An Ultrasound Study on Gradient Coarticulatory Pharyngealization and Its Interaction with Arabic Phonemic Contrast

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ABSTRACT

Arabic maintains a phonemic contrast between plain /t s/ and pharyngealized coronals /tˤ sˤ/, which are produced with a retracted tongue root. This study investigates whether coarticulatory pharyngealization in plain coronals is gradient or categorical and affected by the system of phonemic contrast. Mid-sagittal ultrasound images of the tongue were collected from 15 native speakers.

Results show that coarticulation is categorical on /t s/ and suggest a phonological merger of coarticulated /s/ with phonemically pharyngealized /sˤ/ whereas /t/ exhibits minimal (or no) coarticulation. However, coarticulation is more gradient in coronal /n l/ which do not have a pharyngealization contrast because their coarticulatory pharyngeal gesture is less extreme than in phonemic pharyngealization but more extreme than in the plain context. Phonemic contrast does not impede coarticulation because coronals which are contrastive for pharyngealization, /t s/, exhibit similar degrees of sensitivity to coarticulation as coronals that are not contrastive for pharyngealization, /n l/.

Keywords: Gradience. Coarticulation. Ultrasound. Pharyngealization. Phonemic contrast. Arabic.

1. INTRODUCTION

Coarticulation is influenced by several phonological, prosodic and phonetic factors. Phonological factors such as the density of a language phoneme inventory and phone contrast may contribute to the degree of a segment's sensitivity to coarticulation. According to Manuel [9-12], "output constraints" which determine the sensitivity of a segment to phonetic variability are affected by language-specific systems of phonetic contrasts. Results on the effect of contrast are not conclusive. Some studies found a link between Manuel's constraints and segments' sensitivity to coarticulation. For example, the magnitude of V-to-V coarticulation is greater in English, which has a dense vowel space, than in Shona and Swahili [13]. Other studies, however, such as [3, 5, 16] reported no effect of the size of the phonetic space on coarticulation across languages. For example, the Russian contrast between plain and palatalized trills /r rʲ/ does not impede coarticulatory effects from adjacent vowels [7]. The present study addresses Manuel's output constraints hypothesis in relation to C-to-C coarticulation of pharyngealization.

Arabic maintains a phonemic contrast between plain /t s/ and pharyngealized coronals /tˤ sˤ/. The coarticulatory effect of pharyngealization, which has been studied extensively on vowels, can spread as far as word boundaries [4]. Phonemic pharyngealization is associated with lowering of the tongue body and retraction of the tongue root towards the pharynx [1, 8] or, as Zawaydeh [19] suggested, the retraction of both the root and dorsum. Other consonants whose lingual articulatory demands do not intervene with the pharyngeal gesture such as labials can be coarticulatorily pharyngealized by retracting the tongue root [2].

The purpose of this study is twofold: 1) to investigate whether coarticulatory pharyngealization is gradient or categorical by comparing plain and phonemically pharyngealized coronals both in plain and pharyngealized contexts; and 2) to address the role of phoneme contrast in coarticulation by examining coarticulation sensitivity of coronals, which can be phonemically pharyngealized in relation to other coronals that cannot.

2. EXPERIMENT I: CATEGORICALITY OF COARTICULATION

The first part of the study addresses whether coarticulatory pharyngealization is a gradient phonetic process or a categorical phonological one. In order to achieve this, the study examines the extent of the tongue root retraction or advancement in four types of phones: plain coronals in plain and in pharyngealized phonetic contexts and phonemically pharyngealized coronals in similar contexts.

2.1. Stimuli

The wordlist consists of quadruples of words (N= 24) where the word-initial target coronal /t s tˤ sˤ/ conforms to the conditions illustrated in Table 1. The context consonant, which is either plain or pharyngealized, is separated from the target consonant by the vowel [a] or [aː].

Table 1: Target conditions of word quadruples.

Condition	Target C	Context C	Example
Plain	Plain	Plain	/**t**atliːf/ 'ruining'
Coarticulatory pharyngealization	Plain	Pharyn	/**t**atˤfiːf/ 'cheating'
Phonemic pharyngealization	Pharyn	Plain	/**tˤ**afiːf/ 'shallow'
Double pharyngealization	Pharyn	Pharyn	/qe**tˤ**atˤ/ 'cats'

It was hypothesized that if the magnitude of the pharyngeal gesture in coarticulatory pharyngealization is similar to phonemic pharyngealization, this would be suggestive of a synchronic phonological merger. Otherwise, if the tongue root is retracted to varying degrees across these four conditions, the effect is interpreted as a gradient phonetic process. Also, if phonemically pharyngealized coronals in pharyngealized context undergo a greater retraction than in plain context, there is an additive effect of coarticulation on pharyngealized consonants.

2.2. Procedures

Data were collected from 15 native speakers of Eastern Peninsular Arabic (5 females and 10 males, age: *M*= 28.6 years, *SD*= 9) while reading the randomized target words embedded in a frame sentence. The sentence does not include any guttural consonants. Mid-sagittal ultrasound images were generated at 60 fps using Terason t3000 operating Ultraspeech 1.2 [6] and using a micro-convex array transducer (8MC4 4-8 MHz). The probe was stabilized using an Articulate Instrument headset [18]. For all stop consonants, the ultrasound frames at mid-closure and release were selected, and for non-stop consonants, frames at three equidistant time points (at 25, 50 and 75% of consonant duration) were selected. However, only the frames at mid-stop closure and mid consonant for non-stops are presented here. Tongue contours were traced manually using Palatoglossatron.

Each speaker's tongue contours were rotated to make the occlusal plane horizontal. Following Mielke [14], Smoothing-Spline ANOVAs were computed in polar coordinates using R's 'gss' package and plots were generated in Cartesian coordinates. Each SS-ANOVA plot presented here is for an individual speaker whose results are representative of the majority of speakers in terms of the direction of difference between tongue splines.

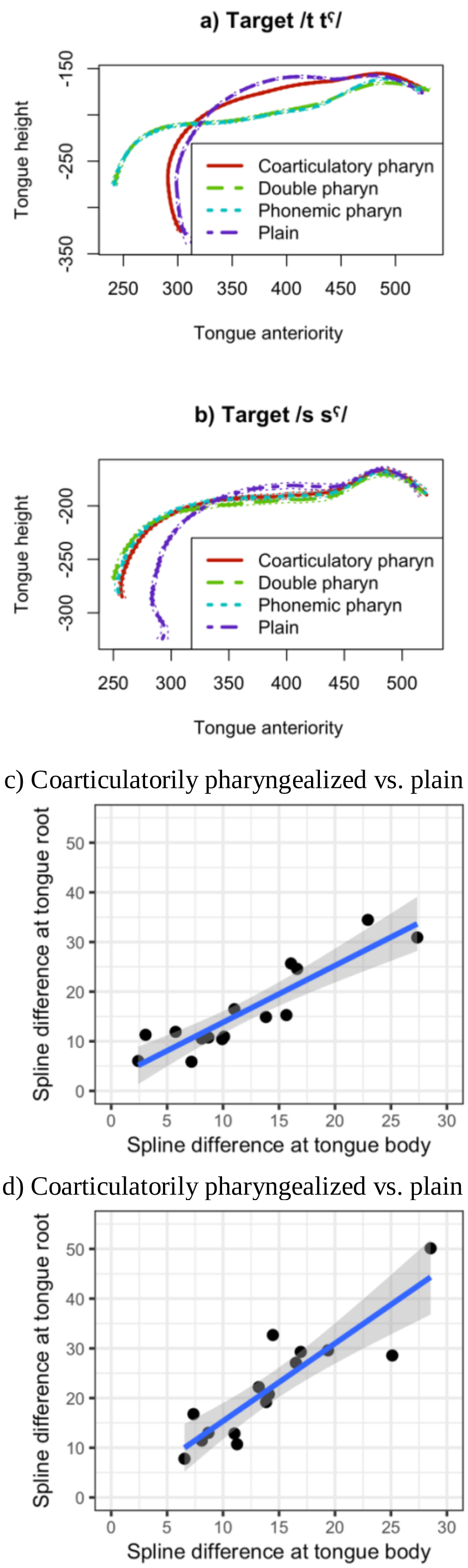
2.3. Results

The tongue root position of /s/ and /sˤ/ is different from /t/ and /tˤ/, respectively, with /s sˤ/ produced with more retracted root than /t tˤ/. Therefore, in this section, the analysis of /s sˤ/ is performed separately from /t tˤ/. Coarticulation can be considered categorical because coarticulatorily pharyngealized /s/ is as retracted as in phonemically pharyngealized /sˤ/ (Fig. 1b) whereas the tongue root position of coarticulated /t/ resembles plain /t/ for most speakers (Fig. 1a). This is found at mid-closure and release of /t/. For a few speakers (*n*= 5), /t/ exhibits the same magnitude of root retraction as in phonemically pharyngealized /tˤ/. Phonemically pharyngealized /tˤ sˤ/ in plain contexts are produced with the same articulatory configuration as in pharyngealized contexts, reflecting the categorical nature of coarticulation and suggesting no additive effect of coarticulation in this particular case. Differences between the tongue splines of coarticulatorily pharyngealized and plain consonants (as in Fig. 1a-b) for all speakers are summarized in scatterplots (Fig. 1c-d). Differences between tongue contours at the tongue root and body regions are computed as in [15]. The y-axis represents the maximum difference (per speaker) between SS-ANOVA fits for the two conditions at the tongue root measured as the angle from horizontal to 45° (0, $\pi/4$). The higher the speaker is located along the y-axis, the greater the tongue root retraction is in the coarticulatory condition relative to the plain condition. The x-axis represents the difference between the two splines in the tongue body anteriority. This is calculated by deducting the maximum difference at the interval 90°-135° ($\pi/2$, $3\pi/4$) from the maximum difference at the interval 45°-90° ($\pi/4$, $\pi/2$) and, then, dividing by two. These scatterplots show that the difference between the splines of coarticulatorily pharyngealized vs. plain /s/ at the tongue root (Fig. 1d) is greater than the difference between the splines in /t/-words (Fig. 1c). That is, comparison of the two scatterplots reveals that the tongue root difference in /s/-words is greater than 50mm whereas it does not exceed 35mm in /t/-words, suggesting that coarticulation on /s/ is greater and more consistent across speakers than /t/.

3. EXPERIMENT II: PHONEMIC CONTRAST

The second part of the study addresses the role of phonemic contrast on coarticulatory pharyngealization in relation to Manuel's 'output constraints' hypothesis. It proposes that segments tolerate deviations from their canonical phonetic form as long as coarticulation does not obscure the distinctiveness between contrastive phones of the language. Therefore, this study addresses whether the pharyngealization contrast has a restrictive effect on coarticulation by examining coarticulation sensitivity of coronals that have corresponding pharyngealized counterparts in Arabic e.g. /t s/ compared to other coronals that cannot be pharyngealized phonemically e.g. /n l/. If the contrastive coronals /t s/ exhibit no or lesser degrees of coarticulation compared to non-contrastive coronals /n l/, phonemic contrast restricts the sensitivity of segments to coarticulation.

Figure 1: SS-ANOVA of tongue contours with 95% CI where the initial target coronal is (a) /t tˤ/ or (b) /s sˤ/ (tongue tip to the right). The scatterplots of the spline difference between coarticulatory and plain (c) /t/, and (d) /s/ of all speakers at the root and body.



3.1. Stimuli and procedures

As illustrated in Table 2, the wordlist consists of 28 words of C_1aC_2 sequence where C_2 is either plain /t s/ or pharyngealized /tˤ sˤ/ and C_1 is either contrastive or non-contrastive in pharyngealization. Contrastive C_1 is a phoneme that has a phonemically pharyngealized counterpart e.g. /t s/, and non-contrastive C_1 does not have pharyngealized counterparts in the language e.g. /n l/. Data collection and analysis procedures are the same as in the first part of the study.

Table 2: Examples of target consonant contrastive and non-contrastive in pharyngealization.

Target C contrast	target	Source	Example
Contrastive	/t/	/s/ /sˤ/	/tasa:fi:r/ ‘travels’ /tasˤa:fi:r/ ‘whistles’
	/s/	/t/ /tˤ/	/sa:tra:t/ ‘covered’ /sa:tˤra:t/ ‘hitting’
Non-Contrastive	/n/	/s/ /sˤ/	/na:sfa:t/ ‘destrying’ /na:sˤfa:t/ ‘fair’
	/l/	/t/ /tˤ/	/xalat/ ‘passed’ /xalatˤ/ ‘mixed’

3.2. Results

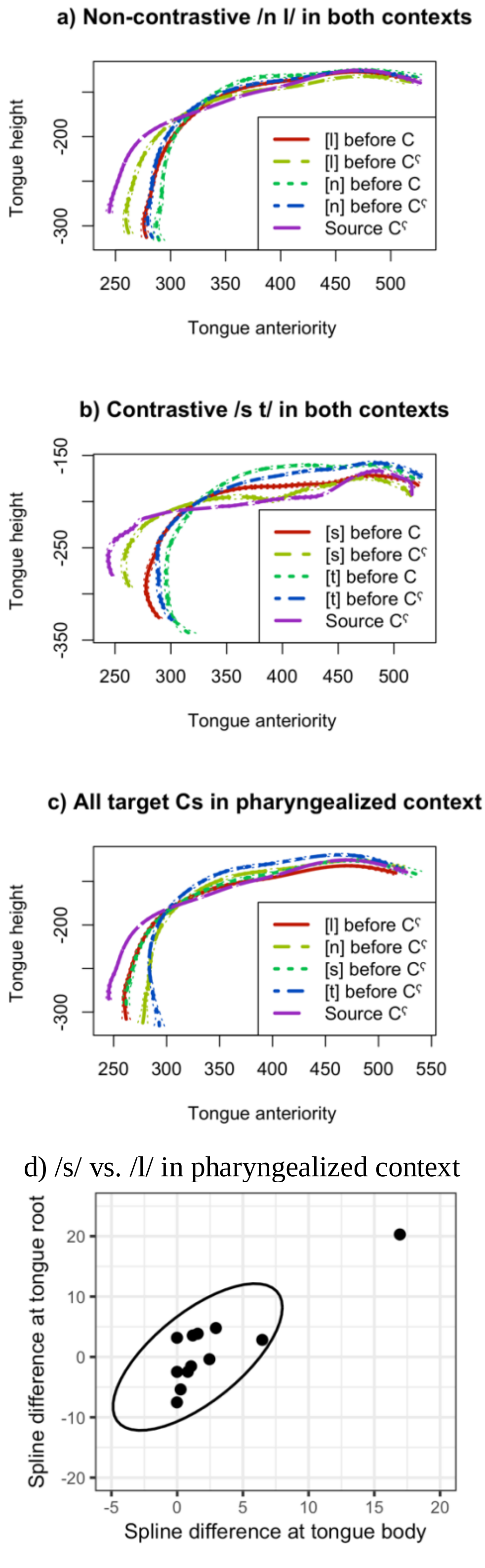
As in Fig. 2a, both non-contrastive coronals /n/ and /l/ are sensitive to coarticulation compared to their plain counterparts; however, the degree coarticulatory tongue root retraction in /l/ is greater and more consistent across speakers than /n/. Coarticulatory retraction in /l/ is as extreme as in phonemically pharyngealized consonants for three speakers. /n/ in the plain context has the most advanced tongue root and when preceding a pharyngealized consonant, its tongue position approaches that of /l/ in the plain context. This indicates a baseline effect for the lesser coarticulatory retraction in /n/ compared to /l/.

Similarly, as in Fig. 2b, contrastive /t/ and /s/ exhibit varying degrees of sensitivity to coarticulation. /s/ undergoes greater coarticulation than /t/. /t/ in pharyngealized contexts can be produced with no coarticulatory root retraction at all (half speakers) or with varying degrees of root retraction that can sometimes be as extreme as in phonemically pharyngealized C. Both contrastive and non-contrastive coronals demonstrate different degrees of coarticulation sensitivity. Comparison of all four coronals in the pharyngealized context (Fig. 2c) shows that contrastive /s/ and non-contrastive /l/ are produced with similar degrees of coarticulatory tongue root retraction. Similarly, contrastive /t/ and non-contrastive /n/ are produced with the same magnitude of coarticulation, and their tongue root is less retracted (weaker coarticulation) than in the other two coronals. The tongue root and tongue body angles in the scatterplot in Fig. 2d are measured as in Fig. 1c-d. As illustrated in Fig. 2d, the tongue root position for /s/ in pharyngealized contexts is not substantially different from /l/ (not exceeding 7 mm). This suggests that phonemic contrast in /s/ does not constrain its sensitivity to coarticulatory pharyngealization as it undergoes the same degree of coarticulatory tongue root retraction as the non-contrastive coronal /l/.

4. DISCUSSION

Coarticulation on word-initial /s/ and /t/ is categorical in nature, as /s/ undergoes an extreme coarticulatory tongue root retraction similar in magnitude to phonemically pharyngealized /sˤ/. The stop /t/, however, is less (or not) sensitive to coarticulation. This finding is suggestive of a synchronic phonological merger whereby a coarticulated /s/ becomes indistinguishable from a pharyngealized /sˤ/. Coarticulation on other coronals /n l/ is more gradient as they exhibit varying degrees of coarticulation at the tongue root. The findings, also, indicate that coronals that are contrastive for pharyngealization e.g. /t s/ can undergo a similar degree of coarticulatory pharyngealization as other coronals that are not contrastive e.g. /n l/. These findings do not conform to Manuel's output constraints hypothesis and the coarticulation pattern observed in this study is not in accord with V-to-V coarticulation which was found in some studies as being highly susceptible to the restrictive effect of phoneme contrast. This can be attributed to the fact that coarticulation in the words used here does not lead to lexical ambiguity and, therefore, should not be avoided. For example, pharyngealizing the word-initial /s/ in /**s**aːtˤraːt/ 'hitting' by coarticulation does not confuse it with another word in the language where the initial /s/ is phonemically pharyngealized */**s**ˤaːtˤraːt/. Therefore, contrastive consonants potentially allow coarticulation to take place as long as this does not yield ambiguous lexical items, an issue that represents a venue for future research. Coarticulation on contrastive /s/ is as extreme as on non-contrastive /l/ and the effect is greater than on /t n/. Physiological factors such as the articulatory demands on the tongue dorsum to sustain frication in /s/, which have been reported to impede coarticulatory pharyngealization in velars [1, 2], do not align with these results.

Figure 2: SS-ANOVA with 95% CI of coarticulation in (a) non-contrastive and (b) contrastive Cs, and (c) all coronals in pharyngealized context. (d) tongue spline difference between coarticulatorily pharyngealized /s/ and /l/ of all speakers.



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