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Phonetic Correlates of Pharyngeal and Pharyngealized Consonants in Saudi, Lebanese, and Jordanian Arabic: an rt-MRI Study

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Abstract

The phonemic inventory of Arabic includes sounds that involve a pharyngeal constriction. Sounds referred to as 'pharyngeal' (/ʕ/ and /ħ/) are reported to have a primary constriction in the pharynx, while sounds referred to as 'pharyngealized' (/sˤ/, /tˤ/, /dˤ/, and /ðˤ/ or /zˤ/) are reported to have a secondary constriction in the pharynx. Some studies propose grouping both types of sounds together, citing phonetic and phonological evidence. Phonetically, pharyngeal consonants are argued to have a primary constriction below the pharynx, and are thus posited to be pharyngealized laryngeals. Under this view, the pharyngeal constriction is secondary, not primary. Phonologically, it has been established that pharyngealized sounds trigger pharyngealization spread, and proposals for grouping pharyngeal and pharyngealized consonants together cite similar, but not identical, spread patterns triggered by pharyngeals. In this study, Real-time Magnetic Resonance Imaging is employed to investigate the phonetic correlates of the pharyngeal constriction in both pharyngeal and pharyngealized sounds in Saudi, Lebanese, and Jordanian Arabic as exemplified by one speaker from each dialect. Our findings demonstrate a difference in the location of constriction among both types of sounds. These distinctions in place possibly account for the differences in the spread patterns triggered by each type of sound.

Index Terms: Pharyngealized consonants, Pharyngeal, consonants, Emphatics, Post-velar harmony, Pharyngealization spread, Magnetic Resonance Imaging

1. Pharyngeal and Pharyngealized Consonants in Arabic

The phonemic inventory of Arabic includes speech sounds manifesting a constriction in the pharynx. Within this group, most studies distinguish two types of sounds: those in which the pharyngeal constriction is primary, and those in which it is secondary. The latter includes the pharyngealized coronals /sˤ/, /tˤ/, /dˤ/, and /ðˤ/ (or /zˤ/ depending on the dialect), and the former includes the pharyngeal /ʕ/ and /ħ/. Pharyngealized consonants are distinguished from their plain phonemic counterparts /s/, /t/, /d/, and /ð/ or /z/ respectively, in which the secondary posterior constriction is not posited. However, some scholars suggest grouping pharyngeals together with pharyngealized consonants, claiming that pharyngeal /ʕ/ and /ħ/ are really the pharyngealized counterparts of laryngeal /ʔ/ and /h/ respectively [1], [2], and [3]. Under such analyses, the pharyngeal constriction in both /ʕ/ and /ħ/ is a secondary, not a primary articulation. Heselwood & Al-Tamimi [1] maintain that: "the pharyngeal gesture in /ʕ/ and /ħ/ as a primary articulation can be empirically challenged" (p. 124). In the case of /ʕ/, Heselwood & Al-Tamimi [1] suggest that larynx elevation and simultaneous gestures below the pharynx involving the aryepiglottic folds, ventricular bands and the arytenoid cartilage [4, p. 8 and 5, pp. 141-142] may constitute the primary articulation. In the case of /ħ/, they suggest the place of articulation to be "the narrow space between the arytenoids and the base of the retracted epiglottis, and between the aryepiglottic folds and the upper part of the epiglottis at the laryngeal aditus [6, pp. 75-76, 353]" [1, pp. 124]. They also cite an observation by Henry Sweet that the Arabic pharyngeal fricative /ħ/ is "simply a bronchial hiss" [8, pp. 37]. Jakobson [3, p. 112] also adopted a similar viewpoint and cited Gairdner's advice to students learning to pronounce /ħ/, viz., that they should pronounce the familiar glottal /h/ "and try to tighten the pharynx during its production" [9, p. 27]. For Jakobson, the pharyngeal fricative /ħ/ is "essentially a pharyngealized laryngeal". He also refers to Meinhof's "ingenious [phonetic] transcription" of pharyngeal /ʕ/ as /ˀ̣/, glottal /ʔ/ as /ˀ/, and pharyngeal /ħ/ as /ḥ/. This suggests that the relationship between /h/ and /ḥ/ and between /ˀ/ and /ˀ̣/ is analogous: thus, /ḥ/ is a pharyngealized /h/, and /ˀ̣/ is a pharyngealized /ˀ/ [10, p.113].

Proposals for grouping pharyngeals and pharyngealized consonants cite both phonetic and phonological arguments. Phonetically, it is argued that both sets of sounds involve a posterior pharyngeal constriction, and that in some dialects this constriction occurs in the same place [11]. Furthermore, it is argued that both sets of sounds trigger the same or similar formant modifications in surrounding vowels resulting in similar auditory modifications. Vowels surrounding pharyngealized speech sounds are impressionistically described as "dark, fat, thick, corpulent, heavy" [3], "dull" [12], and "intense" [2]. Phonologically, it has been suggested that both sets trigger similar pharyngealization spread patterns. Watson [2], however, argues that the pharyngealization triggered by pharyngealized consonants spreads over longer distances than the same process triggered by pharyngeal consonants. She further argues that the former affects both vowels and consonants, whereas the latter is restricted to adjacent vowels. McCarthy [13] and Herzallah [14] also refer to another phonological phenomenon in which both pharyngeals and pharyngealized consonants pattern similarly: the blocking of *imāla* in a following feminine suffix (in Standard Arabic /a/). *imāla* is defined as the fronting and/or raising of a vowel. In Levantine Arabic, the underlying representation of the feminine suffix is the non-low /e/ or /i/ [13, p. 219]. The fronting and raising of this feminine suffix, however, is blocked when it is preceded by pharyngeal, laryngeal, pharyngealized and uvular consonants. McCarthy cites the examples in Table 1 from Syrian Arabic (from [15, p. 138] and [16, p. 45]) to demonstrate this. All words are feminine, ending with the feminine suffix

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(underlyingly, the non-low /e/ due to *imāla*). In words in which the feminine suffix is preceded by pharyngealized, pharyngeal, and laryngeal consonants, it is observed that *imāla* is blocked, and the feminine suffix is realized as the low [a].

Table 1: *Syrian words illustrating imāla (fronting and raising of feminine suffix) and the blocking of it.*

Word	Gloss	Word	Gloss
kbiːre	large (f)	madrase	school (f)
ʔəsˤsˤa	story (f)	ʕariːdˤa	wide (f)
xajjaːtˤa	seamstress (f)	mniːħa	good (f)
sˤanʕa	handcraft (f)	waːʒha	display (f)
xərʔa	rag (f)		

In this study, we use real-time Magnetic Resonance Imaging ([17] and [18]) to investigate the posterior articulatory configuration associated with pharyngeal and pharyngealized consonants in three dialects of Arabic and the pharyngealization spread triggered by both sound types on adjacent vowels.

2. Methodology

Dynamic rt-MRI with high spatial and temporal resolution is used to examine the articulatory correlates of pharyngealization. For this study, we analyze midsagittal rt-MRI slices, which provide holistic two-dimensional views of the vocal tract, including the posterior velopharyngeal and pharyngeal regions implicated in pharyngealization. A method for extracting pharyngeal contours is implemented to examine the place and degree of constriction in the pharynx for the different speech sounds.

2.1. Data Collection

rt-MRI data was acquired in the Biomedical Imaging Center at the Beckman Institute for Advanced Science and Technology at the University of Illinois at Urbana-Champaign. Data was collected from three male native speakers of Saudi Arabic, Jordanian Arabic, and Lebanese Arabic. The speakers were 26, 33, and 23 years old at the time of acquisition. It was somewhat difficult to find and recruit a large number of speakers of the different dialects of Arabic on campus. Ideally, a larger number of participants would have been recruited so that generalizations about production patterns in a certain dialect can be made confidently. With one speaker representing each dialect, it is of course uncertain whether observed articulatory patterns are due to dialect or individual speaker differences. We are hopeful that this question can be clarified in future studies.

Prior to the acquisition, each participant was trained to repeat the utterance described below in their most native dialect (Saudi, Lebanese, or Jordanian). After training, the participant lay supine inside the Magnetom Trio 3T scanner, his head fitted with a head/neck coil and resting on a NoMoCo support system (NoMoCo Pillow, Inc., San Diego, CA) to reduce movement. As the participant spoke, the midsagittal scans of the vocal tract were acquired and later reconstructed at a nominal frame rate of approximately 100 fps using a partial separability model [19]. A study on the effect of posture on the dimensions of the upper airway concludes that pharyngeal cross-sectional areas slightly decrease when the speaker assumes a supine position, compared with when the same speaker assumes a sitting position [20]. The MRI scanner used for this study requires that the speaker assume a supine posture. Nonetheless, the speaker lies supine throughout the acquisition, and thus, it is reasonable to assume that the consequence of this posture affects all the speech segments in the same manner.

Speakers were asked to repeat the carrier phrase: /ʕuːluː X sitt marraːt/ 'Say X six times!', where X is the target word. The target words are all real CVCVC words of Arabic where C2 is /sˤ/, /ħ/ and /ʕ/ as shown in Table 2. For each target word, the speaker was asked to continue to repeat the carrier phrase for a duration of 90 seconds. This yielded a different number of repetitions for each speaker because of their different speaking rates. Table 3 lists the number of repetitions produced by each speaker for each target word.

Table 2: *Glossed target words*

Word	Gloss
basˤar	eyesight
Saħar	dusk
saʕar	fire

Table 3: *Number of repetitions by each speaker for each target word*

Speaker	basˤar	saħar	saʕar
Saudi	32	34	34
Lebanese	25	27	28
Jordanian	37	37	37

Each MR image is 128 × 128 voxels (volume elements). Each voxel measures 2.2 mm × 2.2 mm × 8.0 mm (through-plane depth). The midsagittal plane was located after acquiring a three-dimensional scan of the head. Using this imaging volume, we used coronal and axial views to interactively place the sagittal slice at the prescribed location. We have observed that at a slice thickness of 8.0 mm, the vocal tract structures of interest remain visible throughout the session. A thinner slice in future studies may improve the reliability of results. Further information relating to the acquisition and reconstruction are available in [17], which describes a comparable study by members of our research group.

2.2. Data Segmentation

Simultaneous acoustic data was acquired using an optical noise-canceling microphone (Dual Channel-FOMRI, Optoacoustics, Or Yehuda, Israel). The microphone's software applies a noise cancellation method to attenuate some of the background noise produced by the MR scanner during acquisition. The resulting acoustics were not suitable for spectral analysis, but could to be used to annotate segmental boundaries in Praat [21]. The start and end times of the pharyngeal and pharyngealized speech sounds of interest were used to identify the midpoint of the speech sound and extract the corresponding MR image.

2.3. Data Analysis

A Matlab interface developed by Proctor et. al. ([22], [23], and [24]) was used to automatically detect the contours of the vocal tract from the glottis to the lips in the MR images corresponding to the speech sounds of interest. In this application, the user is presented with an MR image and manually clicks on four anatomical landmarks: the glottis, the highest point on the palate, a point on the alveolar ridge, and a point midway (vertically) between both lips. The xy-coordinates of these landmarks are registered and tract-normal semi-polar gridlines (orthogonal to the midline of the vocal tract) are generated from the lips to the glottis. Based on changes in pixel intensity, tissue boundaries along the vocal tract are detected. These include the contours of the back pharyngeal wall and the palate, as well as the tongue root (forming the anterior pharyngeal wall), and body (Figure 1).

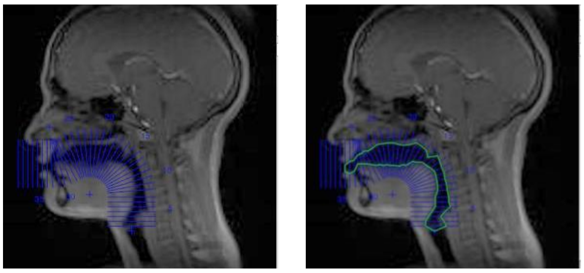
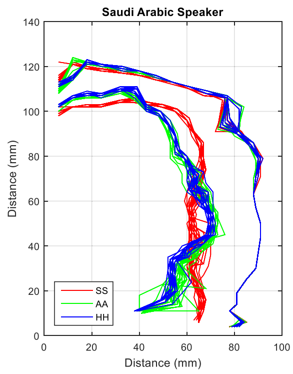


Figure 1: *a. (left) midsagittal view of the vocal tract (Saudi Arabic speaker) during a midconsonantal /sˤ/ with tract-normal grid lines superimposed. b. (right) detection of vocal tract contours (including lingual and pharyngeal contours).*

3. Results

In Figure 2, the pharyngeal contours are plotted for the speaker of Saudi Arabic. The contours run from the tongue tip (upper left) to the glottis (lower right). All iterations produced by the speaker are plotted. Contours corresponding to midconsonantal pharyngealized /sˤ/ are plotted in red; those for pharyngeal /ħ/ are plotted in blue; and those for pharyngeal /ʕ/ are plotted in green. The contours are averaged in order to capture variable postures of the vocal tract from one repetition to the next. The average contour for each speech sound is plotted in Figure 3. Average contour plots are generated for both the Lebanese and Jordanian speakers and plotted in Figures 4 and 5 respectively.



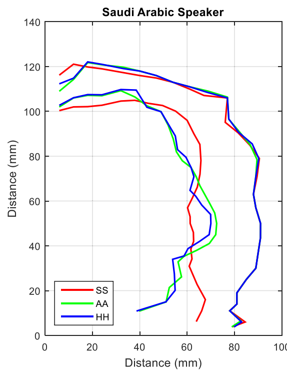
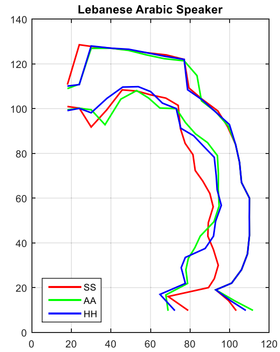


Figure 2 (left): *Midconsonantal vocal tract contours for all tokens of pharyngealized /sˤ/ in red (SS), pharyngeal /ħ/ in blue (HH), and pharyngeal /ʕ/ in green (AA) for the speaker of Saudi Arabic.* Figure 3 (right): *Average midconsonantal vocal tract contours for the same speaker. /sˤ/ in red (SS), pharyngeal /ħ/ in blue (HH), and pharyngeal /ʕ/ in green (AA).*



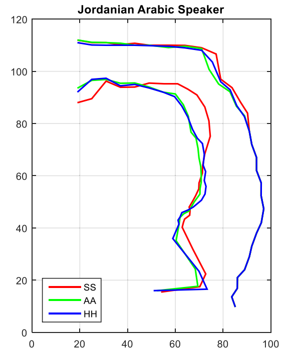


Figure 4 (left): *Average midconsonantal vocal tract contours for the speaker of Lebanese Arabic. /sˤ/ in red (SS), pharyngeal /ħ/ in blue (HH), and pharyngeal /ʕ/ in green (AA).* Figure 5 (right): *Average midconsonantal vocal tract contours for the speaker of Jordanian Arabic. /sˤ/ in red (SS), pharyngeal /ħ/ in blue (HH), and pharyngeal /ʕ/ in green (AA).*

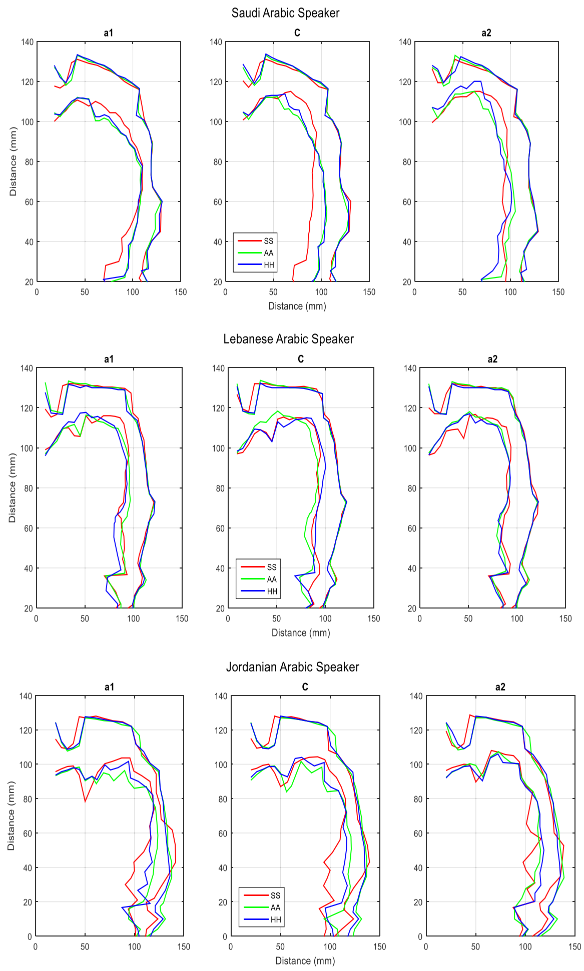


Figure 6: *Average lingual and pharyngeal contours during /basˤar/ in red, /saħar/ in blue, and /saʕar/ in green for the three speakers. The panels from left to right show the contours during V1 (/a/), C (/sˤ/, /ħ/, or /ʕ/), and V2 (/a/). /sˤ/ in red (SS), pharyngeal /ħ/ in blue (HH), and pharyngeal /ʕ/ in green (AA).*

In order to examine and compare the pharyngealization spread triggered by pharyngealized and pharyngeal consonants, lingual and pharyngeal contours are also plotted for the vowels preceding and following the consonants at the midpoint in Figure 6. These contours are averaged from three repetitions.

4. Discussion

Average lingual and pharyngeal contour plots for the three speakers show differences in place among the pharyngealized and pharyngeal consonants. This is especially evident in the plots for the Saudi and the Jordanian speakers (Figures 3 and 5). The red contour depicting /sˤ/ appears to be forming a uvularized constriction. Indeed, the pharyngealized consonants of Arabic are described as uvular in previous literature [4]. In the average vocal tract contour plots for all three speakers, we see a constriction deeper in the pharynx for both pharyngeal /ħ/ and /ʕ/. Furthermore, the lingual and pharyngeal contours for all three speakers suggest that the constriction during the pharyngeal is not restricted to a single place, rather it extends over a large region resulting in a more constricted pharynx overall. Proposals that suggest grouping pharyngeals and pharyngealized consonants into one class argue that "when the primary articulation is above the secondary constriction, as for coronal emphatics [e.g. /sˤ/], then the secondary constriction is higher in the pharynx; when it is below the secondary articulation [e.g. /ħ/ and /ʕ/], then the secondary constriction is lower in the pharynx" [4, p. 124]. Our results agree with these observations.

The differences in place observed here may partly account for the different pharyngealization spread patterns reported for pharyngeal and pharyngealized sounds. Though both types trigger pharyngealization spread, Watson [2] argues that, in the case of the pharyngealized consonants, the pharyngeal constriction is highly contingent on the primary oral one. The latter adds tension to the tongue dorsum and restricts the place of the former to the upper pharynx [2, pp. 271]. In contrast, in the case of the pharyngeal consonants, the pharyngeal constriction is not influenced by other articulations associated with these sounds. Thus, Watson maintains that "the more contingent the phonetic realization of the non-primary feature on the primary feature, the further the non-primary feature will spread and the less specific the targets of the spread will be" [2, pp. 271]. This then explains differences in the pharyngealization spread patterns triggered by pharyngealized consonants and those triggered by pharyngeal consonants in terms of distance and targets. Figure 6 shows the articulatory configuration associated with the vowels preceding and following pharyngeal and pharyngealized consonants. Both sound types seem to trigger leftward and rightward pharyngealization spread, as can be observed by the constricted pharyngeal contours in the vowels preceding and following both sound types. Pharyngealization spread in both sound types, however, is not identical. For all three speakers, we observe that /a/ preceding and following pharyngealized /sˤ/ is more uvularized, while /a/ preceding and following the pharyngeal /ħ/ and /ʕ/ are constricted deeper in the pharynx, especially in the case of the speakers of Saudi and Jordanian Arabic. This is evidently due to coarticulation with the pharyngeal or pharyngealized consonant. This likely results in different auditory qualities for the vowels adjacent to the pharyngeals compared with those adjacent to the pharyngealized consonants. Pharyngeal contours of the vowels preceding pharyngealized consonants seem to be generally more constricted than those following them. This suggests stronger anticipatory (leftward) pharyngealization spread. In contrast, with the exception of the Saudi speaker, the pharyngeal contours of the vowels preceding both pharyngeal consonants have similar constrictions, suggesting that both leftward and rightward spread triggered by pharyngeals is comparable in terms of strength.

Another observation concerns the articulatory configurations associated with pharyngeal /ħ/ and /ʕ/. While they are typically considered fricative cognates, sharing the same place of articulation and contrastive in voicing, some studies have reported various realizations of /ʕ/, including stop and approximant realizations [4]. Our results here show very similar articulatory configurations for both pharyngeals.

5. Conclusions

This study employs rt-MRI with high spatial and temporal resolution to examine the posterior articulatory configurations associated with pharyngeal and pharyngealized consonants in three dialects of Arabic. Our analysis shows a clear difference in place. Whether it is accepted that the pharyngeal constriction in both types of sounds is secondary, or if it is only secondary in the latter and primary in the former, the place of the constriction is clearly different among both types. The place difference may be explained by the degree of contingency upon the primary (or other) articulation. This determines the extent of the pharyngealization spread patterns triggered by both types of sounds. This study also examined the phonetic correlates of the pharyngealization spread patterns triggered by both sound types. Our results suggest stronger anticipatory pharyngealization spread in the case of pharyngealized consonants when compared with perseverative spread. They also show different articulatory configurations corresponding to the pharyngealization spread from pharyngeal and pharyngealized consonants. Our results confirm the similarities reported for both sound types in terms of the presence of a pharyngeal constriction and the influence on adjacent vowels. Further examination of the primary articulations associated with laryngeal /ʔ/ and /h/ are necessary to conclusively determine whether pharyngeal /ħ/ and /ʕ/ may be regarded as phonetically pharyngealized counterparts of the laryngeals.

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