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Structural effects on properties of consonantal gestures in Tashlhiyt

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Abstract

Tashlhiyt Berber is a language in which every consonant can take up the nucleus position in a syllable. The present study investigates how gestural properties are modified when the consonants occur in different syllable positions (onset, nucleus, coda). Furthermore, the effect of higher structural components such as morphology on the respective gestural organization patterns are examined.

Therefore, we collected articulographic data for different consonantal roots, such as /bdg/ and /gzm/ with varying affixes, entailing different syllabification patterns in Tashlhiyt. Consonantal properties in different syllable positions are investigated with respect to their intragestural properties and intergestural properties, i.e. bonding strength. Furthermore, gestural coherence with respect to prefixation were examined.

Results reveal that consonantal gestures were not modified on the intragestural level in terms of duration, velocity, stiffness or displacement, when the morphological structure was kept constant. However, on the intergestural level syllable relation was encoded, revealing a tighter bonding for onset-nucleus relations than for heterosyllabic sequences. Furthermore, when changing the morphological marker, modifications of intragestural parameters occur, inducing temporal changes of consonantal gestures. We conclude that higher structural components should be taken into account when investigating syllable internal timing patterns.

Index Terms: syllable structure, consonantal gestures, morphology, bonding, prosodic units, Tashlhiyt Berber

1. Introduction

The present paper investigates structural effects on gestural properties of consonantal gestures in Tashlhiyt. These gestures are tested with respect to different syllable positions (onset, nucleus, coda) and different morphological conditions. Electromagnetic articulography recordings are used to capture properties within and across consonantal gestures when they are produced with respect to different syllable domains and different morphological conditions.

Tashlhiyt, the language under investigation, allows long strings of consonants without vowels. It has been shown that these consonantal sequences are organized into syllables [1-4]. For example in a three-syllable item such as /tftktstt/ - [t**f**.t**k**.t**s**tt] ('you sprained it'), /f/, /k/, and /s/ take up the nucleus positions (Consonantal nuclei are bold, '.' mark syllable boundaries).

Within the framework of Articulatory Phonology [5], it has been shown that Tashlhiyt favors a simple onset analysis for consonant clusters in word initial sequences either containing a consonantal or a vocalic nucleus [6,7]. Thus, a form such as /gli/ ('guide') is syllabified as follows [**g**.li], although the sequence /gl/ compiles with the Sonority Sequencing Principle [8].

So far, studies investigating the gestural characteristics of consonants in nucleus position are relatively rare. When focusing on intragestural properties of consonantal nuclei in the same morphological conditions, it seems that a consonant remains a consonant whether being syllabic or not and thus does not become more vowel-like. However, when investigating the coordination between gestures in different syllable positions, timing differences can arise. [9] investigated consonantal timing in Tashlhiyt (for one speaker only) and report on tighter bonding for onset-nucleus relation than for sequences that span a syllable boundary. The bonding factor captures the tightness of coordination between gestures. It expresses the degree of temporal coherence between a pair of gestures. A tight organizational bonding between gestures means that a change in the internal dynamics of one gesture directly influences the internal dynamics of another gesture, in order to keep phase relation between the gestures constant. In onset-nucleus position, it is assumed that gestures exhibit a tighter bonding showing a low degree of phasing variability. Loose bonding, however, can be found in gestures that span a syllable boundary, allowing for a high degree of variability in phasing.

[10] did show for one speaker of Tashlhiyt that the consonant is not modified on the intragestural level when being in nucleus position (EPG data for obstruent /k/). In line with [9] they also showed that the onset-nucleus relation revealed a tighter coordination with adjacent consonants (measured as overlap between the consonants). Another study by [11] on Slovak (liquids only), also revealed no modification on the intragestural level, but containing a consonant in nucleus position did show a different timing patterns in terms of gestural overlap between the consonants. Thus, they concluded that consonantal nuclei are not marked by gestural modification, but rather by their gestural coordination with other consonants.

In what follows, we investigate consonantal properties in Tashlhiyt in different syllable positions with respect to their intragestural properties (step 1) as well as to their intergestural properties, i.e. bonding strength and gestural coherence (step 2). Furthermore, we will involve in the analysis higher structural components triggered by morphology (step 3) to emphasize the need for including complex interactions of structural, contextual and phonetic cues into the gestural and/or segmental analyses.

2. Method

2.1. Recordings

We recorded 3 native speakers of Tashlhiyt with a 2D Electromagnetic Articulograph (AG 100, Carstens

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Medizinelektronik). To track the movement of the articulators, we put sensors on the upper and lower lip, tongue tip, tongue blade and tongue body. Two additional sensors on the bridge of the nose and the upper gums served as references for dynamic head movement corrections. All kinematic data were recorded at 500Hz, downsampled to 200Hz and smoothed with a 40Hz low-pass filter.

We tested consonants differing in manner (fricative, stop, lateral) and place of articulation (labial, alveolar, velar). Target words were designed to elicit a distinct syllable status for each consonant under investigation, i.e. onset, nucleus and coda position. We used a set of three verbs of triconsonantal roots (see Table 1), /gzm/, /bdg/, /bks/, modified by means of four different affixes (either (a) suffix -as, (b) suffix -t, (c) prefix t- and suffix -as or (d) prefix t- and suffixe -t, entailing different syllabifications:

gzm-*as* (tear-*dat3s*) [g**z**.mas] *'tear for him'*

gzm-*t* (tear-*do3s*) [g.z**m**t] *'tear it'*

t-gzm-*as* (*3fs*-tear-*dat3s*) [t.g**z**.mas] *'she tore for him'*

t-gzm-*t* (*2s*-tear-*2s*) [**t**g.z**m**t] *'you tore'*

The target words, shown in Table 1, were embedded in a carrier sentence [inna _____ bahra] ('He said ___ a lot').

Table 1: *Speech material and syllabification of target words; consonantal nuclei marked in bold.*

Root	Suffix -as	Suffix -t	Prefix t-/ Suffix -as	Prefix t-/ Suffix -t
gzm	g**z**.mas 'tear for him'	g.z**m**t 'tear it'	t.g**z**.mas 'she tore for him'	**t**g.z**m**t 'you tore'
bdg	b**d**.gas 'be wet for him'	b.d**g**t 'make it wet'	t.b**d**.gas 'she was wet for him'	t**b**.d**g**t 'you were wet'
bks	b**k**.sas 'encircle for him'	b.k**s**t 'encircle him'	t.b**k**.sas 'she encircled for you him'	t**b**.k**s**t 'you encircled'

2.2. Annotation

Within the EMU speech database system, we labelled articulatory movements from the start of the consonantal gesture to the maximum target, e.g. onset, peak velocity and target of the respective consonants. The relative points of minimum and maximum constriction of the consonantal gestures were identified at zero-crossings in the respective velocity traces, the peak velocity at the zero-crossing in the respective acceleration trace. Figure 1 displays an example for the averaged trajectories (movement of the lower lip for /b/, tongue tip for /d/ and tongue body for /g/) for the root /bdg/ in [b**d**.gas] and [b.d**g**t].

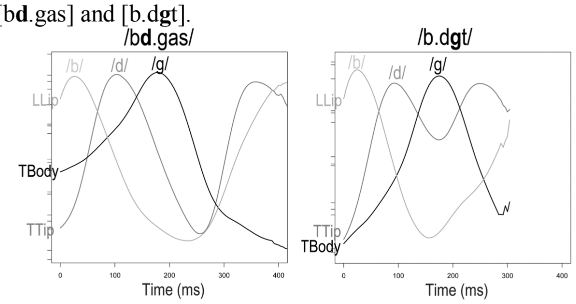

Figure 1: *Averaged trajectories for articulatory movement of lower lip (/b/), tongue tip (/d/) and tongue body (/g/) in triconsonantal root /bdg/ in [b**d**.gas] and [b.d**g**t].*

2.2.1. Measurements

We computed different variables for the intra- and intergestural analysis in the articulatory domain.

For the *intragestural* analyses, we calculated several articulatory parameters related to the mass-spring model (schematised in Figure 2):

- Gestural activation interval (GAI; in ms): The time the articulator travels from onset to target of the movement.
- Displacement (in cm): The way the articulator travels from onset to target of the movement.
- Peak velocity in (cm/ms): The maximum velocity during the articulator's movement.
- Stiffness: Stiffness is an abstract control parameter related to the relative speed of the articulator's movement in the physiological signal. According to [12], stiffness is calculated as the ratio of peak velocity to the displacement of the articulator's movement.

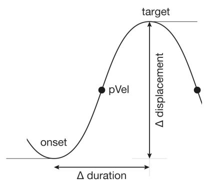

Figure 2: *Gestural annotation scheme to calculate mass-spring parameters.*

For the *intergestural* analysis, we calculated the bonding index proposed by [9]. To capture the stability of phase relations between a pair of gestures, we calculated the ratio of the gestural activation interval (GAI) of the C_{n-1} to the latencies of the onset C_{n-1} to the target achievement of the C_n. Note, that in our case we deal with n=2, i.e. $C_1 = C_{n-1}$ and $C_2 = C_n$, see Figure 3. In case of stronger bonding relations, the correlation is expected to be higher, i.e. the internal dynamics of C_1 directly influences C_2 to keep phasing relations constant. In case of loose bonding, the correlation is lower or even negative (inverse correlations).

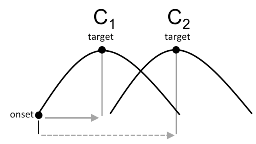

Figure 3: *Bonding index, ratio of GAI of* C1 *(grey solid line) to latencies of onset of* C_1 *to target of* C_2 *(grey dotted line).*

3. Results

3.1. Intragestural analysis (step 1)

In this section, we focus on whether the internal dynamics of consonantal gestures are modified depending on their syllabic status, i.e. whether occurring in onset, nucleus or coda position.

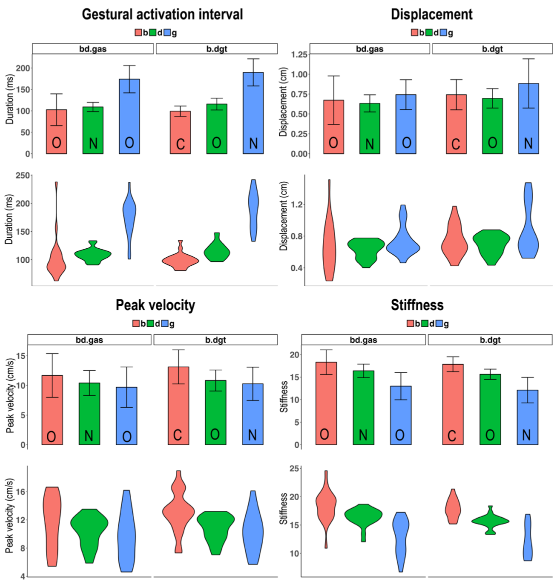

Figure 4: *Barplots and violin density plots for intragestural parameters in triconsonantal root /bdg/ in [**bd**.gas] vs [b.**dg**t]: gestural activation interval, displacement, peak velocity and stiffness.*

Figure 4 displays results for the following parameters: gestural activation interval, displacement, peak velocity and stiffness for the triconsonantal root /bdg/. Results are presented as barplots (top) and violin density plots (bottom). We compared target words with the suffix -as to suffix-t, changing the syllabic status of the consonants of interest: /b/ in [**bd**.gas] is an onset, whereas it is a coda of the preceding syllablle in [b.**dg**t]; /d/ in [b**d**.gas] is in nucleus position, whereas it is in onset position in [b.dgt]; /g/ in [bd.gas] is the onset, whereas it is a nucleus in [b.dgt]. The morphological structure is kept constant (i.e. both forms are suffixed).

Although the consonants change their syllabic status, the intragestural patterns are strikingly similar. We ran a mixed linear regression model with the critical predictor SUFFIX (-as vs -t) and CONSONANT. Random effects component included random intercepts for speakers. We corrected for multiple testing using the Dunn–Šidák correction, lowering the analysis wide alpha level to 0.0127. There was no main effect of suffix on the parameters GAI ($\chi2(1)$=13.693; p=0.05692), peak velocity ($\chi2(1)$=14.856; p=0.0379) and stiffness ($\chi2(1)$=9.0006; p=0.2526). However, we find an effect of suffix on the displacement (displacement: ($\chi2(1)$=18.97; p=0.008). We did not find any interaction for the suffix and consonant. These findings thus suggest that syllable status, i.e. taking up the nucleus, onset or coda position (by changing the suffix) has no effect on the internal dynamics of consonantal gestures.

3.2. Intergestural analysis (step 2)

In this section we investigate the stability of phasing relations (bonding index, [9]) between a pair of gestures with respect to different syllable affiliations, e.g. onset-nucleus relations (within the syllable) vs. coda-onset/nucleus-onset relation (with a syllable boundary in between). The morphological structure is kept constant. Note, that we expect a tighter organizational bonding in terms of higher correlation values for onset-nucleus relations, while the heterosyllabic coda-onset/nucleus-onset relation should reveal lower correlation and thus less tight bonding.

Figure 5 displays the bonding index for the root /bdg/ in tautosyllabic onset-nucleus relation compared to heterosyllabic coda-onset and nucleus-onset relation (spanning a syllable boundary). Figure 5 (top) compares onset-nucleus relation for /bd/ in [**bd**.gas] with coda-onset relation [b.**dg**t]; Figure 5 (bottom) compares onset-nucleus relation /dg/ in [b.**dg**t] with nucleus-onset relation in [b**d.g**as]. Table 2 shows the bonding indices for all roots.

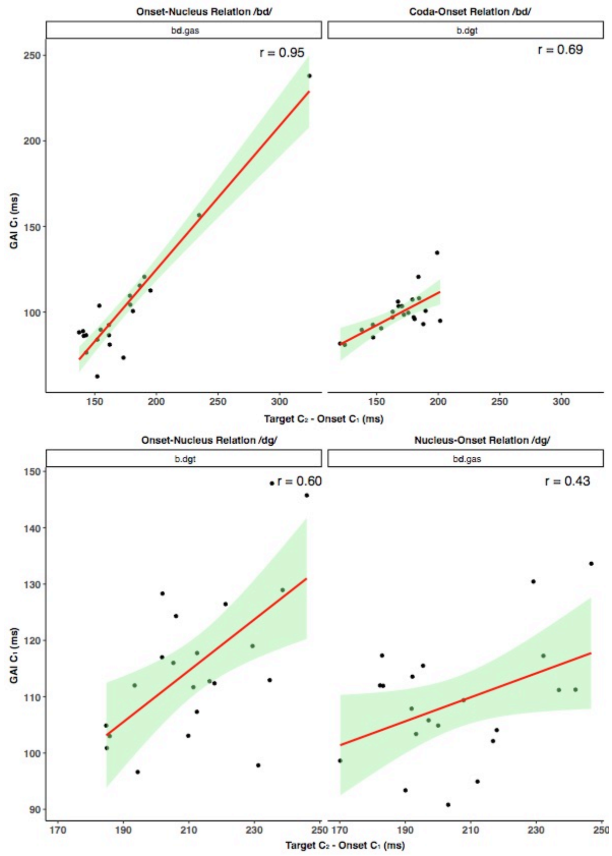

Figure 5: *Bonding index for onset-nucleus vs heterosyllabic coda-onset and nucleus-onset relations for root /bdg/. Higher positive correlation reveals a tighter bonding.*

Consonantal gestures in a tautosyllabic onset-nucleus relation show a higher correlation than in a heterosyllabic relation (O-N: /bd/ = 0.89, /bk/ = 0.65 vs N-O: /bd/ = 0.69 and /bk/ = 0.03, see Table 2). The organizational bonding between the same pairs of gestures to preserve temporal coherence is stronger for onset-nucleus relation than for heterosyllabic sequences (N-O and C-O). The results reveal that the syllable as a timing unit plays an important role in terms of bonding relations.

Table 2: *Bonding index (Pearson correlation coefficient) for onset-nucleus relation vs. to coda-onset and nucleus-onset relation (higher coefficient marked in italics).*

(a) Root	Onset-Nucleus		Coda-Onset	
bdg	**bd**.gas	*0.95*	b.**dg**t	0.69
gzm	**gz**.mas	0.75	g.**zm**t	*0.82*
bks	**bk**.sas	*0.65*	b.**ks**t	0.03

(b) Root	Onset-Nucleus		Nucleus-Onset	
bdg	b.dgt	*0.60*	bd.gas	0.43
gzm	g.zmt	*0.29*	gz.mas	-0.33
bks	b.kst	*0.31*	bk.sas	-0.49

3.3. Modifications triggered by morphology (step 3)

In a final step, we investigate possible modifications on the intragestural level triggered by adding the most common prefix /t-/ to the verbal root. Adding this prefix has the effect of changing both the morphological structure of the verb and the syllable status of the root initial consonant. Figure 6 displays barplots and corresponding violin density plots for gestural activation interval and peak velocity for triconsonantal roots /bdg/ (Figure 6, top) and /gzm/ (Figure 6, bottom), with and without prefix t- (e.g. [b.**dgt**] vs. [t**b**.**dgt**]).

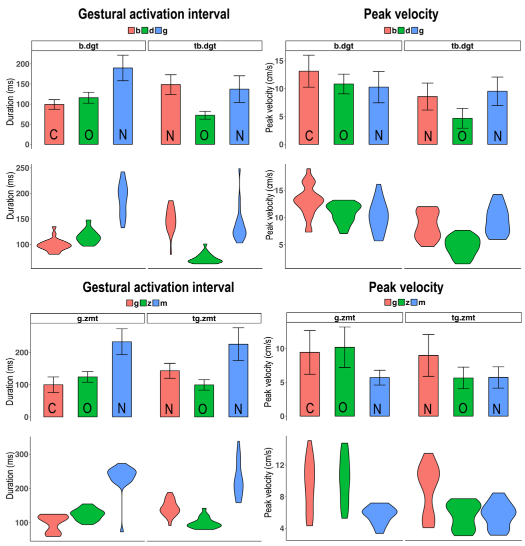

Figure 6: *Barplots and violin density plots for parameters GAI and peak velocity in triconsonantal root /bdg/and /gzm/ in without and with prefix t-.*

Again, we ran a mixed linear regression model with the critical predictor PREFIX (no prefix vs t-). Random effects component included random intercepts for speakers. We corrected for multiple testing using the Dunn–Šidák correction, lowering the analysis wide alpha level to 0.0127. There was a main effect of prefix on all parameters GAI ($\chi2(1)$=138.31; p< 2.2e-16), peak velocity, displacement ($\chi2(1)$=203.54; p< 2.2e-16) ($\chi2(1)$=127; p< 2.2e-16) and stiffness ($\chi2(1)$=286.56; p p< 2.2e-16). Further there was an interaction of prefix and consonant for all parameters.

The results reveal that adding prefix t- entails modifications of the intragestural properties of the consonantal gestures. For example, the consonant /d/, which takes up the onset position in [b.**dg**t] as well as in [t**b**.**dg**t], is shorter (longer GAI) and slower (lower peak velocity) when prefix t- is added. Furthermore, we also find modifications of consonantal gestures with different syllabic status. When comparing /b/ as coda in [b.**dg**t] to /b/ as a nucleus in [t**b**.**dg**t], the consonantal gesture is longer and slower in coda. Note that when we tested the intragestural parameters without a prefix (3.1.), there were no modifications due to a change in syllabic status.

4. Discussion and conclusion

When the morphological structure was kept constant, we found no modifications of consonants on the *intragestural level* (step 1). The internal dynamics of consonantal gestures such as the duration of gestural activation interval, peak velocity, displacement and stiffness remained the same, although the consonants changed their syllable status (onset, nucleus or coda position).

However, syllable status was encoded in syllable internal coordination patterns on the *intergestural level* (step 2). There were differences in the stability of phasing relations between a pair of gestures. Onset-nucleus relations revealed a tighter organizational bonding than sequences spanning a syllable boundary [9]. The same pairs of consonantal gestures in onset-nucleus relation showed stronger interdependencies and therefore allowed for less variability in phasing than those in heterosyllabic sequences. The results of the intragestural and intergestural analysis of consonantal nuclei are in line with what was stated by [10] for Tashlhiyt and [11] for Slovak.

However, a different picture arose when investigating the effect of morphological prefix t- on the internal dynamic of consonantal gestures in different syllable positions (step 3). When changing the morphological marker (adding prefix t- to the target word), we found variation in the duration of the gestural activation interval and the peak velocity due to different syllable positions, reflecting the influence of the linguistic structure. It is unlikely that the modifications are simple driven by the segmental make-up but we cannot exclude this option. We assume, that the presence of the wordinitial t- in [tb.dgt] versus [b.dgt] in the target sentence [inna (t)b.dgt bahra] should not induce the observed strong temporal parameter modifications on the onset consonant of the second syllable, [d]. Furthermore, the duration of the lip closure during [b] should be shorter after the stop consonant [t] than after the open vowel [a], but the opposite was found in our data.

We conclude that there is a need to incorporate higher structural components into the analysis of gestural internal parameters to capture the complex interaction between structural, contextual and phonetic cues [7, 13-15]. Gestural coherence patterns are reflected in the syllable-internal organization of gestures with tightest stability for onset-nucleus relation [9], but they are modified by higher units such as morphological triggers.

5. References

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