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Pharyngealization in Amazigh: Acoustic and articulatory marking over time

Philipp Buech¹, Rachid Ridouane¹, Anne Hermes¹

¹Laboratoire de Phonétique et Phonologie, UMR 7018, CNRS/Sorbonne Nouvelle, France

philipp.buech@sorbonne-nouvelle.fr, rachid.ridouane@sorbonne-nouvelle.fr,
anne.hermes@sorbonne-nouvelle.fr

Abstract

Pharyngealization refers to a secondary articulation whereby a set of consonants is produced with the backing of the tongue towards the pharyngeal wall. This typologically rare phenomenon appears in some Afroasiatic languages, including Arabic and Amazigh. While the phonetic characteristics of pharyngealization in Arabic have been investigated in-depth, the comparative data currently available on Amazigh is particularly scant.

The present study aims to fill this gap and provides a comprehensive study on the phonetic characteristics of pharyngealization in an Amazigh language. The empirical data comes from acoustic and articulatory recordings of six Tashlhiyt speakers producing a set of singleton and geminate plain coronals and their pharyngealized counterparts in intervocalic position. We analyze formant trajectories of the vowels surrounding plain and pharyngealized consonants and articulatory trajectories during the consonantal movements and examine how the manner of articulation, voicing, and length shape variability in the way the contrast is implemented.

Results show that pharyngealization is principally characterized by a large drop of F2 of adjacent vowels at the acoustic level and an extensive lowering of the tongue body at the articulatory level. These attributes are consistent across voicing, length and manner of articulation.

Index Terms: pharyngealization, acoustics, articulation, formant trajectories, articulatory trajectories, Amazigh

1. Introduction

Pharyngealization is a secondary articulation by which a specific set of consonants, often dentals and alveolars, is produced with a backward movement of the tongue towards the pharyngeal wall [1]. This is a prominent feature in Arabic, where it received considerable research attention. In this study, we examine pharyngealization in Amazigh, one of the rare languages outside of the Semitic family where this secondary articulation is particularly productive. In this language the seven consonants /t, d, s, z, ʃ, r, l/ and their geminate counterparts /tˤ, dˤ, sˤ, zˤ, ʃˤ, rˤ, lˤ/ have the corresponding pharyngealized cognates /tˤ, tˤˤ, dˤ, dˤˤ, sˤ, sˤˤ, zˤ, zˤˤ, ʃˤ, ʃˤˤ, rˤ, rˤˤ, lˤ, lˤˤ/. This study provides acoustic and articulatory data to explore how pharyngealization is marked in these consonants and the adjacent vowels.

1.1. Tashlhiyt Amazigh

Amazigh is an Afro-Asiatic language spoken in North Africa. Tashlhiyt is one of the three varieties of Moroccan Amazigh, and the largest by its number of speakers, estimated between 6 and 8 million [2, 3, 4, 5]. It is spoken over a continuous area including the Anti-Atlas and High-Atlas, and the southern plains, but large numbers of speakers live outside of Morocco, mainly in European capitals such as Paris and Brussels. The language is well documented in terms of its grammar, and much work

has been done on its linguistic system. The phonology of the language is also well studied and documented (see [6] for a review).

At the lexical level, pharyngealization in Tashlhiyt is a property of coronal consonants [7, 8, 9, 10]. Various minimal pairs attest to the lexical function of pharyngealized consonants in distinguishing words (e.g., /izi/ ‘fly’ vs /izˤi/ ‘gallbladder’, /bdu/ ‘start’ and /bdˤu/ ‘share’). At the surface level, pharyngealization is a property that can be displayed by any segment; an instance of emphasis spread by which underlying pharyngealized coronals spread their secondary articulation on neighboring sounds, including vowels. Although there are clear auditory differences between items containing pharyngealized consonants and items containing plain ones, experimental data on the articulation and acoustics of these segments are still missing (see [11] for some preliminary observations). The first objective of this study is therefore to fill this gap, by providing the first comprehensive description of pharyngealization in Tashlhiyt based on acoustic and articulatory data. The second objective is to show whether pharyngealized consonants in Tashlhiyt share the same acoustic and articulatory characteristics observed in other languages, mainly in Arabic.

1.2. Acoustic and articulatory correlates for pharyngealization

Acoustic characteristics of pharyngealization are described mostly on data from Arabic varieties (see among others, e.g., [12] for Moroccan and Jordanian Arabic, [13] for Qatari Arabic, [14] for Assiri Arabic). The main differences between plain and pharyngealized consonants are found in the surrounding vowels rather than in the consonants themselves, as observed for secondary articulations in general [1]. In the context of pharyngealized consonants, surrounding vowels were described as having higher F1 and F3 and a lowered F2 [15]. F2 lowering in particular appears to be a stable acoustic parameter across languages, while variations in F1 and F3 appear to be language-dependent (at least for vowels [16]).

Articulatory studies of pharyngealization on the other hand involve a variety of methods, including X-ray measurements [17, 18], ultrasound [19], rtMRI [20], fiberoptic [21], and electromagnetic articulography (EMA) [22, 23]. Pharyngealization is generally described as being manifested by a retraction of the tongue root, which is supported by [18, 20, 19], as well as a narrowing of the pharyngeal cavity, and a slight lip protrusion [17]. However, the role of the tongue dorsum is a matter of debate and described as being raised, lowered, or retracted [19].

In this study, we focus on formant trajectories obtained using acoustic data and on the underlying articulatory trajectories over the time-course of Tashlhiyt plain and pharyngealized consonants and the surrounding vowels. The aim is to identify how these consonants are manifested, how they affect adjacent vowels, and whether the manner of articulation, voicing, and length

affect the way the contrast is implemented.

2. Methods

2.1. Recordings and speech material

Articulatory and acoustic data from six native male speakers of Tashlhiyt (32-50 years, mean=44(7); one is a co-author) were collected simultaneously using the Electromagnetic Articulograph AG 501 (Carstens Medizintechnik GmbH). Sensors were placed on upper and lower lips (ULIP, LLIP), tongue tip (TTIP), tongue mid (TMID), and tongue body (TBO), with additional reference sensors behind the left and right ear. The articulatory signal was recorded with a sample rate of 1250 Hz. The EMA data were filtered with a Butterworth lowpass filter with a cut-off frequency of 25 Hz and order 5. The acoustic data were recorded at a sample rate of 44.1 kHz and 16-bit resolution.

The speech material presented here is part of a larger corpus. In this study, we report the analysis of VCV sequences with plain and pharyngealized consonants with surrounding vowels [a], differing in manner, voicing, and length (cf. Table 1 overview of target consonants). These [aCa] sequences correspond to the way Amazigh alphabetic consonants are pronounced. In total, 288 tokens went into the analysis (2 types * 6 (4 manners + 2 voicing) * 2 lengths * 2 repetitions * 6 speakers).

Table 1: Plain and pharyngealized target consonants by manner and length.

manner	length	
	singleton	geminate
stop	d, t, d ^ɣ , t ^ɣ	d:, t:, d ^ɣ :, t ^ɣ :
fricative	z, s, z ^ɣ , s ^ɣ	z:, s:, z ^ɣ :, s ^ɣ :
lateral	l, l ^ɣ	l:, l ^ɣ :
tap	r, r ^ɣ	r:, r ^ɣ :

2.2. Annotations and measurements

First, manual segmentation of the acoustic vocalic and consonantal segments was done by using Praat [24]. The start/end of the VCV sequence was defined via the start/end vocal fold vibration in the oscillograms. The acoustic onset for plosive was marked by abrupt damping of the vocal fold vibration and their acoustic offsets by the abrupt beginning of vocal fold vibration. Fricative boundaries were set at the beginning and the end of high-frequency noise, and boundaries for laterals and taps were set at the end and the start of a stable formant structure in the spectrogram. Regarding the kinematic data, the onset and the offset of the consonantal movement for the TTIP in the low-high dimension were identified automatically as the two minima within the acoustic VCV sequence. The alignments were corrected manually. An example of the annotation of the data is provided in Figure 1, with a waveform and its boundaries for the acoustic segments (VCV) and the vertical movement (y-dimension) of the tongue tip (TTIPy) with the onset and offset of that movement.

The measurements were done in Parselmouth v.0.4.0 [25] which includes a Praat [24] distribution in version 6.1.38. The formants F1, F2 and F3 were measured in 10 steps for the preceding and the following vowel. Since all speakers are male the

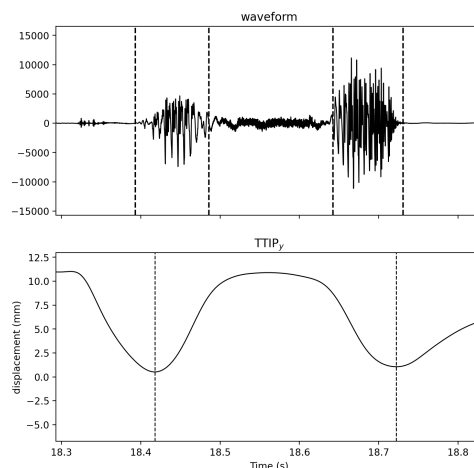


Figure 1: Example of an [as^ɣ:a] sequence with waveform (top) and TTIPy trajectory (bottom). Dashed lines in the waveform mark the acoustic boundaries, dashed lines in the TTIPy trajectory mark the onset (left) and the offset (right) of the consonantal movement.

maximum formant frequency was set to 5000 Hz. Regarding articulatory data, the position of the sensors LLIP, TTIP, TMID and TBO were measured in 30 steps for both, the horizontal (front-back, x) and the vertical (high-low, y) dimension over the time-course of the articulatory movement for the coronal consonants (from onset to offset of the TTIPy movement). The EMA data was normalized for each speaker: The x-dimension was normalized using the mid of the left ear and the right ear sensors as point of reference. The y-dimension was normalized according to the lowest y-position measured.

2.3. Statistical analyses

We applied generalized additive mixed models (GAMM) to analyze the formant and kinematic trajectories. The collected data was analyzed with R version 4.1.3 [26]. The packages *mgcv* [27] and *itsadug* [28] were used for the analysis of formants and kinematic tracks with GAMMs. The formant tracks of F1, F2 and F3 were analyzed separately over the time-course for the preceding and the following vowel. The kinematic tracks for the LLIP, TTIP, TMID and TBO sensors in the front-back (x) and high-low (y) dimensions were analyzed separately. GAMMs were performed for each variable with TYPE (plain, pharyngealized) as fixed effect and smoothing parameters and the interaction of TYPE with MANNER (plosive, fricative, lateral, tap), VOICING (voiced, voiceless) and LENGTH (singleton, geminate) to see whether the trajectories differ in TYPE. Further, random slopes and intercepts for speakers were added. Significance levels were set at 0.05, 0.01 and 0.001. In this paper, we only report the fixed effect in the text and the differences of the smooth terms for TYPE in figures 3 and 5.

3. Results

3.1. Formant trajectories

The results for acoustic analyses are presented first. Figure 2 shows the mean formant trajectories of F1 (blue), F2 (red) and F3 (yellow) in the surrounding vowels for plain (solid lines) and pharyngealized consonants (dashed lines). The clearest differ-

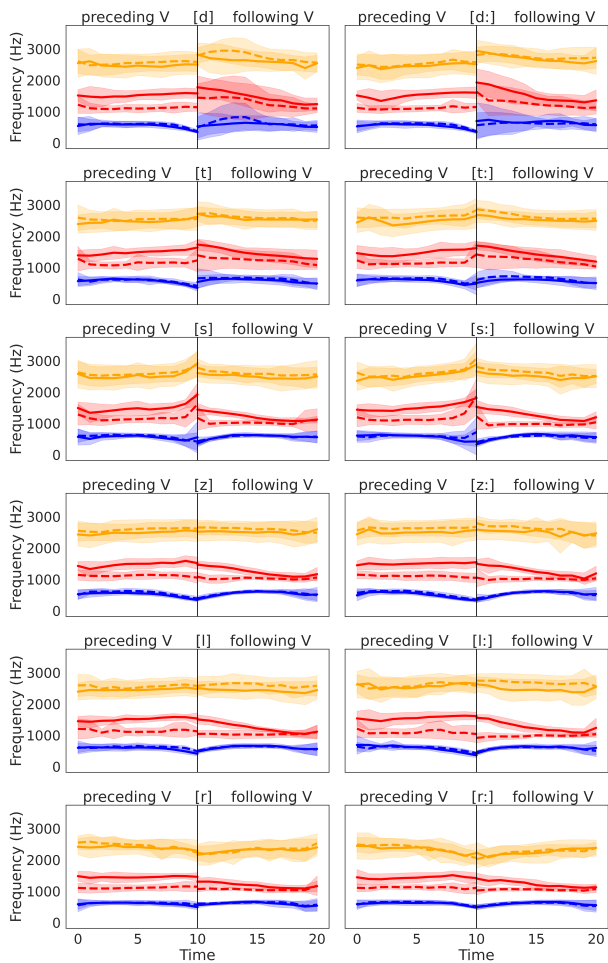


Figure 2: Formant trajectories (F1=blue, F2=red, F3=yellow) of the surrounding vowels for singletons (left column) and geminates (right column) in plain (solid lines) vs. pharyngealized (dashed lines) consonants, averaged across speakers.

ence appears in F2 trajectories. In the context of pharyngealized consonants, one can observe a lowering of F2 over the entire time-course of the surrounding vowels. This difference is even more evident in the preceding vowel. Importantly, F2 lowering is consistent for all pharyngealized consonants, regardless of their manner of articulation, voicing, or length. Differences in F3 trajectories are also visible in Figure 2, with vowels having a raised F3 in the context of pharyngealized consonants. This effect, however, is not consistent, and seems to vary depending on manner, voicing, and length (and also speakers not reported here). The trajectories of F1 are even less affected by the presence or absence of pharyngealization, although in some cases a raising can be observed (e.g., for the following vowel in [d], or the following vowel in [t]).

The statistical analyses confirm and expand upon the effect of pharyngealization on the formant trajectories. We found a strong effect of TYPE (plain vs. pharyngealized) on the F2 trajectories for both preceding ($p < .001$) and following ($p < .001$) vowels, as well as an effect on F3 trajectories for preceding ($p < .01$) and following ($p < .01$) vowels. No significant effect of TYPE was found on the F1 trajectories. These differences in plain vs. pharyngealized (using GAMMs) are visually pre-

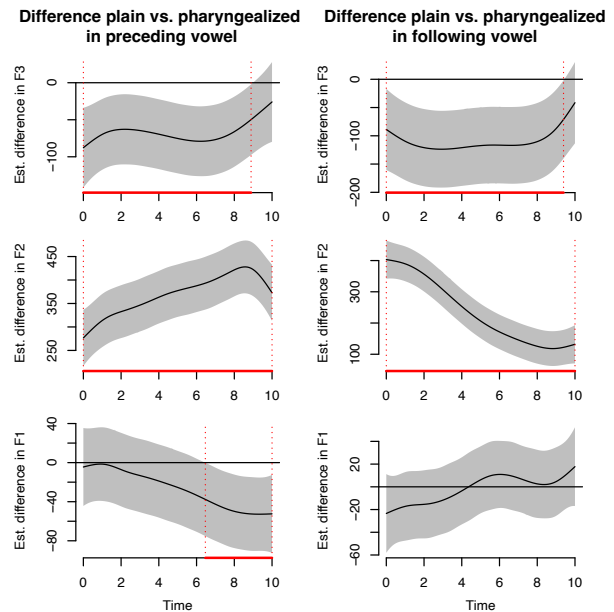


Figure 3: Estimated differences in plain-pharyngealized consonants for F1 (bottom), F2 (mid) and F3 (top) in (a) preceding vowel and (b) following vowel with 95% confidence interval by time (normalized). The red area represents the significant difference in plain vs. pharyngealized consonants.

sented in Figure 3. For F2 trajectories (Figure 3, mid), a sharp drop in F2 is observed from the onset to the offset of the preceding and the following vowel. For F3 trajectories, a slight but significant raising can be seen throughout the vowel with the exception of the offset portions. For F1, the only difference observed is limited to the last part of the preceding vowel. This difference, however, is small and does not reach statistical significance.

3.2. Articulatory trajectories

The articulatory trajectories for the consonantal movement for LLIP (green), TTIP (yellow), TMID (red), and TBO (blue) are presented in Figure 4. Looking at the x-dimension (front-back, Figure 4; first and third columns), minimal differences can be seen between plain and pharyngealized consonants for TTIPx, TMIDx and TBOx, but none for LLIPx. In the y-dimension (low-high), however, clear differences are visible for TMIDy and TBOy which are extensively lowered during pharyngealized consonants (Figure 4; second and fourth column). This lowering of the tongue mid and the tongue body is consistent across manner of articulation, voicing, and length. No difference is observed for TTIPy, while the differences for LLIPy are small and inconsistent (compare the different patterns for [t:] and [s:]).

The statistical analyses confirm the absence of any significant effect of TYPE on LLIPx, TTIPx, TMIDx, TBOx, and TTIPy. In line with what we observed in Figure 4, there is a significant effect of TYPE on TMIDy ($p < .001$) and TBOy ($p < .001$). A significant effect of TYPE is also reported for LLIPy, although it appears small and close to the significance boundary ($p = 0.0448$). As for the formant trajectories, we visually present the articulatory differences for the front-back and low-high dimensions over the time course using GAMMs (see

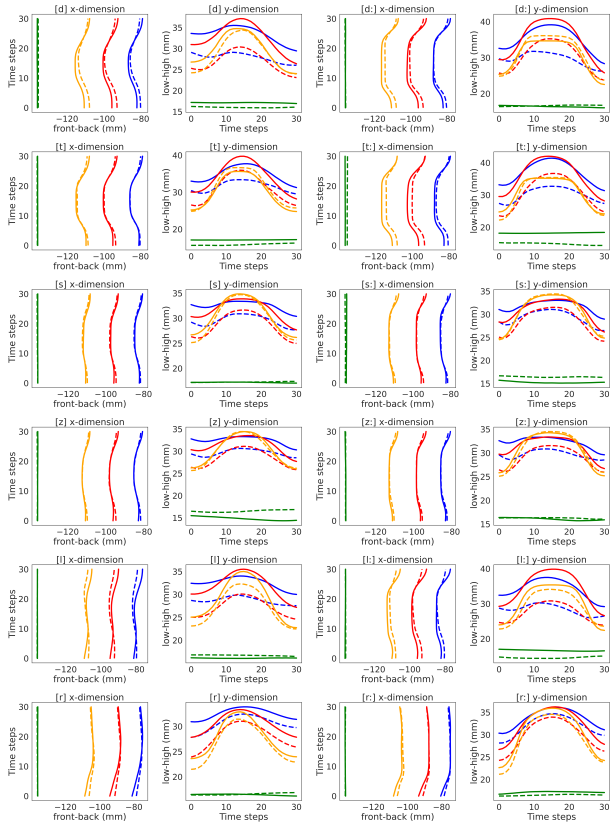


Figure 4: Articular trajectories for LLIP (green), TTIP (yellow), TMID (red), TBO (blue) in plain (solid lines) vs. pharyngealized (dashed lines) consonants in x-dimension (left) and y-dimension (right), for singletons (first and second columns) and geminates (third and fourth columns), averaged across speakers.

Figure 5). Concerning the front-back dimension (Figure 5, left column), the movement trajectories for LLIP_x, TMID_x, and TBO_x remain unchanged in the context of plain and pharyngealized consonants (although a slight difference is observed at the offset of the TTIP_x movement). Furthermore, no effect of pharyngealization can be seen in the low-high dimension for TTIP_y. The important effect of pharyngealization on TMID_y and TBO_y is clearly visible, with these two sensors displaying a sharp lowering throughout the time-course of the pharyngealized consonants (Figure 5, right lower-mid). For the LLIP_y movement, a significant difference is observed in the first half of the consonantal trajectory, but this is rather small with approx. 1 mm on average (see Figure 5, top row, right).

4. Discussion and conclusion

In this study, we investigated the acoustic and articulatory markings that distinguish plain coronals from their pharyngealized counterparts in Tashlhiyt VCV sequences. In particular, we looked at how pharyngealization affects the formant trajectories of surrounding vowels and the kinematic trajectories during consonantal movements.

Results reveal that the main acoustic parameter that distinguishes plain and pharyngealized consonants is the large drop of F2 over the time-course of both preceding and following vow-

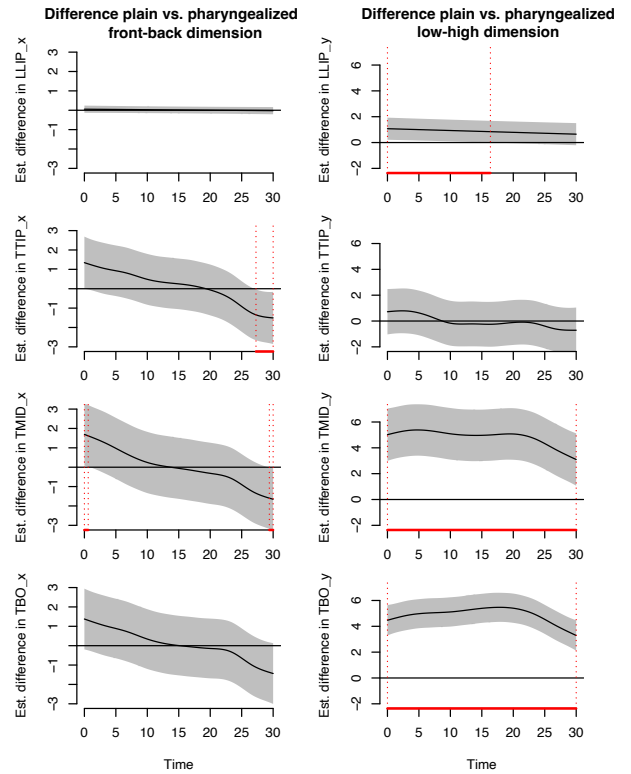


Figure 5: Estimated differences in plain -pharyngealized consonants for the (a) front-back (left) and (b) high-low dimension of LLIP (top), TTIP (upper-mid), TMID (lower-mid) and TBO (bottom) with 95% confidence interval by time (normalized).

els. This result is in accordance with what has been reported for different Arabic varieties and confirms that F2 lowering is the tell-tale parameter of pharyngealization. This lowering of F2 is present in all types of consonants, regardless of their manner, voicing, or length. The effect of pharyngealization on the other formants is either negligible (e.g., for F1) or varied depending on the nature of the consonants (e.g., for F3).

The main articulatory parameter that distinguishes plain and pharyngealized is a lowering of the tongue (i.e., tongue mid and tongue body) in pharyngealized context. However, the exact articulatory mechanism responsible for the found acoustic effect on F2 is not clear and seems to be more complex than a simple one-to-one mapping [29]. The lowered F2 can be attributed to a pharyngeal constriction, but it can also be the consequence of a simultaneous lowering of the tongue [30]. This lowering is most probably accompanied by a backward movement of the pharyngeal portion of the tongue dorsum (which cannot be captured with EMA). Since the data from this study is part of a larger corpus, in the following step, we will expand the analyses on pharyngealization in different word positions and with different surrounding segments, including consonants and vowels other than [a].

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