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Kinematics of Syllable Structure in Tashlhiyt Berber: The Case of Vocalic and Consonantal Nuclei

Anne Hermes¹, Rachid Ridouane^{2*}, Doris Mücke¹, Martine Grice¹

¹I/L – Phonetik, University of Cologne, Germany

²Laboratoire de Phonétique et Phonologie (CNRS/Sorbonne Nouvelle), Paris, France

{anne.hermes; doris.muecke; martine.grice}@uni-koeln.de,
rachid.ridouane@univ-paris3.fr

Abstract. *This study provides evidence from the coordination of articulatory gestures, using electromagnetic articulography (EMMA), in favour of a heterosyllabic analysis of word initial clusters in Tashlhiyt. Evidence from calculations of C-center and Rightmost C to a following anchor in the syllable as well as the stability index consistently supports the predominant analysis amongst phonologists of Tashlhiyt that this language permits only simple onsets. These timing patterns hold regardless of whether the syllable nucleus is vocalic or consonantal.*

1. Introduction

The syllable is a key concept in the organisation of consonants and vowels in phonological theory. Recent research in Articulatory Phonology has provided important evidence for the claim that this abstract organisation is reflected in the temporal patterns of speech production (Krakow 1999, Goldstein et al. 2007, Shaw et al. 2009). In this article, we investigate articulatory patterns to evaluate a specific aspect of the syllable organisation of Tashlhiyt.

1.1 Tashlhiyt Syllable Organisation and the Constraint against Complex Onsets

In Tashlhiyt, it has been argued that the entire set of consonants may alternate between nuclear and non-nuclear positions (Dell and Elmedlaoui 1985, 2002, Boukous 1987 and Ridouane 2008). A specific aspect of this language is that it does not allow for complex onsets. Consequently, highly frequent word initial clusters of the form CCV (e.g. /kfit/ ‘give it’) are parsed as heterosyllabic C.CV (i.e. k.fit where /k/ can be a syllable on its own or coda of the preceding syllable if any).

Impressive evidence, both external and internal, has been put forward in favour of the above syllabification. The external evidence includes native intuitions and native judgments about well-formedness in versification (Dell and Elmedlaoui 2002). The internal evidence includes insights into various morphological regularities captured by

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assuming the proposed syllabification of consonant clusters (Dell and Elmedlaoui 2002: 115–134 for a detailed discussion). In addition, generalisations about the form of Tashlhiyt syllables and the distribution of their nuclei are independently motivated by constraints of syllable theory, e.g. Onset Constraint and constraints against complex codas and onsets (Prince and Smolensky 1993, Zec 1995, Clements 1997).

Some of these arguments may be challenged (e.g. Angoujard 1997, Coleman 1996). With regard to native intuitions, although they have some value in studies of syllabification, they cannot be relied on in highly complicated cases like #(C)CCVC words. In addition, one may reasonably argue that complex onsets are less marked than syllabic obstruents, and that a CCVC syllable template, where CC is a complex onset, is less marked than C.CVC.

In this work, we investigate whether the simple onset analysis - as opposed to the complex onset hypothesis - has a reflex in the coordination of articulatory gestures.

1.2 Gestural Coordination and Syllable Structure

Within Articulatory Phonology, syllables are viewed as the automatic outcome of a specific temporal organisation into which gestures coalesce. This temporal organisation of consonant clusters differs depending on whether a language allows complex onsets or not. In languages which do allow complex onsets (e.g. English, Georgian, Italian), consonants in a cluster adjust their timing relative to a following articulatory anchor when compared to single consonants comprising simple onsets. This adjustment can be measured as the interval of the mean of consonantal targets relative to a following target in the word (i.e. the C-center effect or center stability; Browman and Goldstein 1988, Hermes et al. 2008, Shaw et al. 2009, Marin and Pouplier 2010).

In languages allowing simple onsets only, the temporal alignment corresponds to a pattern whereby the rightmost C in a cluster is timed the same way as a single C relative to a following anchor within the syllable (right-edge stability; see Shaw et al. 2009 on Moroccan Arabic). Goldstein et al. (2007) presented some preliminary data on Georgian and Tashlhiyt that support this view. They found that in a language allowing complex onsets, here Georgian, the rightmost C to a following anchor interval (in /riali/, /kriali/ and /skriali/) decreases as the number of initial consonants increases. In this case the rightmost C target is shifted towards the V target. In Tashlhiyt, however, no shift was found in /mun/, /smun/ and /tsmun/.

In addition to the rightmost C Measure as used in Goldstein's study (2007), we also calculate the C-center Measure and analyse the stability index for these two variables. Furthermore, we test the gestural timing pattern not only in items with vocalic nuclei but also in those with consonantal nuclei.

2. Method

We recorded 3 native speakers (aged between 37 and 39 years) of Tashlhiyt with a 2D-EMMA (electromidsagittal articulograph) at the I/L Phonetik, University of Cologne. Coils were placed on upper and lower lip, tongue tip, tongue blade and tongue body. For head correction two coils were placed on the upper gums and the bridge of the nose. To rotate the articulatory data in relation to the occlusal plane, a bite plate was used. The acoustic recordings were recorded at 400Hz, downsampled to 200Hz and smoothed with a 40Hz low-pass filter.

2.1 Speech Material

The speech material was presented to the 3 subjects on a screen. In order to compare items with different nucleus types, the target words were structured according to whether the nucleus was *vocalic*: CVC, C.CVC and CC.CVC (e.g. /fik/, /k.fik/ and /tk.fik/) or *consonantal*: CCC, C.CCC and CC.CCC (e.g. /fnk/, /k.fnk/ and /tk.fnk/). All target sequences constitute real words and were embedded in a carrier sentence: Inna ___ bahra ('He said ___ a lot'). In total 1134 items were recorded (54 target utterances * 7 repetitions * 3 speakers). 252 tokens were included in the statistical analysis (see Table 1; 6 items with vocalic nucleus + 6 items with consonantal nucleus * 7 repetitions for each target word * 3 speakers).

	Vocalic Nucleus		Consonantal Nucleus	
C_C	fik (give yourself)	kif (same)	fnk (they gave you)	kIf (to appoint)
C.C_C	kfik (give yourself)	lkif (hashish)	kfnk (they gave you)	lkIf (skin patches)
CC.C_C	tkfik (she gave you)	flkif (for hashish)	tkfnk (she buried you)	flkIf (on skin patches)

Table 1. Target words containing either a vocalic or a consonantal nucleus, varying from one to three consonant(s) word initially.

2.2 Annotation & Measurements

The acoustic and articulatory data were hand-labelled in the EMU Speech Database System. In the acoustic domain the target word and its acoustically defined segments were identified. For analysing the gestural timing interval, we labeled onset, peak velocity and target for vocalic and consonantal movements.

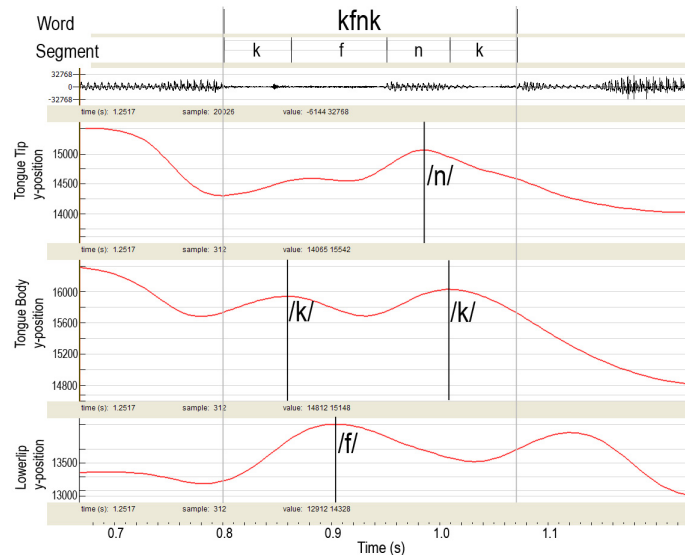


Figure 1. Example for labeling scheme in /kfnk/: waveform, and vertical position for tongue tip, tongue body and lower lip (top to bottom). Targets labeled for /n/ in nucleus position, /k/ and /f/ in word initial position as well as coda /k/.

Gestural onsets and targets were identified by zero-velocity crossings; peak velocity was identified by zero-acceleration crossings. A labeling scheme including waveform and vertical position of articulatory trajectories is provided in Figure 1.

For the Rightmost C to Anchor, the interval from the target of the rightmost C to the gestural target of the coda consonant was calculated (see Figs 1 and 2: temporal interval from rightmost C, i.e. target /f/ to coda target /k/). For the C-center to Anchor, we measured the interval from the mean of all consonantal targets in word initial position (i.e. C-center) relative to the anchor point (see Figs 1 and 2: temporal interval of mean of target /k/ and target /f/ in initial position relative to coda target /k/). Furthermore, we calculated the Stability Index (Relative Standard Deviation as percentage, see Shaw et al. 2009) for both measurements, where a *lower* index corresponds to a *better* stability. If consonant clusters in Tashlhiyt do not form a complex onset, they would not be expected to exhibit a C-center effect. Rather they should exhibit a pattern of stability between the rightmost C and a following anchor (see Figure 2).

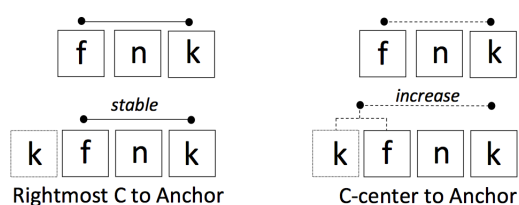


Figure 2. Predictions for right-edge stability in Tashlhiyt syllables.

3. Results on Gestural Timing Interval

In line with Goldstein et al. (2007), our results show that the latencies for the rightmost C measure do not decrease when a C is added, but remain stable. The results will be presented for two triads containing a vowel in nucleus position (triad 3a: /fik-k.fik-tk.fik/ and triad 4a: /kif-l.kif-fl.kif) and two triads containing a consonant (triad 3b: /fnk-k.fnk-tk.fnk/ and triad 4b: /klf-l.klf-fl.klf). Table 2 provides means and standard deviations for C-center to Anchor and Rightmost C to Anchor.

Figure 3a displays the gestural timing interval between the target of the rightmost C and the target of the coda C, compared to the latencies between the C-center to the same anchor point in items with a *vocalic* nucleus in /fik/, /k.fik/ and /tk.fik/. Where the rightmost C is stable in its timing relation (Relative Standard Deviation: S1=7%, S2=10%, S3=7%; right-edge stability), the C-center moves further away from the anchor as the number of word initial consonants is increased (RSD: S1=23%, S2=18%, S3=21%; no center stability). Figure 3b provides an illustration of the results for items with a *consonantal* nucleus /fnk/, /k.fnk/ and /tk.fnk/. Interestingly, we obtained the same pattern of temporal stability as for vocalic nuclei. The rightmost C is not shifted towards the consonantal nucleus; it remains stable across different cluster sizes (RSD: S1=4%, S2=7%, S3=14%; right-edge stability). The latencies for the C-center measure, on the other hand, constantly increase as consonants are added (RSD: S1=21%, S2=20%, S3=20%; no center stability).

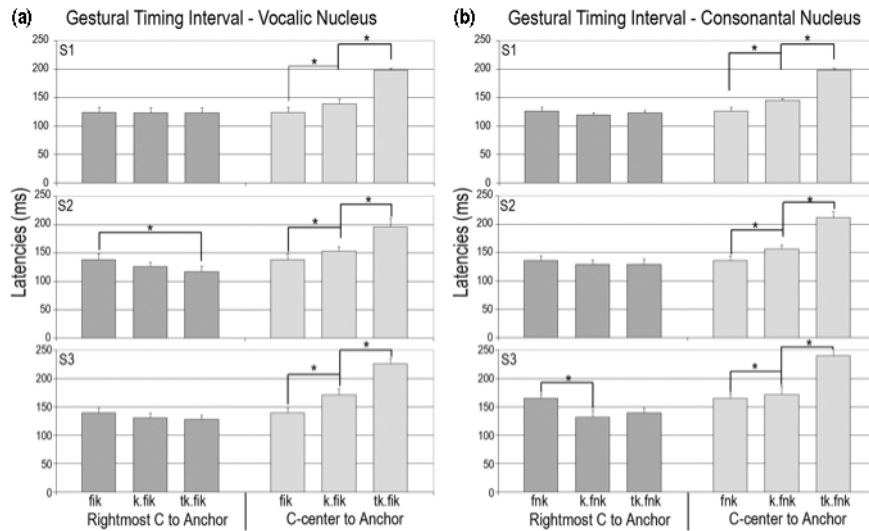


Figure 3. /fk-kf-tkf/: Gestural timing interval for Rightmost C to Anchor (dark grey) and C-center to Anchor (light grey) comparing (a) vocalic (fik-k.fik-tk.fik) and (b) consonantal nucleus (fnk-k.fnk-tk.fnk); each speaker separately.

In order to provide qualitative information we tested both measurements by a series of one-way ANOVAs with NUMBER OF INITIAL CONSONANTS (one/two/three) as independent variable for each speaker separately. A Bonferroni correction was made for multiple comparisons ($\alpha'=0.0043$). Results are presented for each triad separately.

In the first triad, for items containing a *vocalic* nucleus (see Fig. 3a: /fik – k.fik – tk.fik/), NUMBER OF INITIAL CONSONANTS had no effect on the Rightmost C to Anchor (S1: $F(2,21) = 0.040$, $p>0.0043$, n.s.; S3: $F(2,21) = 4.469$, $p>0.043$, n.s.). For speaker S2 we found a small effect on the Rightmost C to Anchor, due to a significant difference between one and three consonants initially, whereas there was no difference between one and two consonants or also between two and three consonants ($F(2,21) = 8.041$, $p=0.003$). Crucially, the NUMBER OF INITIAL CONSONANTS strongly affects the measured variable C-center to Anchor (S1: ($F(2,21) = 114.680$, $p<0.0043$; S2: $F(2,21) = 52.913$, $p<0.0043$; S3: $F(2,21) = 142.320$, $p<0.0043$): C-center to Anchor latencies increase as consonants are added.

In comparison, we tested items containing a *consonantal* nucleus (see Fig. 3b: /fnk – k.fnk – tk.fnk/). We found no effect of the NUMBER OF INITIAL CONSONANTS on the Rightmost C to Anchor (S1: $F(2,21) = 4.415$, $p>0.0043$, n.s.; S2: $F(2,21) = 1.644$, $p>0.0043$, n.s.). For speaker S3, there was a small effect on the Rightmost C to Anchor (S3: $F(2,21) = 9.527$, $p<0.043$). Testing the NUMBER OF INITIAL CONSONANTS on the C-center to Anchor, we found a strong effect (S1: $F(2,21) = 471.072$, $p<0.0043$; S2: $F(2,21) = 153.705$, $p<0.0043$; S3: $F(2,21) = 44.055$, $p<0.0043$).

Figure 4a displays the results for the second triad (/kif – l.kif – fl.kif/) containing a *vocalic* nucleus: Rightmost C to Anchor and C-center to Anchor. The rightmost C is stable in its timing relation (Relative Standard Deviation: S1=10%, S2=12%, S3=13%; right-edge stability), whereas the C-center moves further away from the anchor as the number of word initial consonants is increased (RSD: S1=20%, S2=18%, S3=23%; no center stability).

The same results were obtained for the triad with a *consonantal* nucleus (/klf - l.klf - fl.klf/, see Fig 4b). The rightmost C is not shifted towards the consonantal nucleus; it remains stable across different cluster sizes (RSD: S1=11%, S2=10%, S3=9%; right-edge stability). The latencies for the C-center measure, on the other hand, constantly increase as consonants are added (RSD: S1=21%, S2=16%, S3=18%; no center stability).

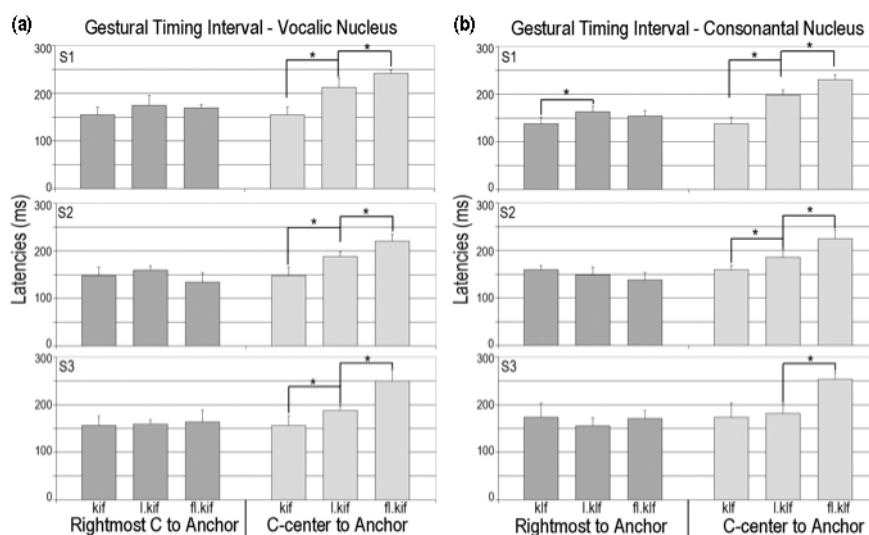


Figure 4. /k-lk-flk/: Gestural timing interval for Rightmost C to Anchor (dark grey) and C-center to Anchor (light grey) comparing (a) vocalic (kif-lkif-flkif) and (b) consonantal nucleus (klf-lklf-flklf); each speaker separately.

We test the Rightmost C to Anchor and the C-center to Anchor by one-way ANOVAs with NUMBER OF INITIAL CONSONANTS (one/two/three) as independent variable for each speaker separately. For items containing a *vocalic* nucleus (kif - lkif - flkif), the NUMBER OF INITIAL CONSONANTS had no effect on the Rightmost C to Anchor (S1: $F(2,21) = 3.223$, $p > 0.0043$, n.s.; S2: $F(2,21) = 2.080$, $p > 0.0043$, n.s.; S3: $F(2,21) = 0.338$, $p > 0.043$, n.s.). The C-center to Anchor was significantly affected by the NUMBER OF INITIAL CONSONANTS (S1: ($F(2,21) = 59.856$, $p < 0.0043$; S2: $F(2,21) = 41.040$, $p < 0.0043$; S3: $F(2,21) = 39.727$, $p < 0.0043$). In line with the results for /fik-kfik-tkfik/, the C-center to Anchor increases when a C is added to word initially in /kif-lkif-flkif/.

For the items containing a *consonantal* nucleus (/klf - l.klf - fl.klf/), we found no effect of the NUMBER OF INITIAL CONSONANTS on the Rightmost C to Anchor (S2: $F(2,21) = 4.140$, $p > 0.0043$, n.s. S3: $F(2,21) = 0.338$, $p > 0.043$, n.s.). For speaker S1 we found a small effect on the Rightmost C to Anchor - /klf/ vs /l.klf/- but in the wrong direction: Rightmost C to Anchor increases (S1: $F(2,21) = 7.853$, $p > 0.0043$). As predicted, NUMBER OF INITIAL CONSONANTS affected the C-center to Anchor significantly (S1: $F(2,21) = 110.615$, $p < 0.0043$; S2: $F(2,21) = 35.073$, $p < 0.0043$; S3: $F(2,21) = 37.878$, $p < 0.0043$).

For across-speaker comparison, an overall two-way ANOVA (3x2, repeated measure based on cell means, including the independent variables NUMBER OF INITIAL CONSONANTS and NUCLEUS TYPE) with a Tukey post-hoc test was conducted. This qualitative analysis reveals that the independent variable of the NUMBER OF INITIAL CONSONANTS word initially strongly affects the C-center to Anchor ($F(2,36)=42.398$,

$p < 0.001$, one < two < three, strong effect size of $d = 0.75$ for one < two and $d = 0.76$ for two < three), but did not affect the Rightmost C to Anchor ($F(2,36) = 0.153$, $p > 0.05$, n.s.). Thus, there was no effect of NUCLEUS TYPE, either being vocalic or consonantal.

		Rightmost C to Anchor			C-center to Anchor		
		S1	S2	S3	S1	S2	S3
Vocalic Nucleus	f _i k	124 (9)	138 (11)	140 (8)	124 (9)	138 (11)	140 (8)
	k.f _i k	123 (9)	126 (8)	131 (8)	139 (8)	153 (8)	171 (11)
	tk.f _i k	123 (9)	117 (10)	128 (7)	198 (3)	196 (15)	226 (9)
	k _i f	155 (16)	148 (18)	156 (20)	155 (16)	148 (18)	156 (20)
	l.k _i f	175 (20)	159 (9)	159 (9)	212 (20)	188 (10)	188 (10)
	fl.k _i f	169 (7)	134 (20)	164 (25)	242 (7)	220 (15)	250 (23)
Consonantal Nucleus	f _n k	126 (7)	136 (8)	164 (22)	126 (7)	136 (8)	162 (22)
	k.f _n k	119 (4)	129 (8)	132 (12)	145 (3)	156 (7)	172 (14)
	tk.f _n k	123 (4)	129 (9)	140 (8)	198 (3)	212 (10)	240 (13)
	k _l f	138 (13)	159 (9)	174 (29)	138 (13)	159 (9)	174 (29)
	l.k _l f	163 (12)	149 (16)	155 (18)	198 (11)	185 (17)	182 (19)
	fl.k _l f	154 (12)	138 (15)	171 (17)	230 (11)	225 (18)	253 (15)

Table 2. Mean values for gestural timing interval in ms (sd) for Rightmost C and C-center to Anchor, comparing vocalic and consonantal nuclei; each speaker separately.

In sum, the results for all triads, both with vocalic and consonantal nuclei, show a similar pattern: C-center to Anchor increases when a consonant is added to the beginning of the word, whereas the Rightmost C to Anchor remains stable. Word initial clusters in Tashlhiyt are timed differently from initial clusters that form a complex onset in other languages (e.g. American English, Georgian, Italian). The right-edge stability measure provides support for a phonological analysis in which Tashlhiyt only allows for simple onsets.

4. Conclusion

We have presented results on gestural coordination indicating how Tashlhiyt word initial clusters are timed relative to a fixed anchor point and how this temporal alignment is related to the syllabification proposed for these clusters. The results obtained are consistent with the evidence in other domains in favour of the simple onset analysis. This suggests that the organisation of word initial clusters into syllabic constituents is reflected in patterns of temporal stability of articulatory gestures, and is not just a purely abstract property of the phonological structure of the sequence. These timing patterns hold regardless of whether the syllable nucleus is vocalic or consonantal. This study lays the groundwork for future investigations into Tashlhiyt that will seek to determine how vowel-less syllables and their subconstituents are articulated.

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