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On the phonetic implementation of syllabic consonants and vowel-less syllables in Tashlhiyt

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Abstract

This paper presents an acoustic and electropalatographic study of how vowel-less syllables and their constituents are phonetically implemented in Tashlhiyt Berber. Three issues are addressed. First, we determine whether the acoustic and articulatory make-up of a consonant changes as a function of its position within a syllable (C-nucleus *vs.* C-onset *vs.* C-coda). Second, we consider the patterns of articulatory coordination between consonants as a function of their position within and across the syllable. Third, we test whether nuclei consonants are produced as sequences of schwa vowels + consonants. While some differences are observed in linguopalatal articulation, position in a syllable is not found to affect the acoustic and articulatory duration of a consonant in Tashlhiyt. Interestingly, syllable organization appears to be reflected in the specifications of the coordination between consonants. Consonants in nucleus position are more stable in their coordination with flanking consonants and are less overlapped by a following consonant. In addition, our results suggest that the occurrence of a schwa-like element before a consonant depends on the laryngeal specifications of the consonants in the sequence rather than on its syllabic status.

1. Introduction

Important linguistic and metalinguistic facts contribute to place the syllable as a fundamental unit of human speech. Ample justification has been presented showing that it is an essential unit of phonological organization (Kahn 1976, Steriade 1982, Clements & Keyser 1983, Blevins 1995, etc.). Current research continues, however, to raise essential questions concerning the nature of this unit and the relation it has to measurable physical properties. A number of phoneticians, from Scripture (1902) and Rousselot (1909) to Rosetti (1963) and Malmberg (1971), consider the syllable merely as a psychological reality with no direct physical correlates. Others, on the other hand, consider the syllable as a physical unit (Sievers 1881, Stetson 1951, Catford 1977,

MacNeilage 1998). Many arguments have been confronted, but efforts to find clear, reliable, and regular acoustic and physiological correlates of the syllable (i.e. specific properties of the different syllable constituents and/or cues to syllable boundaries) have largely failed (see Krakow 1999 and Meynadier 2001, for a review). One reason why "... *the syllable is probably the most elusive of all phonological/phonetic notions* (Kenstowicz and Kisseberth 1979: 255-6)" is in part related to its structure. In the majority of the world languages, the distribution between the nucleus of a syllable and its margins is almost always correlated with the lexical distinction between vowels and obstruents. Hence, there is some doubt on whether syllable nucleus (i.e. the obligatory central element of this unit) must be defined by its intrinsic properties as a segment (a vowel, a sonorant), its properties relative to the surrounding segments ("peak" of sonority, or specific phasing relationships). Tashlhiyt Berber, the language investigated here, is a notable exception to the dominant trend of clear nucleus syllables¹. In this language, the entire set of the consonantal inventory may alternate between nuclear and non-nuclear positions (Dell & Elmedlaoui 2002), making vowel-less syllables of the shape [t̩], [t̩f], or [t̩k] quite common as illustrated in table 1. (here and henceforth, nucleus consonants are underlined and syllable boundaries are marked by a period)

Table 1. Illustrative examples of different syllabic segments in Tashlhiyt (from Dell and Elmdelaoui 2002). Nuclei consonants are underlined and periods are used to mark syllable boundaries. Glosses are given in column 3, where 'you' = 2psg. English present and past translate the aorist and the perfect, respectively.

<i>Nucleus Type</i>	<i>Example</i>	<i>glosses</i>	<i>Reference</i>
Vowel	t̩.s̩.ti	she selected	p. 179
Nasal	i.χ̩ŋg	he strangled	p. 182
Liquid	r̩.g̩lɛ	I lock	p. 182
Voiced fricative	t̩.s̩.b̩ɣt	you painted	p. 180
Voiceless fricative	t̩.s̩.ti	She selected	p. 179
Voiced stop	i.f̩.k̩d	broken branch	p. 182
Voiceless stop	ta.z̩.n̩.k̩ ^w tt	female gazelle	p. 74

The existence of vowel-less syllables offers an interesting opportunity to handle the issue of the phonetic manifestation of the syllable. The fact that one and the same consonant (e.g. /k/) may alternate between one of the three possible positions in a syllable (onset in [n̩.k̩s̩] "we feed on", nucleus in [t̩.k̩.s̩a] "she fed on", and coda in [n̩.k̩.s̩a] "we fed on"), makes it possible to test several physical properties that might be related to the status of this consonant in the syllable.

¹ The Salish language Nuxalk is another language which is reported to contain obstruant-only syllables (Bagemihl 1991).

Three issues are addressed experimentally. First, we determine whether the acoustic and articulatory make-up of a consonant changes as a function of its position within a syllable (C-onset *vs.* C-nucleus *vs.* C-coda). It has been demonstrated that the acoustic and articulatory characteristics of a consonant vary depending on whether it is an onset or a coda. Coda consonants are more often prone to reduction of gestural magnitude, deletion, and assimilation than onset consonants (Bell & Hooper 1978, Krakow 1989, Browman & Goldstein 1992, Goldsmith 1990, Byrd 1996a). Onsets, on the other hand, have been shown to be longer (in their movement duration: Krakow 1989, in their EMG activity: Fromkin 1965, in their acoustic duration: Lehiste 1960), and display greater movement displacements (Macchi 1988, Krakow 1989, 1993, de Jong 1991, Browman & Goldstein 1992, Barry 1992, Byrd 1994). However, little work has yet focused on the acoustic and articulatory properties of a consonant occupying a nuclear position. The few studies reported in literature are limited to sonorants, and duration has been advocated as the main cue of syllabicity (Price 1980, Clark & Yallop 1995, but see Toft 2002 for different results). We will examine temporal, spatial, and “pseudo-dynamic” properties of several consonants, as well as the variability of their articulation, as they occupy different positions within a syllable. Our basic assumption is that in Tashlhiyt, distributional restrictions that could be used as cues to identify syllable position in other languages cannot be applied since consonants can occupy all the positions. Therefore, one might expect to find even more positional allophonic cues in Tashlhiyt than in other languages to cue syllabic structure and the syllabic status of the consonant.

Secondly, we consider the patterns of articulatory coordination between consonants as a function of their position in the syllable. Within Articulatory Phonology (Browman and Goldstein 1988, 1995), speech is viewed as a complex coordination of linguistically relevant vocal tract configurations, called *gestures*. Syllables are viewed as the automatic outcome of a specific temporal organization into which these gestures coalesce. Hence, syllable affiliation affects the relative timing in consonant sequences both within and across syllables. Byrd (1996a), for instance, found evidence that in American English onset clusters, coda clusters, and heterosyllabic sequences differ in their inter-gestural timing and in the stability of their timing. This study is however limited to two-consonant sequences occupying the margins of the syllable. In Tashlhiyt, we can study the patterns of coordination in three consonant clusters to determine how syllable structure affects the coordination of its constituent elements. More specifically, we will examine the temporal alignment of specific articulatory events and the amount of overlap in C1C2 and C2C3 sequences, as well as the stability/variability of these properties. We expect the

temporal coordination between consonant gestures to cue differences in syllable structure, the nucleus status of C2, and the syllabic affiliation of the consonant in the sequence.

Thirdly, we test whether nuclei consonants are produced as sequences of schwa vowels + consonants. Syllabic (sonorant) consonants in many languages are said to alternate with a pronunciation of schwa plus a consonant (Wiese, 1996, Gussenhoven & Jacobs, 1998, Hall 2002). In Tashlhiyt, while voiceless consonant sequences are produced with no vocalic element that can act as a syllable peak (see Ridouane 2008), clusters containing voiced segments do sometimes surface with schwa-like elements. By comparing the distribution of these vocoids in the three conditions and comparing their occurrences before and after C2 we test whether these schwa-like elements are more frequent at the adjacency of nucleus consonants.

In the remaining of this section, we present a brief overview of some phonological and phonetic characteristics of Tashlhiyt and present the main arguments in favor of the syllabification structure proposed for this language. The method used and the results obtained are presented in sections §2 and §3. The implication of the results on the general issue of the nature of vowel-less syllables is outlined in the general discussion (§4).

Table 2. List of Tashlhiyt phonemes

Labials	Dentals	Palatoalveolars	Velars	Uvulars	Aryepiglottals	Glottal
	t t ^ʔ tt tt ^ʔ		k k ^w kk kk ^w	q q ^w qq qq ^w		
b bb	d d ^ʔ dd dd ^ʔ		g g ^w gg gg ^w			
	n n ^ʔ nn nn ^ʔ					
f ff	s s ^ʔ ss ss ^ʔ	ʃ ʃʃ		χ χ ^w χχ χχ ^w	ħ ħħ	
	z z ^ʔ zz zz ^ʔ	ʒ ʒ ^ʔ ʒʒ ʒʒ ^ʔ		ʕ ʕ ^w ʕʕ ʕʕ ^w	ʕ ʕʕ	h hh
w ww	l l ^ʔ ll ll ^ʔ	r r ^ʔ rr rr ^ʔ	j jj			
u			i		a	

Tashlhiyt is a Berber language spoken in southern Morocco. Its phonemic system is founded

upon the correlations laid out in table (2). Except for vowels, each phoneme in (2) has a geminate counterpart in the underlying representation². In addition, Tashlhiyt has a set of dorsopharyngealized phonemes, all of which are coronal. At the phonetic level, dorsopharyngealized phonemes spread emphasis to all the other segments present in a word (Elmedlaoui 1985, Boukous 1987). For instance, in [tbd^ʔit] “you divided”, which contains only one dorsopharyngealized phoneme, the whole word is dorsopharyngealized.

The syllable structure of Tashlhiyt was initially described by Dell and Elmedlaoui (1985, 1988, 2002). According to these two authors, syllables in this language may consist only of consonants with CC and CCC (where the second C is the nucleus) in addition to the more conventional syllable types CV and CVC. The Tashlhiyt facts, cited as a typologically unique phenomenon (Zec 1995), have since served as a testing ground for important theoretical proposals (Hyman 1985, Clements 1997, Prince & Smolensky 1993). One reason why any consonant may act as a syllable peak in this language is that it allows words and long consonantal clusters without intervening vowels. As shown in Ridouane (2008), based on acoustic, fiberoptic, and photoelectroglottographic data, entire utterances may contain voiceless obstruents only (e.g. [tʃk.tstt] “you gave it”, [ts.sk.fʃ.tstt] “you dried it”), with no intervening schwa vocalic element that can act as a syllable peak. Various arguments have been provided showing that such long consonantal sequences are organized into a syllable structure (Dell and Elmedlaoui 1985, 1988, 2002, Prince and Smolensky 1993, Clements 1997). First, insight into various morphological regularities is captured by assuming the proposed syllabification of consonant sequences (e.g. length alternations in the causative prefix, syllable onset gemination in the formation of imperfective stems)³. Second, various generalizations on the form of Tashlhiyt syllables and the distribution of their nuclei are independently motivated constraints of syllable theory, e.g. the Onset Constraint, constraints against complex codas and onsets, constraints on syllable nuclei and margins (Zec 1988, 1995, Prince and Smolensky 1993, Clements 1997). Probably, the richest source of evidence in favor of the syllabification proposed for Tashlhiyt consists in the native speakers’ judgments about syllable count. These judgments reflect both native linguist intuitions (for e.g. Elmedlaoui 1985, Boukous 1987, Jebbour 1995, Ridouane 2008) as well as judgments about well-formedness in versification (Dell and Elmedlaoui 2002, Ridouane 2008). A related question is whether these judgments are based on some surface physical differences perceived by Tashlhiyt native speakers. Based on consonant-only syllables, we will try to determine whether

² Note, however, that geminate counterparts of aryepiglottals and laryngeal are very rare (see Ridouane 2003).

³ See Dell and Elmedlaoui (2002: 115-134) for a detailed discussion of these morphological regularities.

and how the position of a consonant within a syllable affects its acoustic and articulatory make-up, and examine the inter-gestural coordination of consonants within and across syllables.

2. Method

2.1. Linguistic material and speaker

The material collected consist of 18 consonant sequences of the shape C1C2C3(V), where C1 is alveolar, C2 velar, and C3 alveolar, embedded in the following carrier sentence [innajam ... bahra] “*he told you ... a lot*”. The target consonant C2 is placed in three different positions within the syllable (nucleus, coda, onset) by manipulating the degree of sonority of C1 (/t/ “3rd person feminine singular” and /n/ “1st person plural”) and the presence (or absence) of a vowel after C3. The material and conditions are presented in table 3. Most of these consonantal sequences correspond to Tashlhiyt verbs, but in condition C we had to use three non-words (/nkt/, /nkn/ and /ngz/) in order to have a perfect match in consonantal context. The material was recorded by one native speaker of Tashlhiyt (the second author) and each item was repeated 12 times⁴. The reported syllabifications, based on Dell & Elmedlaoui’s algorithm, make it possible to study C2 properties and its coordination with flanking consonants while occupying three different positions within the syllable: nucleus (condition A) *vs.* coda (condition B) *vs.* onset (condition C). The syllable structures of the entire sentences in the 3 conditions are:

[in.na.jam.C1_(O)C2_(N).C3_(O)V.bah.ra] in condition A,

[in.na.ja.mC1_(N)C2_(C).C3_(O)V.bah.ra] in condition B,

[in.na.ja.mC1_(N).C2_(O)C3_(N).bah.ra] in condition C

Table 3. Test items in the three conditions ((N), (O), and (C) stand for nucleus, onset and coda, respectively)

Item #	Condition A C2 = nucleus C1 _(O) C2 _(N) • C3 _(O) V	Condition B C2 = coda C1 _(N) C2 _(C) • C3 _(O) V	Condition C C2 = onset C1 _(N) • C2 _(O) C3 _(N)
01	tk.ti “ <i>she remembered</i> ”	nk.ti “ <i>we remembered</i> ”	n.kt * <i>non word</i>
02	tk.sa “ <i>she fed on</i> ”	nk.sa “ <i>we fed on</i> ”	n.ks “ <i>we feed on</i> ”
03	tk.nu “ <i>she bended</i> ”	nk.nu “ <i>we bended</i> ”	n.kn * <i>non word</i>
04	tg.za “ <i>she was disgusted</i> ”	ng.za “ <i>we were disgusted</i> ”	n.gz * <i>non word</i>

⁴ Note that for item 06 in condition B, 2 repetitions contained errors, thus only 10 repetitions are analyzed

05	tg.nu “she sewed”	ng.nu “we sewed”	n.gn “we sleep”
06	tg.d ² i “she plunged”	ng.d ² i “we plunged”	n .gd ² “we plunge”

2.2. EPG Data collection

Simultaneous electropalatographic (EPG) and acoustic data were recorded in one session using the Reading EPG3 system. EPG is a measure of linguopalatal contact, that is the contact of the tongue against the hard palate, during the time course of an utterance. The speaker is fitted with a custom made artificial palate (pseudo-palate), on which 63 electrodes are embedded. When the tongue touches the electrodes on the pseudo-palate, a contact is made and a signal is conducted via lead-out wires to an external processing unit (for more details, see Fougeron et al. 2000). EPG contact is recorded at a sampling rate of 100 Hz.

Linguopalatal contact recorded by EPG provides spatial and temporal information on lingual articulation. However, it is essential to recall that EPG gives a measure of the contact between the tongue and the palate, and not a measure of the tongue movement. However, we will analyze here the evolution of the linguopalatal contact profile over time as if it were an articulatory ‘pseudo-gesture’. For this, different acoustic or electropalatographic events will be defined as pseudo articulatory events, though it should be kept in mind that they are the consequences of the articulatory movements.

Velar and alveolar regions on the EPG palate for the speaker were established based on the recording of 10 repetitions of /aCa/ sequences with C=/k, g, t, n, s, z/, produced in the same carrier sentence as the test material. Examination of the electrodes contacted at least once during the articulation of /a/ and each of the consonants (from the minimum contact of /a/ to the maximum contact for the consonant) was used to define the front (alveolar) and back (velar) regions presented in figure 1. All electrodes contacted during the alveolar and velar consonants were associated to the front and back region, respectively. In order to ensure that onset of contact in a region is concomitant to the formation of the consonant constriction rather than the outcome of context influence, no electrodes contacted during the articulation of /a/ were included in the consonantal regions, and electrodes contacted in the production of both alveolar and velar consonants were also excluded. All the electrodes not contacted during the sequences were included in the closest region (see Byrd and Tan 1996 for a similar procedure).

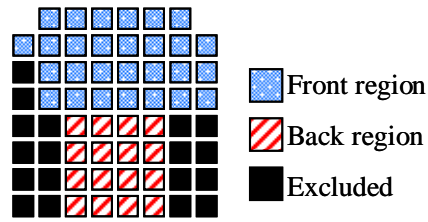


Figure 1. Electrodes included in the front (alveolar) and back (velar) regions on the EPG palate for the speaker recorded.

2.3. Measurements

We evaluated a series of dimensions in order:

- (i) to determine how the acoustic and articulatory make-up of consonants vary as they occupy one the 3 different positions in the syllable
- (ii) to determine how the patterns of coordination in C1C2 and C2C3 sequences vary depending on syllable position and affiliation
- (iii) to test whether the apparition of vowel-like elements in the vicinity of a consonant is a function of the position of this consonant within the syllable.

Concerning the first issue, we examined temporal, spatial, and pseudo-dynamic properties of C2 depending on its position within the syllable. The temporal properties of C2 were measured to determine whether nucleus consonants (condition A) are longer than their non-nucleus counterparts (conditions B and C). Two types of duration were considered:

1. *acoustic duration of C2*: Based on the acoustic waveform and spectrogram, we measured C2 closure, C2 release, and the total duration of C2 (i.e. closure + release). As illustrated in figure 2, closure duration was defined as the temporal interval between the offset of C1 release (i.e. offset of release frication noise for stops and formants for nasals) or offset of a schwa-like element, if any, and the onset of the impulsional aperiodic signal corresponding to C2 burst. The duration of C2 release was measured from the onset of the burst to the onset of C3 or the onset of a schwa-like vocalic portion if any. C2 release was not measured for item 04 where the following /z/ made the exact segmentation quite hard to obtain (see example in figure 3c). Total acoustic duration of C2 was computed by summing the duration of the closure and the release for all items except for item 04.
2. *duration of C2 lingual closure*: This parameter was measured from the EPG data, as the temporal interval between the first frame showing a full velar closure in the velar region to the first frame with the velar seal broken. In figure 2, these frames are indicated with boxes. Note that all the cases with an incomplete velar closure (incomplete seal on the

EPG palate) were excluded from this analysis, as well as the only 2 repetitions of item 6 that were produced with a complete seal in condition C (thus N=100).

The spatial articulatory properties of C2 were compared between the three conditions to test whether nucleus consonants present specific articulatory properties that could be related to strengthening or resistance to lenition (Fougeron 1999). The amount of linguo-palatal contact was measured by computing the percentage of electrodes contacted in the velar region (see above for region definition) for consonants showing a complete seal at the back of the EPG palate. Two measures were taken

- (1) amount of velar contact over the whole duration of C2 closure
- (2) amount of velar contact in the first frame showing the largest amount of contact, that is, at the point of maximum velar constriction in the articulation of the consonant.

This frame is indicated by a diamond in figure 2.⁵

As an index of lingual articulation, the rate of occurrences showing an incomplete velar seal on the palate was also compared across conditions. The absence of an incomplete closure on the EPG palate can result from either a lenition of the velar stop or an articulation that is more posterior than the limits of the artificial palate.

In order to test whether syllabic consonants differ in the dynamic properties of their articulatory movements, pseudo-dynamic properties were compared. In the framework of Articulatory Phonology, vocalic and consonantal gestures are defined with different dynamic properties. Vocalic gestures are specified with a smaller stiffness than consonantal gestures, reflecting the fact that the articulators take more time to achieve their targets (Browman and Goldstein 1986). Would nucleus consonants behave more like vowels in this regard? Two types of parameters were considered to describe the dynamics of the evolution of the linguopalatal contact over time (N=100, see note 5):

1. a measure of *pseudo-stiffness* ('a' in figure 2) is defined as the time from the onset of contact in the velar region ('pseudo-velar movement onset') to the frame with maximum contact ('pseudo-velar target').
2. a measure of *pseudo-velocity* ('b' in figure 2) is computed as the slope of the evolution of contact from the onset of contact in the back region to the amount of maximum contact

⁵ As for the duration of C2 lingual closure, cases with an incomplete velar closure and the 2 repetitions of item 6 were excluded from the analyses of amount of contact and of the pseudo-dynamic parameters.

in the velar region ('pseudo velar closure movement') over the duration of this 'pseudo movement'.

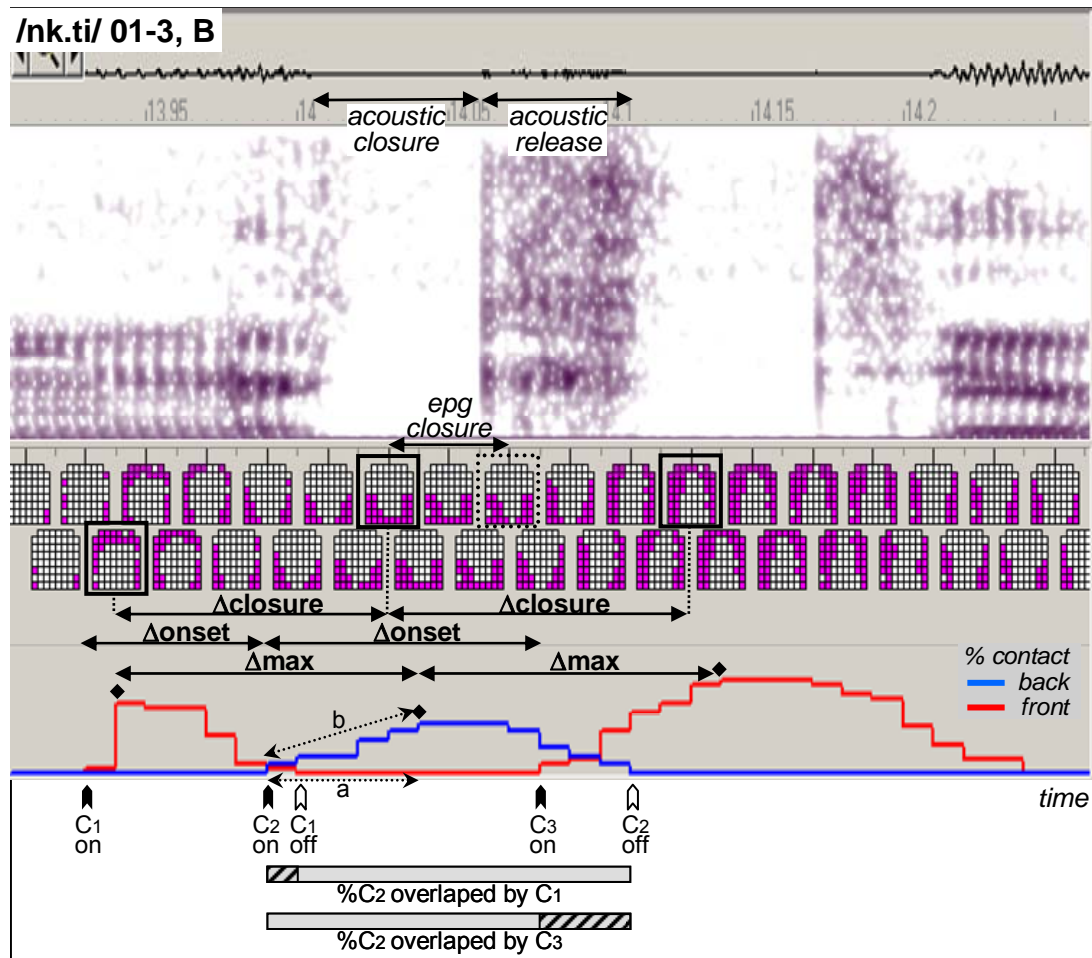


Figure 2. Illustration of the measurements considered. Acoustic closure and release duration are segmented on the signal and spectrogram displays. The palates displayed below the spectrogram show the location of the electrodes contacted on the palate (colored squares), the frames (displayed for convenience into 2 lines) are recorded every 10 ms. Black boxes indicate the onset (first frame with full seal) of the alveolar and velar closures. Dashed box indicates the offset of C2 closure (first frame with a broken seal). In the lower panel, the contact profiles in the alveolar (red) and velar (blue) regions give the percentage of electrodes contacted in these regions over time. The first and last frames showing contact in each region were labeled as onset and offset of contact. The first frame with maximum contact was also labeled (here with diamonds). For other measurements refer to the text for details.

For most of the parameters considered for defining the acoustic and articulatory properties of a consonant depending on its position within the syllable, the comparison between the three conditions was done not only on the values obtained for each measurement, but also on the variability of each measurement across the 12 repetitions. Following the procedure used in Byrd (1996a), absolute values of the deviations of each token from the group mean of the 12 repetitions of the corresponding item in a particular condition were taken as data to test equal variability between the 3 conditions for the relevant measurements. A smaller variability in a

specific condition is interpreted as an index of the acoustic or articulatory stability of the consonant.

Concerning the second issue addressed in this study, we examined the temporal coordination between the consonants in the sequences depending on their positions and the structural relationship they share within and across syllables. Comparisons were made in terms of both their phasing relations and the stability of their coordination (using the variability measures described above). Phasing relations were assessed from the EPG data with measures of the temporal alignment of selected EPG events and of the amount of overlap between contact profiles in the alveolar and velar regions corresponding to the different consonants. Measurements were taken from contact profiles (trajectories) plotting time in frames of 0.01 s against the percentage of contact in the alveolar and velar regions (Byrd 1994, Byrd and Tan 1996). The lower panel of figure 2 gives an example of the contact profile for the sequence /nk.ti/ “we remembered” showing the evolution of contact over time for the first consonant in the alveolar region (red), then for C2 in the velar region (blue), and finally for C3 in the alveolar region (red). Different EPG events were labeled on these profiles as shown in figure 2:

- onsets and offsets of contact in alveolar and velar regions (Cxon, Cxoff)
- time at which the maximum of contact is made in the alveolar and velar regions (shown with diamonds). Cases with incomplete seals were excluded.
- time at which the alveolar and velar seals are formed (first frame with full alveolar and velar seal, indicated in boxes in the figure). Again, cases with incomplete closures were excluded.

The temporal delay between some of these EPG events was examined in order to determine whether EPG articulatory events of a consonant in nucleus position are aligned later or earlier in time relative to those of adjacent consonants. Absolute latencies between different articulatory events were computed as follows:

- Δ *onset*: interval between onset of contact in one region to the onset of contact in the other region,
- Δ *max contact*: interval between the frame of maximal contact in one region to the frame of maximal contact in the other region (cases with incomplete seals were excluded),
- Δ *closure*: interval between the first frame showing a complete seal in one region to the frame showing a complete seal in the other region (cases with incomplete seals were excluded).

In order to assess whether the amount of overlap between C2 and the surrounding consonants is function of the position C2 occupies within the syllable, we computed the percentage of C2 overlapped by C1 and C3. This index provides the percent of the duration of C2 contact profile during which contact related to either C1 or C3 occurs. *%C2 overlap by C1* measures how late in C2 the alveolar contact of C1 remains during the linguopalatal articulation of C2, expressed as a percentage of C2 duration. As illustrated in figure 2, it is measured as $((C1_{offset} - C2_{onset}) / (C2_{offset} - C2_{onset}) * 100)$. *%C2 overlap by C3* measures how early the alveolar contact of C3 occurs during the linguopalatal articulation of C2, expressed as a percentage of C2 velar contact duration. It is measured as $((C2_{offset} - C3_{onset}) / (C2_{offset} - C2_{onset}) * 100)$.

Regarding the third issue, the occurrence of a schwa-like vocalic element between C1 and C2 and between C2 and C3 was determined on the acoustic waveform and spectrogram by the presence of vowel-like voiced periods and formant structure. Figures 3a, b, c present illustrations of consonant transitions surfacing without (3a) or with a vowel-like element (3b, c), and illustrate the cues used to detect the presence of a schwa vowel. As is visible in figures 3b and 3c, these schwa-like elements were sometimes very short and more or less apparent. In some sequences, it was hard to determine whether a schwa-like portion was present which makes the exact segmentation of the sequence hard to obtain. This occurred in 4 of the 214 occurrences of C1-C2 transitions and in 40 of the 214 occurrences of the C2-C3 transitions. This later case included all the C2-C3 transitions of the item 4 (/C1gz/) where it was very hard to distinguish a schwa like element from the voiced frication of /z/ (see figure 3c). These 44 tokens were excluded from the analysis.

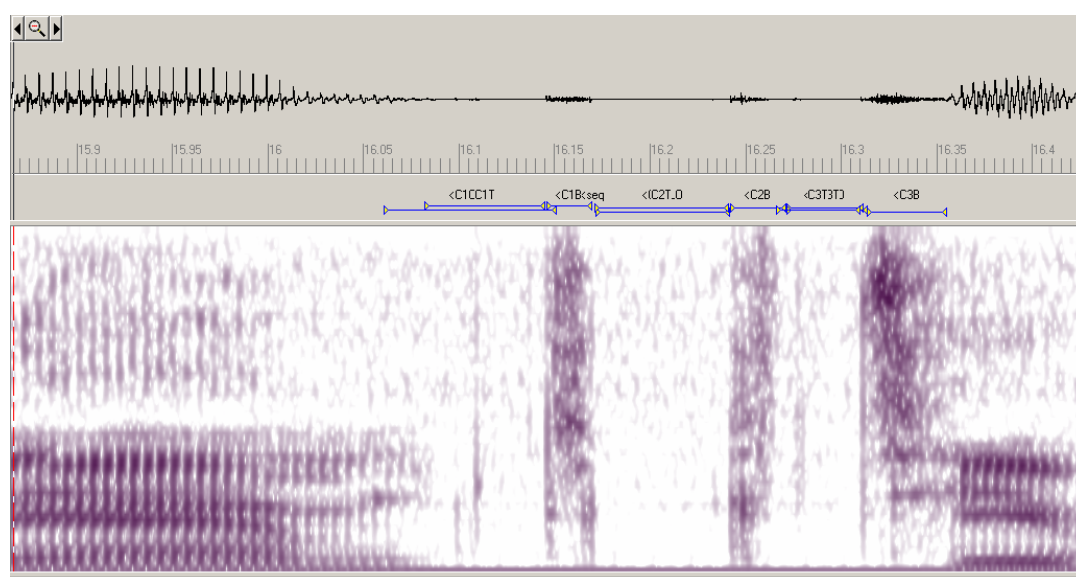


Figure 3a. Sequence /emtkti/ (seq. 01-1, cond. A) produced with no apparent schwa-like elements during the transitions C1C2 or C2C3.

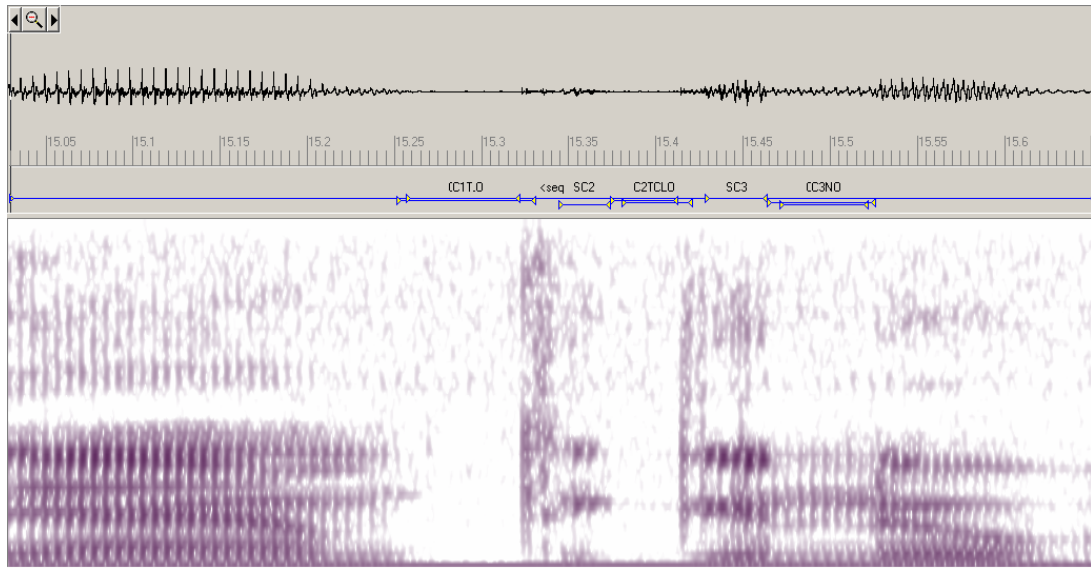


Figure 3b. Sequence /ɛmtgnu/ (seq. 05-10, cond. A) produced with (1) a few voiced periods and a formant structure after C1 /t/ release and before the onset of C2 /g/, and (2) an increase in signal amplitude and presence of formant structure after C2 /g/ release and before C3 /n/ onset. (Note that /g/s were very often produced without voicing during closure).

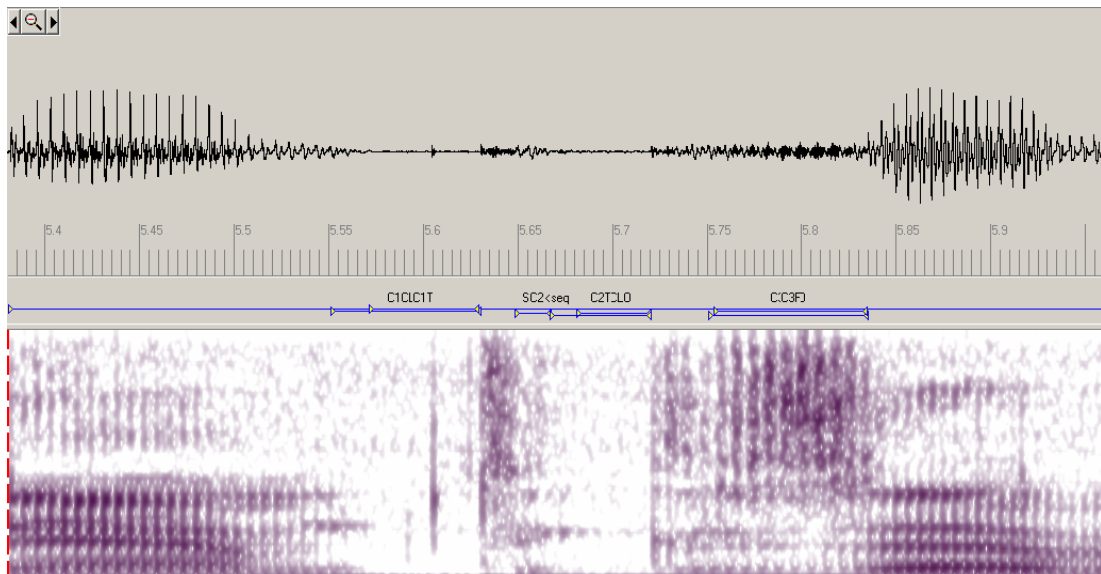


Figure 3c. Sequence /ɛmtgza/ (seq. 04-1, cond. A) produced with about 5 periods of voicing and a weak formant structure after the release of C1/t/. For this item 04, the presence of schwa like element after C2 was not analyzed due to the difficulty of segmenting C2 release and C3 onset.

3. Results

3.1. *Phonetic properties of C2*

3.1.1 *Durational properties of C2*

The position of C2 within the syllable has no effect on the articulatory closure duration of the consonant ($F(2, 97)=.16, p=.9$), nor on the variability of this closure duration ($F(2, 97)=.8, p=.4$). Syllabic consonants are not longer than their non syllabic counterparts and, surprisingly, there are no durational differences between onsets and codas, neither.

Regarding acoustic duration, no effect is found on the duration of the occlusion ($F(2, 211)=1.09, p=.3$), the duration of the release ($F(2, 175)=.52, p=.6$), and the total duration (occlusion+release ($F(2, 175)=.08, p=.9$). However, an interesting tendency is found when looking at the variability of these measurements across repetitions. While no main effect is found for the variability of closure duration ($F(2, 211)=2.54, p=.08$), and the variability of release duration ($F(2, 175)=2.55, p=.08$), post hoc comparisons show differences between conditions⁶. In nucleus position, the duration of C2 occlusion is less variable than that observed in onset position ($p=.03$) and the variability of its release duration is marginally smaller than that in coda ($p=.05$) and onset ($p=.05$) positions.

3.1.2 *Spatial properties of C2*

For the cases with complete velar closure, the amount of linguopalatal contact is compared between the 3 conditions. No effect is found whether the percentage of electrodes contacted in the velar region is computed over the whole duration of C2 closure ($F(2, 97)=.17, p=.2$) or whether it is computed at the frame of maximum contact ($F(2, 97)=2.12, p=.1$). No effect is found in the variability across repetitions neither ($F(2, 97)=.93, p=.4$. $F(2, 97)=1.1, p=.3$, respectively). C2 in nucleus position is not produced with a greater amount of contact, nor with a smaller variability compared to its non-syllabic counterparts. Recall that we are examining velar consonants and that for these consonants the area contacted on the EPG pseudo-palate is rather small (see figure 1). Therefore, potential differences in the amount of contact would consist of a few electrodes. Moreover, recall that this comparison includes only the occurrences showing a full velar closure on the palate (102 out of 214). Consideration of the other half of the occurrences (112 out of 214), showing an incomplete velar closure, shows an interesting pattern. Incomplete and complete closure are not equally distributed across the three conditions ($\chi^2(1, 214)=16, p=.0003$). The rate of occurrence of incomplete velar closure appears to be function of

⁶ Fisher PLSD post hoc tests are used, here and henceforth, for the paired comparisons between the 3 conditions.

the position of C2 in the syllable. 65% of this χ^2 value is explained by the distribution of C2 nucleus (condition A) (few incomplete closure (33%) and much more complete closure), while the distribution is the reverse in the other 2 conditions (63% incomplete seals for C2 coda and 60% for C2 onset). Though velar consonants in nucleus position are more often produced with an apparent velar seal, it is however unclear whether this tendency is due to a fronter articulation or to a lesser tendency to lenite.

Examination of the distribution of incomplete seals for the different items, as illustrated in figure 4, shows that incomplete seals are less prone to be realized in nucleus positions for all the items, except for item 06 where almost all the tokens are produced with incomplete closure. A possible explanation for this may be related to the fact that this segment (and the whole item) is dorsopharyngealized - and thus produced with a backer articulation – because of the presence of the dorsopharyngealized dental stop /d²/ in the item. The tendency for nucleus consonants to be produced with complete closure is particularly visible for the items in which C2 is unvoiced (/k/in items 01, 02, 03). Indeed, it seems that the distribution of incomplete closures also varies according to the voiced/voiceless nature of the velar stops. If we can interpret the occurrence of incomplete seals as a tendency to lenite, this observation would support the contentions in the literature that voiced stops are more prone to lenition than their voiceless counterparts (Foley 1977, Lavoie 1996, Ohala 2002, Ridouane 2007).

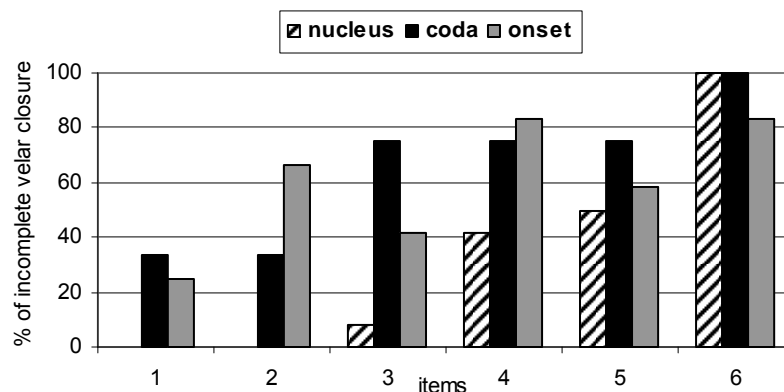


Figure 4. Frequency of occurrence of tokens produced with incomplete velar seals in the 6 items, according to C2 position.

3.1.3. Dynamic properties of C2

Pseudo-stiffness and pseudo-velocity measurements of the contact trajectory from the onset of closure in the velar region to the maximum of contact were computed to determine the effect of

syllable position on the shape of C2 linguopalatal contact trajectory. Results, illustrated in figure 5, show that these two parameters are affected by the position of C2 in the syllable ($F(2, 97) = 31.6$, $p < .0001$ for pseudo-stiffness, and $F(2, 97) = 14.66$, $p < .0001$ for pseudo-velocity). Indeed, the time taken to reach the maximum of EPG contact (a pseudo articulatory target) is shorter for nuclei than for onsets or codas ($p < .0001$ for A vs. B and A vs. C). In addition, the slope of the contact trajectory over time (pseudo-velocity) is sharper when C2 is nucleus compared to onset and coda positions (A > B at $p = .003$, A > C at $p < .0001$).

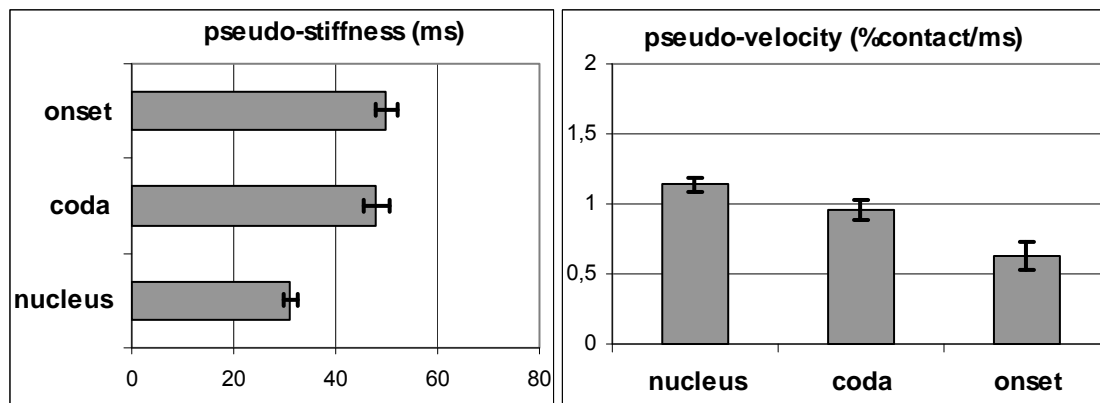


Figure 5. Mean and standard errors for the measurements of pseudo-stiffness (in ms.) and pseudo-velocity (in % of electrode in the velar region/ms.) for C2 according to position in syllable.

3.2. Temporal coordination between C2 and adjacent consonants

While the goal of the comparisons in 3.1. was to investigate how specific phonetic dimensions of a particular consonant are affected depending on the position it holds within a syllable, the present section is concerned with the temporal coordination between the constituents of a syllable. Phasing relations are measured both in terms of the temporal alignment of specific EPG events and of amount of overlap between contact profiles in the alveolar and velar regions. Properties related to the stability of gestural coordination (bounding strength or phase window), are assessed by measuring the variability of these phasing dimensions across the 12 repetitions. Recall that when we compare CC coordination in the three conditions we are comparing the relationships between consonants having different positions in the syllable (onset, nucleus, coda) but also different syllable affiliations (sometimes heterosyllabic, sometimes tautosyllabic).

3.2.1. Temporal alignment

Latencies between some the EPG articulatory events of C2 relative to C1 and to C3 are presented in figure 6. Two out of the three measurements computed to assess the temporal

alignment of C2 relative to C1 show an effect of condition: $\Delta onset$ ($F(2, 208)=54.21, p<.0001$), $\Delta closure$ ($F(2, 93)=3.85, p=.02$). No effect is found for $\Delta max contact$: ($F(2, 93)=1.40, p=.2$). As shown in the left panel of figure 6, there is a longer delay between the onset of contact in the alveolar and velar regions ($\Delta onset$) when C2 is a nucleus preceded by an onset (condition A) compared to when C2 is a coda preceded by a nucleus (condition B, $p<.0001$) or when C2 is an onset preceded by a heterosyllabic nucleus (condition C, $p<.0001$). This alignment is also reflected by a longer delay between the onset of C2 velar closure and the onset of C1 alveolar closure ($\Delta closure$) in condition A ($onset_{C1}$ - $nucleus_{C2}$) compared to condition B ($nucleus_{C1}$ - $coda_{C2}$) ($p=.01$). No differences are found when comparing the degree of variability of these three measurements of latencies.

Regarding the latencies between events related to C2 and events related to C3, illustrated in the right panel of figure 6, no main effects are found ($\Delta onset$ ($F(2,208)=2.2, p=.1$), $\Delta closure$ ($F(2,85)=.59, p=.5$), $\Delta max contact$:($F(2,85)=2.73, p=.07$). However, post-hoc comparisons show a longer delay in condition A ($nucleus_{C2}$. $onset_{C3}$) compared to condition C ($onset_{C2}$ - $nucleus_{C3}$) between the onset of contact in the velar and alveolar regions ($\Delta onset$ $p=.04$) and the times of maximal contact in these two regions (Δmax $p=.04$). Interestingly, the temporal alignment between C2 and C3 appears to be more stable when C2 is a nucleus. A main effect (not illustrated here) is found for the variability of $\Delta onset$ ($F(2,208)=7, p=.001$), which is smaller in condition A ($nucleus_{C2}$. $onset_{C3}$) compared to condition B ($coda_{C2}$. $onset_{C3}$, $p=.003$) and condition C ($onset_{C2}$ - $nucleus_{C3}$, $p=.01$). The variability of $\Delta closure$ is also affected ($F(2,85)=3,19, p=.04$) and is smaller in condition A ($nucleus_{C2}$. $onset_{C3}$) compared to condition C ($onset_{C2}$ - $nucleus_{C3}$ $p=.01$).

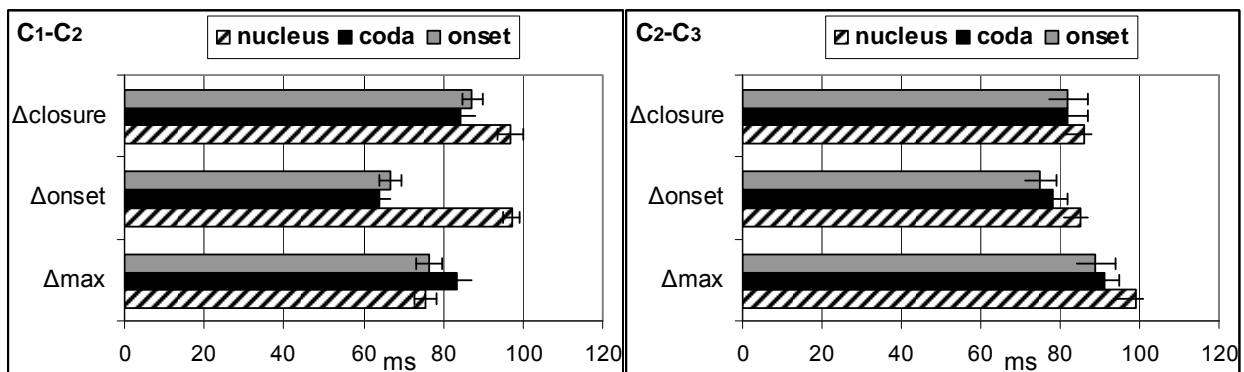


Figure 6. Latencies (mean and std errors) between C1 and C2 (left) and C2 and C3 (right) for $\Delta closure$, $\Delta onset$ et Δmax , according to C2 position.

3.2.2. Percentage of C2 overlapped by the adjacent consonants

The aim of this comparison is to evaluate how much or how little the velar articulation is obscured by the adjacent alveolar gestures and how stable the timing between the consonants is as a function of their position within and across syllables. Figure 7 illustrates the amount of overlap of C2 by C1 and C3, expressed as a percentage of C2 duration. Figure 8 shows the variability of these 2 overlaps.

A main effect is found for the amount of overlap of C2 by C1 ($F(2, 205)=26,71, p<.0001$) as well as for the variability of the overlap across repetitions ($F(2, 205)=4.66, p=.01$) according to C2 position. Within a syllable (i.e. condition A *vs.* B), C2 nucleus is more overlapped by a preceding onset (condition A) than C2 coda by a preceding nucleus (condition B) ($p<.0001$). This large degree of overlap is also more stable, i.e. less variable, for the onset.nucleus structure ($p=.04$). Interestingly, when comparing tautosyllabic and heterosyllabic sequences, this pattern is replicated: C2 nucleus is more overlapped by a preceding onset (condition A) than C2 onset by a preceding heterosyllabic nucleus in condition C ($<.0001$). This timing relationship is also more stable ($p=.003$). No significant differences are found between the tautosyllabic nucleus-coda sequence of condition B and the heterosyllabic nucleus.onset sequence of condition C.

Concerning the percentage of C2 overlapped by C3, the coordination is also found to be affected by the position of C2 within the syllable, though with a difference in the size of overlap. A main effect is found for the degree of overlap ($F(2, 208)=5.78, p=.003$) and for the variability of the overlap ($F(2, 208)=8.15, p=.0004$), but with a pattern showing less overlap in condition A. Across a syllable boundary (condition A *vs.* B), C2 nucleus is less overlapped by the following heterosyllabic onset (cond. A) than C2 coda by a following heterosyllabic onset in condition B ($p=.008$), and this coordination is also more stable ($p=.0002$). Comparing tautosyllabic (cond.C) and heterosyllabic (cond A and B) sequences, the overlap of C2 by C3 differs only between conditions A and C. C2 nucleus is less overlapped by the following heterosyllabic onset (cond A) than C2 onset by a tautosyllabic nucleus ($p=.001$). Again, the coordination is more stable when C2 is nucleus than when C2 is onset (condition C) ($p=.003$).

Comparison between condition B [nucleus-coda.onset] and C [nucleus.onset-nucleus] allows to test for the effect of syllabic affiliation of the consonants in the sequence, while keeping constant the identity of the consonants (C1=/n/ in both cases) and its syllabic status (C1 is nucleus in both cases). The absence of clear differences in coordination between C1 and C2 in these 2

conditions (even when condition A is removed, $t(134)=-1.57, p=.1$) suggests that the presence of a syllable boundary plays no role in the amount or stability of overlap in Tashlhiyt. This lack of effect is also apparent when comparing the degree of overlap between C2 and C3 in condition B (heterosyllabic coda.onset sequence) and C (tautosyllabic onset-nucleus).

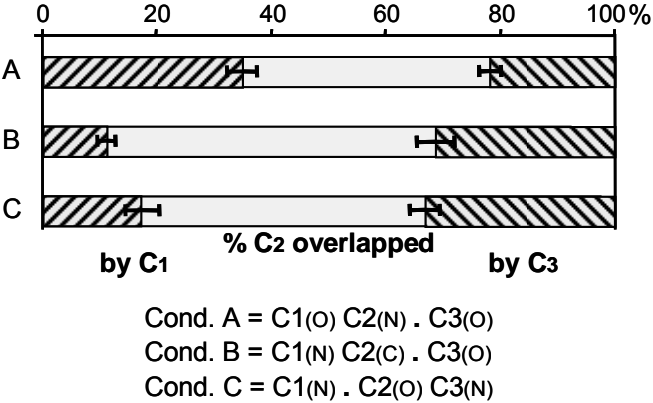


Figure 7. % of C2 duration overlapped by C1 (shaded bars on the left) and by C3 (shaded bars on the right) according to condition A, B and C. (Mean values and standard errors).

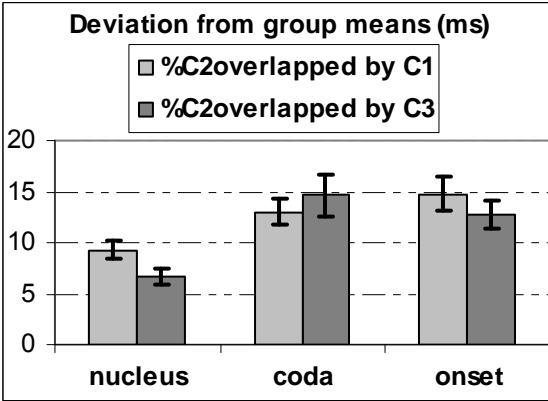


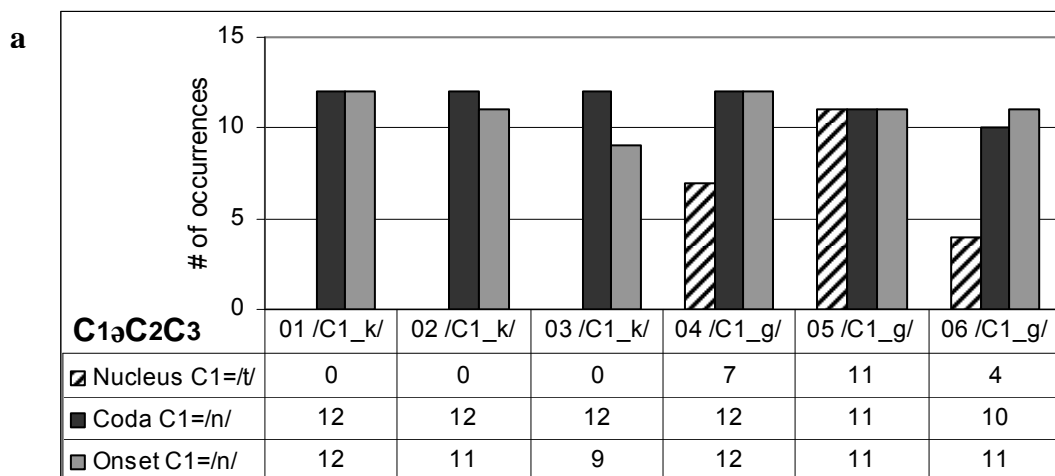
Figure 8. Index of variability in the amount of overlap of C2 by C1 and C3.

3.3. Presence of schwa-like vocalic element adjacent to C2

Figures 9a and 9b detail the number of schwa-like vocalic elements occurring in the adjacency of C2 as it occupies the three different positions within the syllable. Recall that what we counted as ‘schwa-like vocalic element’ are occurrences showing a portion of the acoustic signal containing voicing and a formant structure at the transition between the flanking consonants. Comparison of the distribution of the schwa-like elements in the three syllable structures tested with an expected distribution in which the rate of occurrence was equally distributed, shows interesting results. On the one hand, the rate of schwa occurrence between C2 and C3 is not dependent on the condition, that is on the position of C2 or C3 in the syllable ($\chi^2 = 5.6, p=.06$). There is no tendency for C3 nucleus (see condition C, where C2 is onset, grey bars on the figure) to be more

often preceded by a schwa than in the other conditions. On the other hand, the presence of schwa between C1 and C2 seems to be different in the 3 syllabic structures examined ($\chi^2 = 100.7$, $p < .001$). 50% of this effect is explained by the distribution of the condition where C2 is nucleus (condition A), where less schwa-like elements are observed (31% of the occurrences, compared to 99% in condition B and 93% in condition C).

A closer examination of the data for the different items provides arguments to explain the discrepancies in these results. A confounding factor has to be considered for the prediction of schwa occurrence: the voiced or voiceless nature of the consonants in the sequence. Within two voiceless consonant-clusters (e.g. /tk/ in item 01 in condition A or /kt/ and /ks/ in items 01 and 02 in the three conditions), schwa-like elements never occur. While the following hypotheses have to be tested on a controlled corpus for this purpose, the present data suggest that the voicing of both the first and the second consonants in the sequence affects the occurrence of this vocalic transition. Indeed, schwa occurs more often when the second consonant is voiced (e.g. between C1 and C2 when C2 is /g/ in items 4, 5, 6 vs. /k/ in items 1, 2, 3; and also between C2 and C3 when C3 is /n/ in item 03 vs. /t/ in item 01). Schwa also occurs more frequently when the first consonant is voiced (e.g. C1 = /n/ in condition B and C; and C2 = /g/ in item 05 vs. /k/ in item 03). Overall, syllabic C2 consonants in condition A (or syllabic C3 consonants in condition C) are not more often preceded by a schwa, even when the voicing of C2 favors this schwa-like element. This appears clearly when looking at items 04 and 06: C2 is not more preceded by a schwa when nucleus (condition A). Rather, the voiceless nature of C1 in this condition (/t/ vs. /n/ in the other condition) disfavors the occurrence of schwa-like elements.



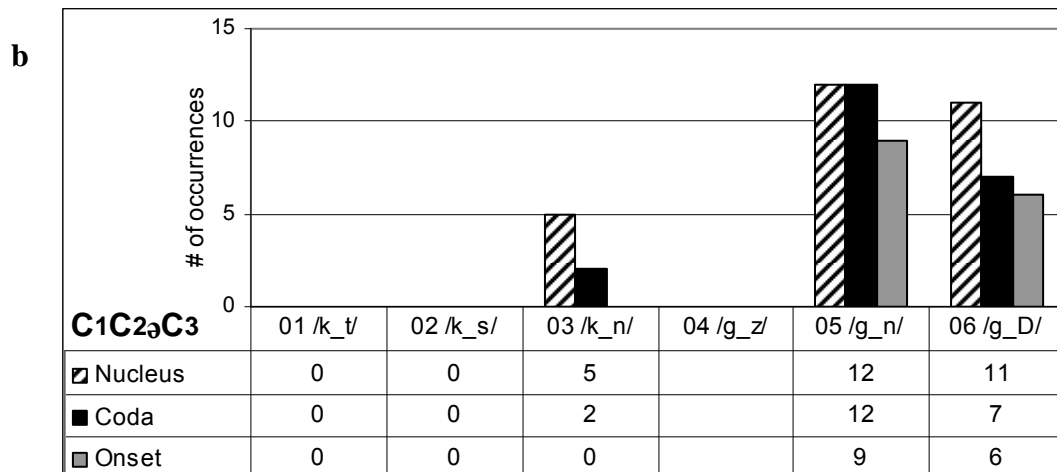


Figure 9a and b. Number of occurrences of schwa between C1 and C2 (a) and C2 and C3 (b), presented according to C2 position in the syllable (nucleus: condition A, coda: condition B, onset: condition C), in the 6 items of the corpus. Consonant context is indicated in the tables. Note that for item 04 [g_z] no values are given due to the difficulty of determining whether a schwa was present.

4. Discussion & conclusion

The results obtained in this study are discussed here while keeping in mind that they are limited to the production of a single native speaker. They provide, however, some interesting findings that ought to be further investigated with additional data and subjects. We hypothesized that syllabic consonants in Tashlhiyt would be cued by phonetic properties that could distinguish them from their non-syllabic counterparts. Our study has shown that the syllabicity of an obstruent does not translate into an increased acoustic or articulatory duration. Indeed, contra to the results reported for sonorant nuclei in languages such English and German by Price (1980), or Clark & Yallop (1995), Tashlhiyt velar consonants in nucleus position are not found to be longer than in onset or coda positions. Note, however, that our results mirror those of Toft (2002) who found that for British English, syllabic /l/ and /n/ are not longer than their non-syllabic counterparts. This may suggest that syllabic consonants are not necessarily cued by longer durations. An interesting tendency that has to be further tested, in a paradigm allowing variation in speech rate for example, is the fact that /k/ and /g/ durations seem to be less variable in nucleus position. If onsets and codas were found to be more flexible in their durations than nucleus consonants, then durational properties could be used as cue to syllabicity.

An interesting difference between consonants in nucleus vs. onset and coda positions is the fact that syllabic consonants are more often produced with a visible complete velar closure. As outlined earlier, interpretation of this result is difficult since incomplete EPG velar closure may

result from an articulation posterior to the limits of the palate or from a real incomplete (lenited) velar closure. With a more frequent apparent complete velar seal in nucleus position, the velar consonants examined here may have a less posterior articulation, and/or have a larger area of linguopalatal contact (spreading over a larger part of the hard palate, thus reaching more often the pseudo-palate, and thus showing more often a complete seal), and/or a lesser tendency to lenite. Examination of the articulation of non-velar consonants in different positions is needed to further test these hypotheses. Nonetheless, these parameters provide further arguments in favor of a reduced variability of the linguopalatal articulation of the consonants in nucleus position. Indeed, if one excludes the productions of items 06 showing incomplete closure in all conditions (probably due to the presence of the dorsopharyngealized consonant /d^ʔ/), syllabic consonants are produced with complete seals in 80% of the cases, while onsets and codas alternate more often between a production with complete closure and a production with incomplete closure (45-55% for onsets and 42-58% for coda).

Regarding the differences in the pseudo-dynamic properties of the linguo-palatal articulation, we have found higher stiffness and velocity of the evolution of the linguopalatal contact when C2 is nucleus compared to onset and coda. This result is opposite to what would be expected if nucleus consonants were to behave like vowels. In the framework of Articulatory Phonology, vocalic and consonantal gestures are specified at the level of their dynamic properties with a smaller stiffness and velocity than consonantal gestures, in order to reflect the fact that the articulators take more time to achieve their target (Browman and Goldstein 1985). Our results refute the view that consonants occupying nuclei positions would become more vowel-like in their dynamic properties. Interestingly, our observations corroborate the result obtained by Browman et al. (1998), based on EMA data from one native speaker of Tashlhiyt. They measured time from onset to target in several consonant sequences and found that the movement time is shorter when the sonorant /r/ is syllabic. As for our data, the interpretation of this effect is obscured by the fact that in order to have a consonant in nucleus position, the adjacent consonants have to be different from the other conditions (here /t/ in condition A, and /n/ is the other conditions). Consequently, it is difficult to tear apart what is due to the nature of the preceding consonant and what is due to the nucleus status. In their discussion of their results, Browman et al. (1998) explained the dynamic properties found for syllabic /r/ by the fact that this sonorant overlaps and blends with the following /t/ consonant. In our data, the increased stiffness/velocity of C2 linguopalatal closure is rather concomitant with an increased overlap by the preceding consonant.

Our study also tested whether the syllabic status of a consonant in Tashlhiyt was associated with the production of a schwa-like element. This question echoes the hypothesis according to which in languages such as German and English syllabic sonorants (/l/, /n/, /r/) in post-tonic stress position are said to alternate with a pronunciation of schwa plus a consonant. Traditionally, schwas observed in the vicinity of syllabic sonorants in German and English are understood as either an epenthetic vowel inserted in the process of derivation (e.g. Wiese, 1996, for German) or as being present in the underlying form and then deleted in the appropriate cases (e.g. Gussenhoven & Jacobs, 1998, for English). Within the framework of Articulatory Phonology, these schwa-like elements are said to derive acoustically from a reduced gestural overlap between the flanking consonants (Price 1980, Browman and Goldstein 1990, 1992, Smorodinsky 2002, Gafos 2002). On the basis of his belief that all words have syllables and all syllables have vowels in all languages, Coleman (2001) has proposed what he calls “the Coproduction Analysis of Syllabic Consonants” and interprets Tashlhiyt syllabic consonants as sequences of schwa vowels plus consonants. More specifically, he argues that the schwa-like element realized between /t/ and /g/ in *tgnu* (see in figure 3b for example) is an epenthetic vowel, introduced by the phonological component to repair syllable structure. In his model, such epenthetic schwas are expected to occur before any syllable nucleus that is not filled by one of the lexical vowels /i/, /u/, and /a/. In addition, he claims that all occurrences of schwa-like vowels are epenthetic introduced by syllabification. Two aspects of our results clearly show that the occurrence of schwa is not conditioned by the syllabicity of the consonant. First, occurrence of schwa before /g/ nucleus is less frequent than before /g/ onset or coda. Second, /k/ nucleus is never preceded by a schwa while /k/ onset and coda are. Though the exact regularities of schwa occurrences have yet to be worked out, closer examination of the results suggest that they are rather linked to the laryngeal specifications of the consonants contained in a sequence. For a schwa-like vowel to be realized in the signal, the consonantal cluster must contain at least one voiced consonant⁷. To account for cases where no schwas are present acoustically, Coleman claims that there is a schwa vowel associated with syllable nuclei, but it is ‘hidden’ behind the consonant gestures. Hence, the realization of this schwa would depend on the nature of the coordination between the consonantal gestures. Though our concern in this study is not to test whether these schwa-like elements are inserted target-full vowels or merely transitional elements, our data provide potential arguments against Coleman’s basic proposal: nuclei consonants are

⁷ In addition, the consonants within the cluster should not be homorganic. We currently analyze electropalatographic and ultrasound data on Tashlhiyt homorganic words (e.g. [tntltnt] “she hid them”) showing that during the production of such items the tongue does not move away from the alveolars, a gesture necessary for a vocalic element to be realized.

more overlapped than any other consonants by its preceding onset and this timing is quite stable. Given this, it is hard to explain in a principled way why the phonological component would insert a vocalic element in a position where it has all the chances to be hidden by adjacent consonants. In other words, according to his account, the phonological component would insert a schwa to repair illegal structures, and phonetic implementation would mask this schwa. Moreover, it is not clear how the claim that Tashlhiyt clusters contain epenthetic hidden schwas would support Coleman's theory: can a hidden segment act phonologically? To be syllabic, a schwa vowel must correspond to a segment which can be independently manipulated by phonological grammar and which the syllable structure can refer to. Ridouane (2008) presents two main arguments, metrics and a spirantization process, as evidence that such vowels are not present at the level of phonological representations of Tashlhiyt (see also Dell and Elmedlaoui 2002).

The examination of the patterns of coordination between consonants within and across syllables reveals interesting differences that merit further examination. Our data present evidence that the syllabicity of a consonant in Tashlhiyt translates into specific patterns of coordination between this segment and the adjacent consonants. This is evidenced by particular patterns of *overlap* and temporal *alignment* of articulatory events, and more interestingly, by a more *stable* pattern of coordination. Overall, the pattern of coordination observed in condition A [onset-nucleus.onset] is characterized by: a long delay between C1 and C2 articulatory events, a large and stable amount of overlap between C1 and C2, a small and stable amount of overlap between C2 and C3, and a long and stable delay between C2 and C3 articulatory events (though compared to condition C only). The apparent contradiction between the latencies of C1 and C2 articulatory events and the degree of overlap can be explained by the fact that C1 in condition A (/t/) is longer than C1 in the other conditions (/n/). As a consequence, the onset or the target achievement of their (pseudo linguopalatal) gestures is further apart, while C1 offset can occur later into C2 (giving more overlap). Since the differences observed in the coordination of C1 and C2 can be attributable to the difference in consonant type between the conditions (/t/ or /n/) – a difference that will always occur in Tashlhiyt since it is this very difference that allows for the different syllable structure – we will focus in the remaining of our discussion on the stability observed in condition A.

Interestingly, the general patterns observed in our study corroborate the pattern observed in the production of the Tashlhiyt speaker studied in Browman et al. (1998): syllable organization was reflected in the tightness of the coordination between consonant gestures bearing an onset-nucleus relation compared to a heterosyllabic sequence. Increased stability in the articulation of a

syllabic consonant (suggested by the patterns we found for duration or occurrences of complete closure) or in the stability of its coordination with adjacent consonants (as shown in the latencies between C2 and C3, and in the overlap within C1C2 and within C2C3) could be related to the functional status of nucleus consonant and to the strength of the structural relations between the constituents of a syllable. In Articulatory Phonology, stability in timing has been modeled to account for the different variability in the coordination between syllable constituents in terms of a phase-window model (Byrd 1996b, Byrd & Satzman 2003), in which intergestural coordination is assumed to allow at least a certain range of relative timing, or in terms of degrees of bonding (or coupling) strength (Browman & Goldstein 2000, Goldstein et al. 2007) specifying the tightness of the coordination between gestures (stable, tightly coordinated gestures are less variable).

According to these models, the stable coordination of a nucleus consonant with its neighboring consonants found in Tashlhiyt would result from a smaller phase-window or a stronger bonding specification. Our comparison between tautosyllabic and heterosyllabic consonant sequences, suggests that this specification is particular to the nucleus position. Indeed, contra to the findings of Byrd (1996b) showing that American English tauto-syllabic consonant clusters were more stable in their coordination than consonants spreading a syllable boundary, no differences are found in the stability of the timing (nor in the amount overlap) of non-nucleus C2 with heterosyllabic or tautosyllabic consonants in Tashlhiyt. Consequently, the stability of the coordination of a nucleus consonant with its neighbors (here: its preceding onset and a following heterosyllabic onset) could be considered as a cue to the syllabic structure of this vowel-less syllable. This finding raises an interesting issue related to speakers' perception of syllables and syllable constituents. One may hypothesize that the patterns of coordination between a nucleus consonant and adjacent consonants in a vowel-less syllable may be related to the preservation of the perceptual recoverability of the nucleus consonant. Basic tenet for this hypothesis is that, while stability in gestural timing does inform on the specific timing specification of the gestures within the syllable, they do not carry perceptual information per se. When listening to a single utterance of a vowel-less syllable, the listeners can not rely on the stability of its gestural coordination without any external reference. This information can not be extracted as such. Nevertheless, the stable pattern of coordination observed in our study, showing longer latencies between articulatory events and less overlap of C2 by C3, could contribute to the preservation of the perceptual cues (e. g. C2 release information) of the most important element within a syllable (the nucleus), so as to optimize its recoverability. Stability in such a coordination pattern would be even more important for vowel-less voiceless syllables for which a too extreme overlap would

have drastic consequences on the consonants recoverability. Metalinguistic judgments are planned to further test this hypothesis.

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