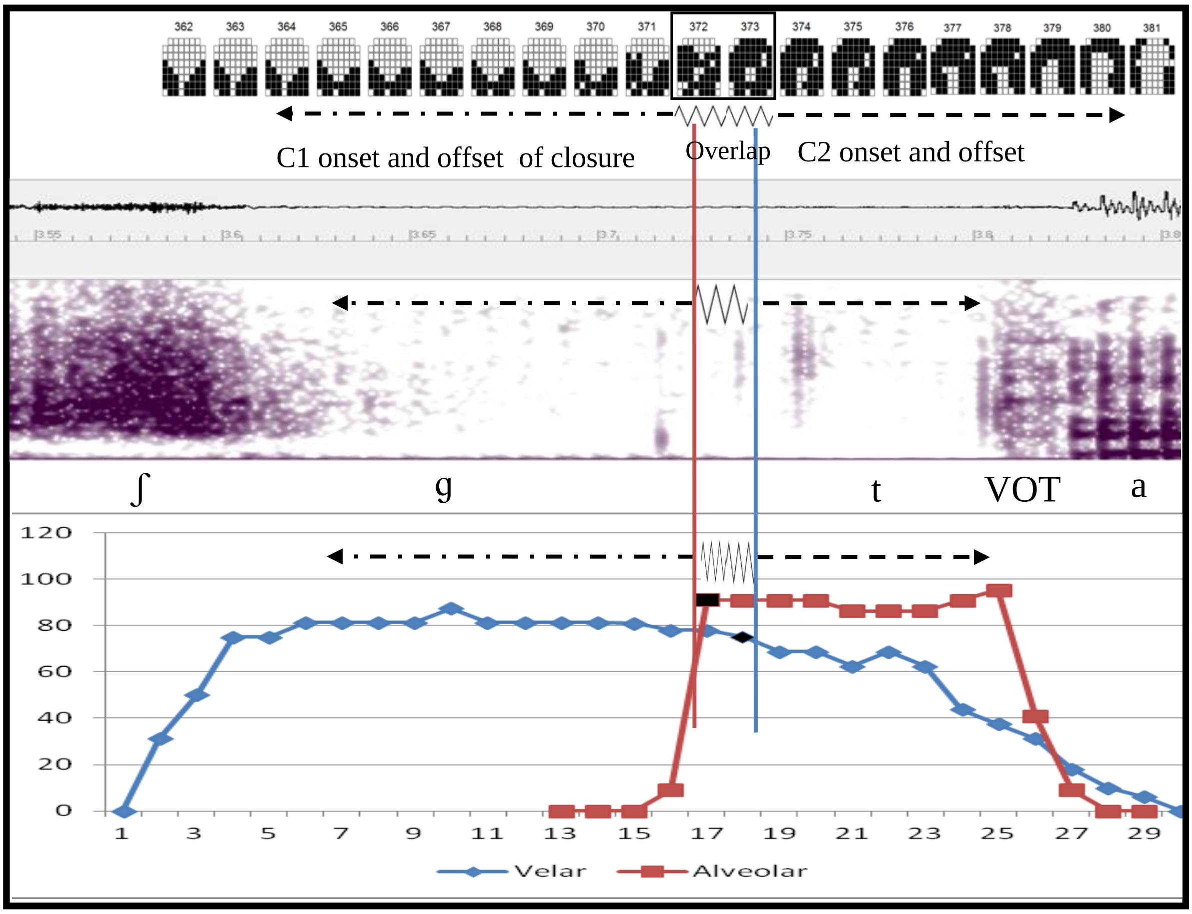


Figure 5.1: Acoustic and EPG printout of the /gt/ cluster in the word /gtal/, showing an overlap (in zigzag pattern) between the velar and the alveolar closure lasting 20 ms (frames 372-373).

In SF, on the other hand, the two closures are pulled apart compared to their pattern in SI. The loose coordination between the two gestures caused the delay between the release of C1 and forming the closure for C2. The TB gesture is also reduced in magnitude. In SF cluster /gt/, the two gestures are coordinated in a less tight fashion. For example, the TB gesture and the TT gesture in /gt/are more loosely coordinated compared to the rest of SF clusters. Figure 4.2 shows the intergestural coordination pattern of /gt/ in SF.

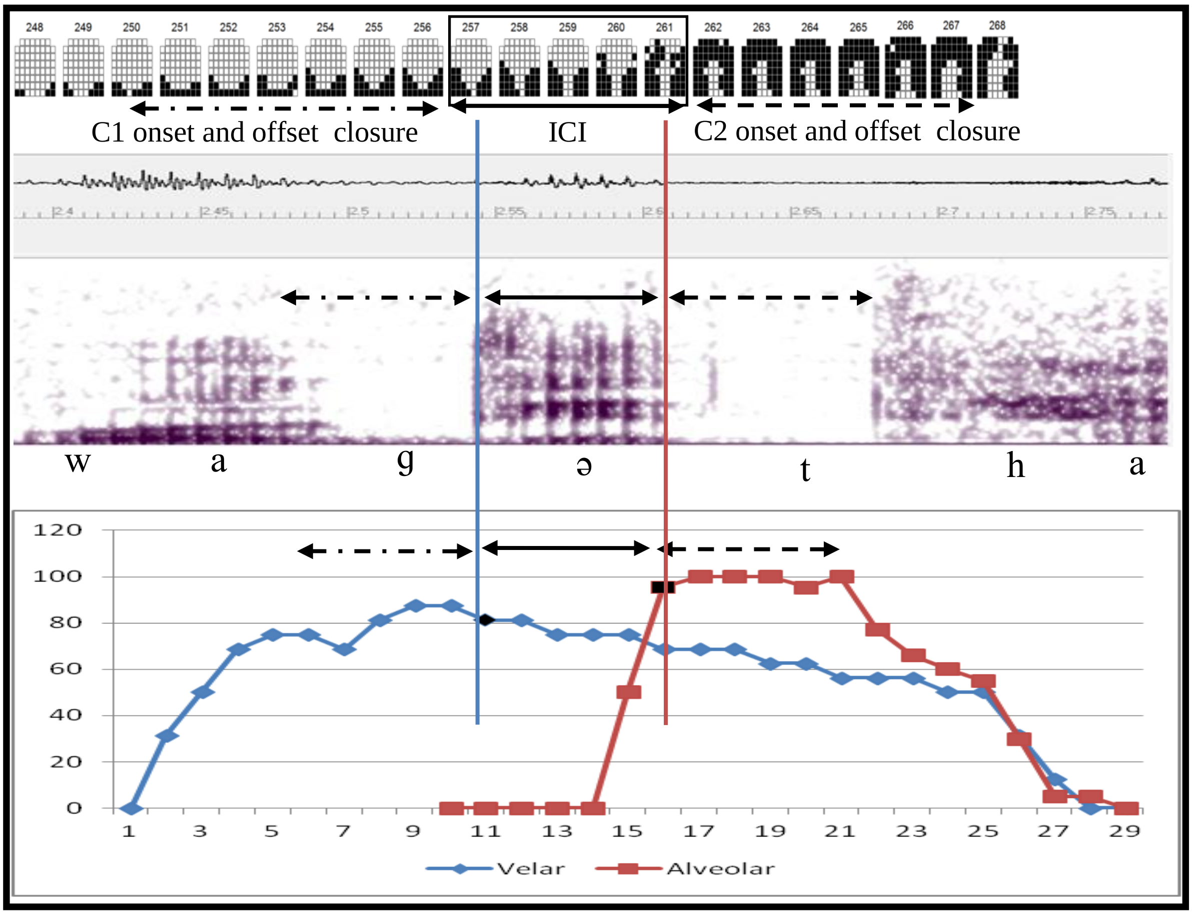
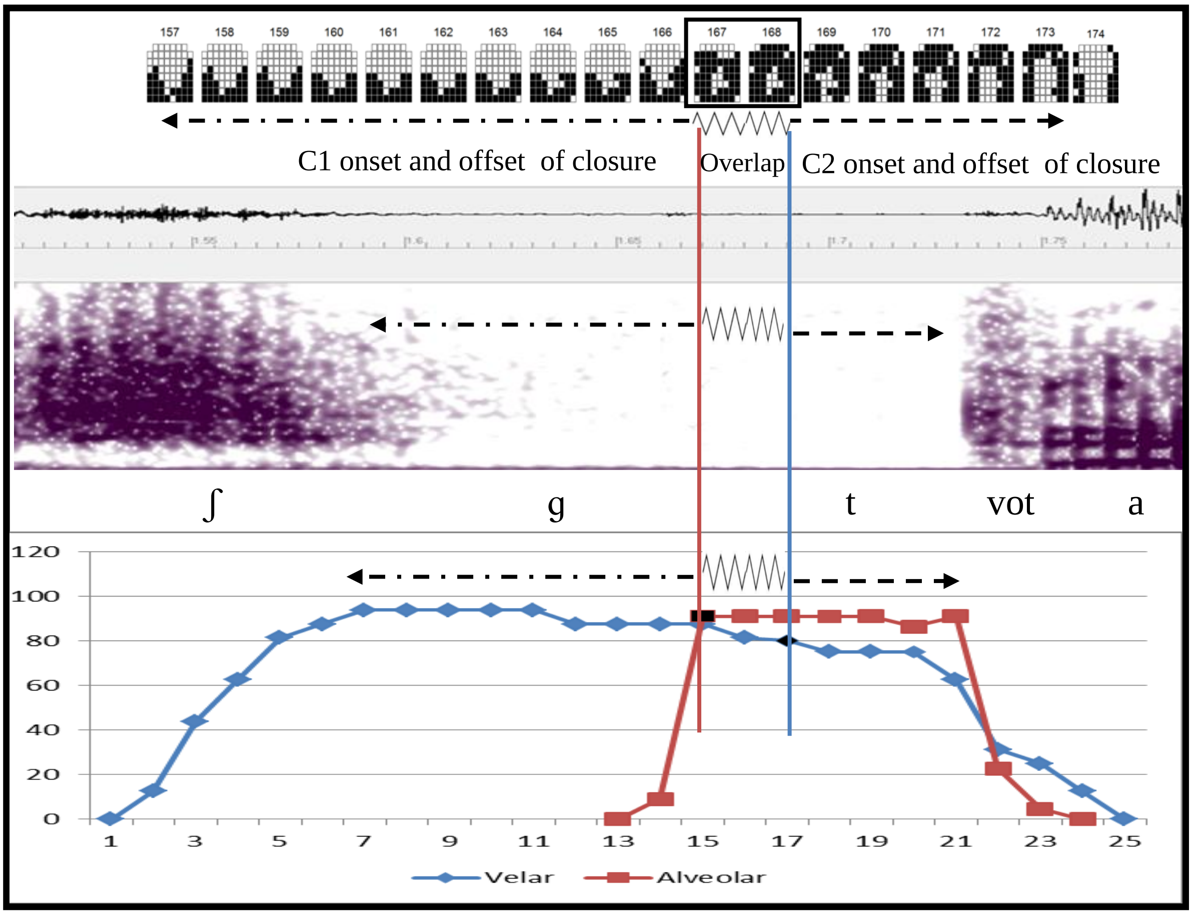


Figure 5.2: Acoustic and EPG printout of the /gt/ cluster in the word /wagt/, showing a long delay between the release of velar gesture (frame 257) and the forming alveolar closure (frame 262). The ICI lasts between frames 257-261inclusive.

5.2 Results of the influence of speaking rate:

In the sentences carrying SI clusters, the average number of syllables per second increased from an average of 4.5 in normal speaking rate to 6.0 in fast speaking rate. The average duration of SI clusters decreased by an average of 24%. The average duration of overlap also increased from 15 to 20 ms. The coordination pattern of SI clusters shows that the TB gesture and the TT gestures become more cohesive in fast speaking rate.

The influence on the amount of overlap is more noticeable in /kd/ which showed no overlap at all in normal speaking rate and exhibited 20 ms of overlap in fast speaking rate. The maximum overlap is of /gt/ in /gtal/ in which the release of the TB gesture is delayed 25 ms after forming the closure by the TT gesture. Figure 5.1 shows the intergestural coordination pattern of /gt/ in syllable-initial position.



5.3: Acoustic and EPG printout of the /gt/ cluster in the word /gtal/ produced in fast speaking rate. The figure shows an overlap between the velar and the alveolar closure lasting 25 ms (frames 167-168)

In SF position, the average number of syllables per second has also increased from 4.7 to 7.0 syllables. The average duration of the target clusters decreased by 34%. The average duration of ICI decreased dramatically from an average of 35 ms in normal speaking rate to an average of 12 ms in fast speaking rate. The shortening of the ICI is more evident in /wagt/.

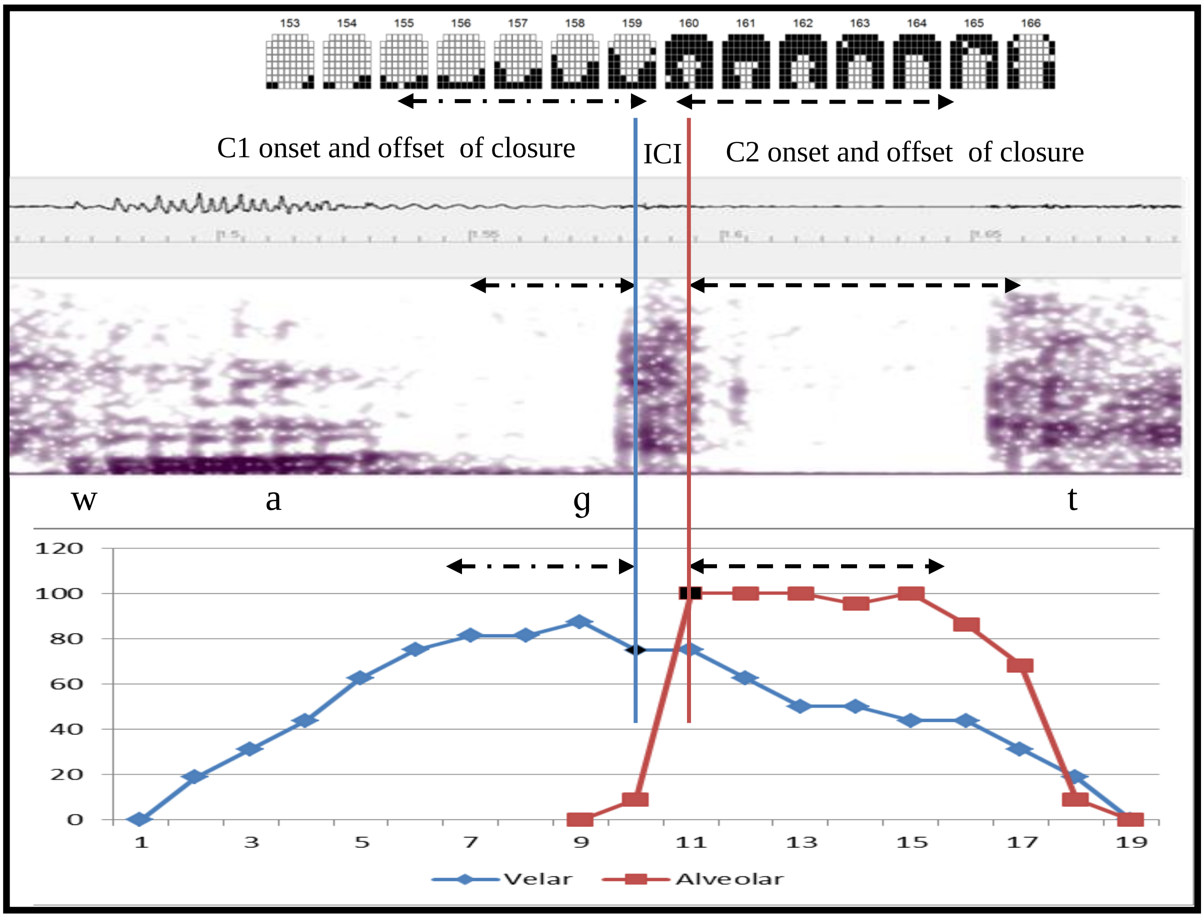


Figure 5.4: EPG printout of the /gt/ in /wagt/ ,produced in fast speaking rate. Although C1 was released, the two gestures show a more cohesive coordination compared to normal speaking rate. The ICI lasts for less than 10 ms.

6. Discussion:

The present results suggest that there are two general patterns of gestural coordination in two-stop clusters in TLA. These coordination patterns are influenced by syllable position and speaking rate. SI clusters are very cohesive as a result of the overlap between the TB gesture and the following TT closures. In this pattern, forming the closure for C2 takes place before the release of C1. Although in back-to-front clusters C1 is expected to be released, due to the need to enhance the perceptual recoverability of the word (Chitoran et al 2002), C1 release is masked by C2 closure. That is why the cluster appears on spectrogram as one long hold phase followed by one acoustic release.

However, this was not the case in /kd/ where C1 has an acoustic release. The release of C1 in this cluster could be motivated by perception. Another factor that could have influenced the coordination of /kt/ and /kd/ is voicing. It may be the case that to facilitate the start of voicing of C2 in /kd/, C1 intraoral pressure is released so that voicing can be easily initiated. In /kt/ where the two stops are voiceless, there is no need to release the intraoral pressure because there is no voicing.

SI clusters were more resistant to decrease in duration compared to SF clusters. This could be related to the fact that SI clusters are articulated differently from SF clusters for many reasons such as perception and stress patterns

In SF, the long duration of ICI arises because of the less cohesive coordination between the two gestures. another evidence of the less tight coordination in SF clusters is the reduction they exhibit, particularly in the velar region. This could be the result of the velocity of the back of the tongue, the fact that the syllable is not stressed, or the economy of gestures. Finally, the ICI is mostly voiced, because of the adjacent stops are voiced. However, in SF /kt/, the ICI is voiceless due to the voicelessness of adjacent consonants. The.

As a result of the increase in speaking rate, the duration of both SI and SF clusters decreased. A strong relationship between speaking rate and degree of overlap has been reported in the literature. (e.g., Miller 1981).

Because SI clusters were overlapped already in normal speaking rate, they remained stable when speaking rate was increased. However, the two gestures of /k/ and /d/ exhibited more overlap in fast speaking rate. The decrease in the duration of ICI in SF clusters is the result of the two gestures becoming synchronous or more cohesive.

In SF clusters, the TB gestures showed more reduction in magnitude and lower percentage of contact in fast speaking rate. The demand on the articulators to achieve their targets in a certain time frame could result in target undershoot.

7. Conclusion:

This study investigated the patterns of inter-gestural coordination of two-stop clusters in TLA. The influence of syllable position and speaking rate were also taken into consideration. Results show that SI clusters are organised differently from SF clusters. The main difference lies in the amount of overlap allowed in different positions. In SI, the coordination pattern is characterised by an overlap between the closures of C1 and C2. As a result, the release of C1 is typically absent. A less cohesive coordination was also observed in SI clusters. This pattern is marked by a short delay between the releases of C1 and forming the closure for C2 giving rise to a short ICI. In SF clusters, a lesser degree of overlap between the two closures is observed. The pattern of coordination is characterised by a delay between the release of C1 closure and forming the closure of C2. This results in the insertion of a longer ICI between the two gestures. As speaking rate increases, a decrease in the duration of C1 and C2 is noticeable. The pattern of coordination, however, remains stable in SI clusters. More overlap, however, was observed in /kd/. SF clusters seemed to be more affected by the increase in speaking rate. Consonantal gestures in SF clusters exhibited tighter coordination, shorter durations, and some reduction in the total percentage of contact in the velar region. In addition, this pattern of coordination usually resulted in shortening the duration of the ICI to make the two gestures more closely bound with each other.

While SI clusters did not show any differences in their internal cohesiveness, SF clusters showed some variability. It seems that the increase in speaking rate causes the gestures to become more in-phase. The coordination of the TB and TB gestures in SI clusters (/gt/, /gd/ and /kt/) clusters appeared to be more resistant to the increase in speaking rate, apart from /kd/, that the gestures are already in-phase relationship..

The present findings are quite consistent with other research which found influence of syllable position and speaking rate on intergestural coordination. Additional studies using more clusters containing emphatic stops and using electromagnetic articulography (EMA) to capture the timing of the lip closure are needed. Another possible topic to investigate is the influence of order of articulation, front-to-back vs. back-to-front, on intergestural coordination.

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