# ACOUSTICS OF PERSIAN UVULAR LENITION IN CONSONANT CLUSTERS*

*Koorosh Ariyaee and Alexei Kochetov*
*University of Toronto*

## 1. Introduction

Consonant lenition is a process in which a consonant (typically a stop) becomes less strongly occluded ('lenited') or weakened. This can happen through weakening of the constriction degree, articulatory displacement, and reduction in gestural duration (Lavoie 2001, Gurevich 2011, Parrell 2014, among others). Lenition is cross-linguistically common and is used as a cover term for a variety of processes such as approximation, spirantization, gliding, among others (Kirchner 1998, Lavoie 2001, Gurevich 2004, Recasens 2016, Cohen Priva 2017, cf. Bauer 2008). It is common to observe variable consonant lenition patterns under the effect of the properties of adjacent segments. There are numerous studies that have inspected such effects on the lenition of labials, dentals/alveolars and velars, while the investigation of uvular stop lenition has remained understudied. Using acoustic analysis, this study examines the production of the Persian uvular stop in word-medial consonant clusters (as, e.g., /elɢɑ/ [elʁɑ] 'to instill') to extend the cross-linguistic typology of lenition patterns to uvulars.

### 1.1 Lenition with different places across languages

Many previous accounts have investigated whether lenition varies depending on the place of articulation of the target stop. Lenition of labial, alveolar/dental, and velar stops has been studied in Italian (Hualde and Nadeu 2012), Gurindji (Ennever, Meakins, and Round 2017), Catalan (Hualde, Nadeu, and Simonet 2011), English (Bouavichith and Davidson 2013), Spanish (Recasens 2016), Sanuma (Borgman 1990, cited in Gurevich 2011), among other languages. Results of these investigations revealed that voiced velars show the highest degree of lenition, followed by coronals and labials (Lavoie 2001, Wheeler 2005, Recasens 2016, cf. Kaplan 2010, Bouavichith and Davidson 2013). The reason for this place effect might be due to the less tight closure in the velar zone, resulting in a less abrupt stop release, and subsequently a longer frication noise (Foley 1977, Lavoie 2001, Recasens 2016). Air pressure during the stop production is another likely factor affecting lenition. When the air pressure level is lower, stops are less subject to lenition. For instance, since labials are produced with a larger oral cavity, and hence lower air pressure, they are less

* We would like to thank the audiences of the 2021 annual conference of the Canadian Linguistic Association for their feedback. We are also grateful to Jessamyn Schertz and Yoonjung Kang for their comments on the earlier versions of the work.

Actes du congrès annuel de l'Association canadienne de linguistique 2021.
Proceedings of the 2021 annual conference of the Canadian Linguistic Association.

prone to lenition than velars. Yet, the relatively small air cavity behind the velar closure causes the air to accumulate below it, thus increasing the supraglottal air pressure level (Ohala 1989, Recasens 2016) forcing velars to undergo lenition more. As uvulars are produced with an even smaller cavity behind the closure, and hence greater air pressure, one would expect these consonants to be particularly prone to lenition. We are not aware, however, of any previous phonetic investigations of uvular stop lenition. Hence, the focus of this study is on the acoustics of Persian uvular lenition with the goal of extending the cross-linguistic typology of this process to uvulars.

### 1.2 Uvular lenition in Persian

The Persian consonant inventory includes one uvular phoneme commonly described as a voiced stop, /ɢ/. Previous acoustic research showed that /ɢ/ is characterized by a short lag VOT, similar to other voiced stops and different from voiceless stops, which are characterized by a long lag VOT (aspiration; Bijankhan and Nourbakhsh 2009). Among posterior consonants, /ɢ/ (e.g., /ɢɑɾ/ 'cave') is contrasted with the velar obstruents /k/ (e.g., /kɑɾ/ 'job'), /g/ (e.g., /gɑɾi/ 'cart'), /x/ (e.g., /xɑɾ/ 'thorn'), and the laryngeal obstruent /h/ (e.g., /hɑɾ/ 'rabid').[1]

The uvular phoneme can occur adjacent to vowels word-initially (/ɢæm/ 'grief'), word-finally (/bɑɢ/ 'garden'), and word-medially (/ɑɢɑz/ 'beginning'). It also appears in consonant clusters as the first and the second consonant. Since Persian does not allow word-initial consonant clusters, /ɢ/ occurs only in word-medial (/ɑʃɢɑl/ 'garbage', /æɢvɑm/ 'relatives') and word-final consonant clusters (/tebɢ/ 'according', /æɢd/ 'marriage contract') (Bijankhan and Nourbakhsh 2009, Reza Asa 2016).

Previous accounts inspecting /ɢ/ in Persian commonly posit that this consonant has several allophones: a stop (/ɢɑli/, [ɢɑli] 'rug'), a fricative (/æɢlæb/, [æʁlæb] 'often'), and an approximant (/ɑɢɑ/, [ɑɻɑ] 'sir') (Bijankhan and Nourbakhsh 2009, Nourbakhsh 2015, Reza Asa 2016). Among these, the stop variant is noted to mostly appear word-initially ([ɢuɾi] 'teapot') and word-finally ([buɢ] 'horn'), while the fricative and approximant variations occurring interchangeably word-medially between two vowels ([ɑʁel] ~ [ɑɻel] 'wise') and in consonant clusters (where /ɢ/ is C1; [æʁɾæb] ~ [æɻɾæb] 'scorpion') (Nourbakhsh 2015, Reza Asa 2016).

### 1.3 Goals of this study

As discussed earlier, the susceptibility of uvular stops to lenition has not received as much attention, leaving a gap in our understanding of how the factor of place of articulation might account for systematic variation in the process. Although there have been acoustic studies on uvulars (Al-Khairy 2005, Ariyaee, Ben-Ammar, Tahtadjian, and Kochetov 2021), especially uvular stops (Alwan 1986, Kim and Pulleyblank 2009), there do not seem to be any studies which have systematically examined uvular stop lenition. Hence, this paper aims to contribute to filling this gap by extending the study of lenition to uvulars.

[1] The items in the current paper are derived from Dehkhda (n.d.) and Moein (n.d.) Online Dictionaries.

With the exception of the relatively small-scale acoustic studies (Bijankhan and Nourbakhsh 2009, Nourbakhsh 2015, Reza Asa 2016), the majority of the accounts reported the uvular allophonic distribution based on introspection or impressionistic data. Hence, another motivation for conducting this study is to acoustically examine the Persian uvular consonant and capture its allophonic variation given that this consonant is phonetically understudied. In particular, this study focuses on lenition of the word-medial uvular that appears as the second consonant of a consonant cluster (e.g., /ebɢɑ/ 'to retain') since there does not seem to be any study which systematically investigates the effect of the preceding consonants' properties on the allophony and lenition of /ɢ/ in Persian. Thus, in this paper we will test the effects of the preceding consonant on the lenition of the Persian uvular by manipulating manner (stop, fricative, or liquid), place (labial or coronal), and voicing features (voiceless or voiced) of the preceding consonant.

Cross-linguistically, there are positions where consonants undergo lenition and positions where they resist it (Foley 1977, Gurevich 2011). The former positions are known as weak, and the latter are referred to as strong positions (Lavoie 2001). Even though the word-medial post-consonantal position is strong cross-linguistically, the target consonant's lenition degree in this position depends on the sonority of the preceding sound (Ségéral and Scheer 2008). Post-sonorant positions may or may not be strong; however, post-obstruent positions are argued to be always strong positions (Ségéral and Scheer 2008, cf. Recasens 2016). In this paper we aim to investigate whether Persian /ɢ/ in post-consonantal strong and weak positions would show lenition patterns similar to cross-linguistic observations.

We will also examine whether there are any gender effects in patterning of the uvular lenition. In a pilot acoustic study with 4 speakers (including 2 female and 2 male speakers) our results revealed that female speakers in general produced /ɢ/ with lesser degrees of lenition compared to male speakers.

### 1.4 Hypotheses

Based on the findings and observations of the research reviewed above, we provide predictions about the Persian /ɢ/ lenition in the word-medial post-consonantal context. The major hypothesis is that the preceding consonant properties affect the lenition of the target consonant. This hypothesis is broken down into three specific hypotheses presented below.

**Hypothesis 1 (the effect of manner):** Post-stop /ɢ/ will show the lowest degree of lenition, and the post-liquid /ɢ/ will undergo the highest degree of lenition. Post-fricative /ɢ/ will have an intermediate situation between post-stop and post-liquid contexts. In general, post-sonorant /ɢ/ will undergo lenition more than post-obstruent /ɢ/.

**Hypothesis 2 (the effect of place):** Post-coronal /ɢ/ will show greater lenition degree than post-labial /ɢ/ since coronals lenite more than labials (Recasens 2016). That is, we expect more lenition after consonants that are more lenited.

**Hypothesis 3 (the effect of voicing):** The uvular that appears after voiced obstruents will show greater lenition degree than the uvular that occurs after voiceless obstruents.

## 2. Methods

### 2.1 Participants

A total of 14 participants (7 female and 7 male speakers) were recorded. The mean age of the participants was 32, and the age range was between 21 and 42. All the participants were native speakers of Spoken Persian (a.k.a. Tehrani Persian, Standard Spoken Persian) from Tehran, Iran. They were born and raised in Iran, while currently residing in Canada. The recruitment procedure ensured that the participants spoke Persian at home, have arrived in Canada after 18 years of age, and were not native speakers of other languages or other varieties of Persian. None of the participants reported any hearing or speaking problems.

### 2.2 Materials

The stimuli consisted of target and control items. Target items were 9 disyllabic monomorphemic words with consonant clusters, as shown in Table 1. In all the words, the /ɢ/ phoneme was the second consonant of the cluster. The first consonant varied in manner (stop, fricative, and liquid), place (labial and coronal), and voicing (voiced, voiceless).[2] All the items but one (/ɑzɢɑ/) were real words frequently used in spoken Persian. The list was created to measure possible effects of C1 manner, place, and voicing on the lenition of C2. Following Recasens (2016), it was expected that the extent of the target consonant lenition would be the lowest after stops and the highest after liquids.

**Table 1.** List of target words with /C1ɢ/ consonant clusters

| Context | C1 manner | C1 place | C1 voicing | Word | Gloss |
|---|---|---|---|---|---|
| b_ | stop | labial | voiced | ebɢɑ | to retain |
| d_ | stop | coronal | voiced | edɢɑm | to mix |
| t_ | stop | coronal | voiceless | motɢæn | solid |
| f_ | fricative | labial | voiceless | mæfɢud | lost |
| s_ | fricative | coronal | voiceless | æsɢær | male name |
| z_ | fricative | coronal | voiced | ɑzɢɑ | nonce word |
| ʃ_ | fricative | coronal | voiceless | ɑʃɢɑl | garbage |
| l_ | liquid | coronal | voiced | elɢɑ | to instill |
| ɾ_ | liquid | coronal | voiced | mærɢub | superior |

Control items (not shown in the table) were monosyllabic nonce words with single word-initial /k/, /g/ and /h/ before /ɑ/ (/kɑs/, /gɑs/, /hɑs/). As lenition does not occur in

[2] There are gaps in consonant clusters of Table 1 because some sequences of consonants (/pɢ/, /vɢ/, /ʒɢ/) do not exist in monomorphemic Persian words. Words with /mɢ/ and /nɢ/ clusters were included in the study, but not analyzed for the current paper due to the difficulty interpreting intensity in post-nasal contexts.

Persian word-initially, these items were included as a reference for the relative constriction degree of /ɢ/. That is, a non-lenited realization of the target /ɢ/ would be similar to the word-initial /k/ and /g/, while its lenited realization would be more similar to /h/.

All words were embedded in a carrier sentence [ɾu kɑɢæz bɑ dæstgɑhe tʃɑp _____ piɾint ʃode bud.] 'Via a printer, the word _____ was printed on a piece of paper.'

## 2.3 Recording procedure

Audio recordings were performed using Gorilla (Anwyl-Irvine, Massonnié, Flitton, Kirkham, and Evershed 2020), an online experimental platform.

Participants filled out a questionnaire asking for their age, sex, place of birth, native language, as well as for the device of audio recording.[3] They were instructed to read the stimuli as naturally as possible, avoiding hyper-articulation. The stimuli were randomized and presented in Persian orthography in a single block. Control items were presented five times and target items were presented three times. In total, each participant read 42 tokens (= 27 target tokens + 15 control tokens). Across all participants, 588 tokens (= 42 tokens × 14 participants) were collected.

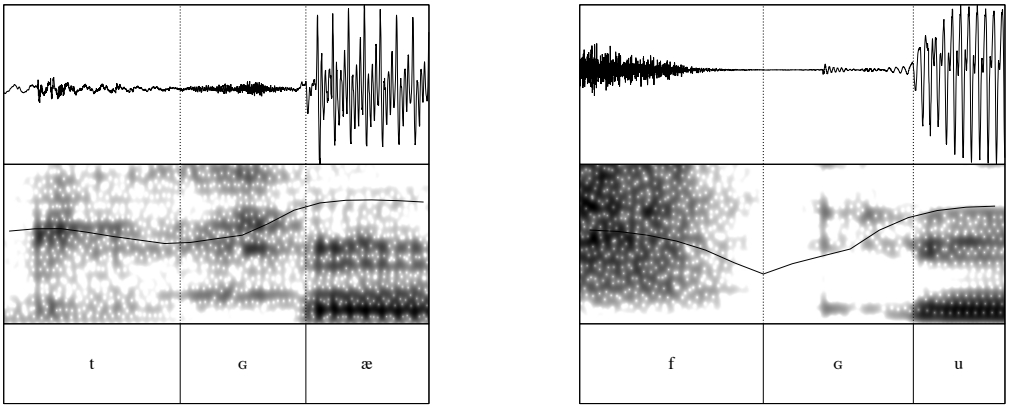
## 2.4 Data annotation and acoustic analysis

Three most naturally produced control tokens and two most naturally produced target tokens per speaker were manually annotated in Praat (Boersma and Weenink 2019) by the first author, a native speaker of Persian. This gave in total 27 annotated tokens per speaker (= 18 tokens in /C1ɢ/ clusters + 9 control tokens), and 378 tokens for the entire group.

The annotations involved the target consonant /ɢ/, the control consonants /k, g, h/, and immediately adjacent vowels and preceding consonants. The onset and the offset of the segments were determined via visual inspection of the intensity profile as well as the waveforms of each sound (Hualde and Nadeu 2012). The onset of the post-consonantal uvular sound was also set depending on the manner of the preceding consonant. The onset of /ɢ/ was set where the amplitude of soundwaves of the preceding sonorant or the noise of the preceding obstruent was at its minimum. The onset of /ɢ/ was where the intensity curve showed a noticeable dip (Figure 1a) or was at its minimum (Figure 1b). As there was no reliable way to find the actual closure onset of word-initial consonants, the onset of control consonants in this position was arbitrarily set where the intensity curve had reached its minimum, right before the increase of the intensity curve. The offset of the prevocalic uvular and the control consonants was set where intensity curve noticeably increased. Specifically, this was the point where the periodic cycle of soundwaves of the following

[3] Participants used different devices for audio recording, such as cellphones, PC, headphone's microphones, etc. Since it was an online experiment, it was not possible to control the use of recording devices.

vowel started to appear and the amplitude of the of vowel's soundwaves began to increase (Hualde et al. 2011).[4]




(a) /motɢæn/ 'solid' (speaker M4) (b) /mæfɢud/ 'lost' (speaker F5)

**Figure 1.** Waveforms and spectrogram of sample tokens of post-consonantal /ɢ/. The spectrogram view range is set to 0-7000 Hz.

A Praat script was used to extract intensity (dB) of each annotated sound at 15 equally distributed timepoints. Intensity, as a primary acoustic correlate of lenition, was measured in order to infer relative degree of the consonant constriction (Hualde et al. 2011, Hualde and Nadeu 2012, Recasens 2016, Ennever et al. 2017, Shaw et al. 2020, among others). Following previous accounts (Parrell 2010, Carrasco Hualde, and Simonet 2012), intensity ratio, as the most reliable acoustic parameter to measure degree of constriction (Parrell 2010), was calculated. It was taken as the minimum intensity of the consonant divided by the maximum intensity of the following vowel. The higher the intensity ratio value is, the lesser is the presumed degree of constriction, indicating higher lenition in the consonant. The intensity ratio values were further normalized across speakers using z-scores of individual productions to control for the proximity of the speakers from the microphone and their loudness while reading the stimuli.[5]

[4] Note that there was variation in the intensity profile and the waveforms within and across speakers' productions when annotating the data. To account for the variation and be as consistent as possible, a global consideration of a combination of the intensity contour, the waveform, the spectrogram as well as the noise was considered.

[5] Following previous work (Babel and Bulatov 2012, Recasens 2016; among others), we initially used high-pass filtering (above 300 Hz) in an attempt to remove the possible contribution of consonant voicing to intensity. This was done for three speakers (M2, M7, F5). However, intensity values of filtered and unfiltered data were essentially the same. Given this, the unfiltered data are used in this study.

## 3. Results

The statistical analysis was performed in R (R Core Team 2019) in order to quantify the lenition of the uvular sound under the effect of various factors. Normalized intensity ratio (intRatio) measurements were submitted to two Linear Mixed-Effects models. Model I was used to test differences among realizations of /ɢ/ across different clusters, focusing on the manner and place of the preceding consonant. Model II was used to evaluate differences among realizations of /ɢ/ across different clusters of consonants, with focus on the effect of voicing of the preceding obstruents only.[6] Further, pairwise tests were conducted between /ɢ/ (categorized by place/manner of C1) and the control consonants (see section 2.2).

### 3.1 Model I: Lenition in clusters by manner and place of preceding consonants

The first Mixed-Effects Model evaluated intRatio differences of /ɢ/ in different /Cɢ/ clusters, depending on the manner and place of the preceding consonant, using the package *lme4* (Bates et al. 2015). The fixed effects were the preceding consonant's Manner (3 levels: stop, fricative, and liquid) and Place (2 levels: coronal and labial) and Gender (2 levels: female and male), and a random intercept for Speaker. The formula for the model was: intRatio.n.full <- lmer(intRatio.n ~ C_manner + C_place + Gender + (1|speaker), data = q1, REML = F). Pairwise tests for the preceding segment's Manner and Place were conducted using the package *phia*.

The results of the model, presented in Table 2, revealed a significant effect of preceding segment's Manner and Place on the intRatio of /ɢ/, while there was no significant effect of Gender.

**Table 2.** Summary of the Linear Mixed-Effects Model I fit by maximum likelihood

| | Sum Sq | Mean Sq | NumDF | DenDF | F value | Pr(>F) |
|---|---|---|---|---|---|---|
| C_manner | 3.76 | 1.88 | 2 | 260 | 3.34 | 0.036 * |
| C_place | 20.33 | 20.33 | 1 | 260 | 36.08 | < .001 *** |
| Gender | 0.015 | 0.01 | 1 | 260 | 0.02 | 0.867 |

Pairwise tests for C1 Manner, shown in Table 3, revealed significant intRatio differences between /ɢ/ after liquids and the same consonant after fricatives and stops. The difference between the two latter contexts was not significant.

[6] The data were not completely balanced in terms of the manner, place and voicing of the preceding consonant. Thus, voicing as well as its interactions with place and manner were not included in the same model. Instead, the voicing effect on the post-obstruent uvular was separately tested in Model II.

**Table 3.** Results of pairwise tests for /ɢ/ after liquids, fricatives and stops

| | Value | Df | Chisq | Pr(>Chisq) |
|---|---|---|---|---|
| ɢ/fric_ - ɢ/liq_ | -0.46 | 1 | 13.06 | < .001 *** |
| ɢ/liq_ - ɢ/stop_ | 0.53 | 1 | 15.53 | < .001 *** |
| ɢ/fric_ - ɢ/stop_ | 0.07 | 1 | 0.38 | 1.000 |

These intRatio differences among /ɢ/ tokens categorized by manner of C1 compared to controls are illustrated in Figure 2, using the package *ggplot2* (Wickham 2011). We see that values for /ɢ/ after liquids were higher than values for the same consonant after fricatives and stops. Values for /ɢ/ after stops and fricatives were relatively similar. This indicates that /ɢ/ was more lenited after sonorants than after obstruents, while the degree of lenition did not differ between the two types of obstruents. Figure 2 also shows that post-consonantal /ɢ/ tokens have intRatio values that are generally greater than intRatio values of stop controls and lower than intRatio values of the fricative control (see section 3.3 for the pairwise tests among /ɢ/ and controls).

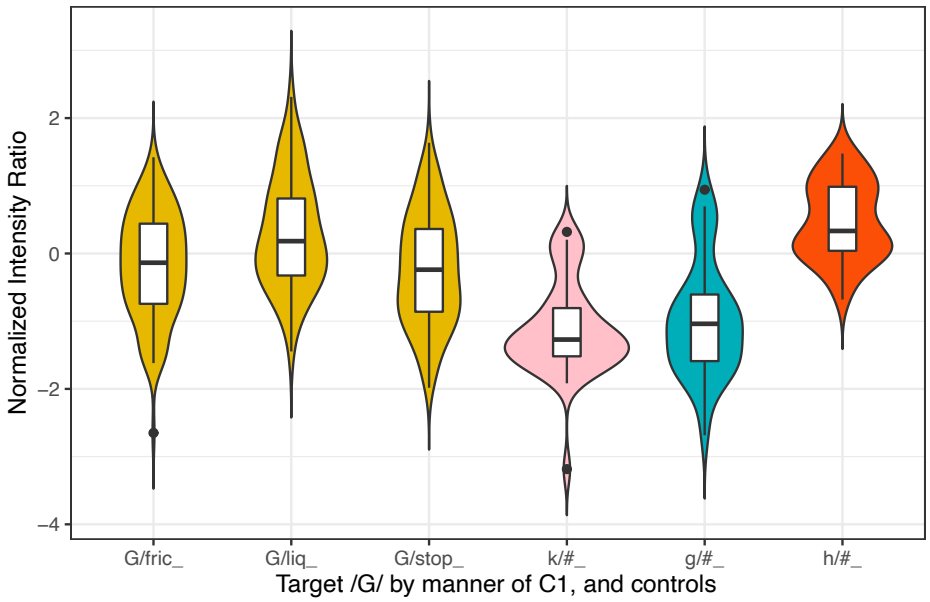



**Figure 2.** IntRatio of /ɢ/ by manner of preceding consonant in /Cɢ/ clusters (shown in yellow) as well as word-initial control consonants

The results of the pairwise tests for the effect of the Place of the preceding segment revealed significant differences between post-coronal and post-labial contexts, with greater intRatio values for the former ($p < .001$). These differences can be observed in Figure 3, and are indicative of a greater /ɢ/ lenition after coronal consonants. Figures 3 also shows that the post-coronal /ɢ/ has intRatio values similar to values of /h/, and the post-labial /ɢ/ intRatio values are closer to the values of the stop controls (see section 3.3 for pairwise test results among /ɢ/ and controls).

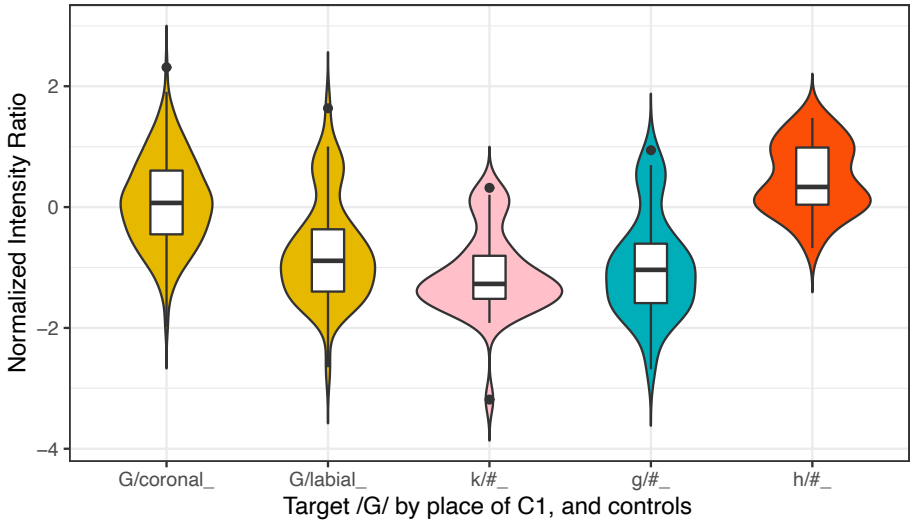



**Figure 3.** IntRatio of /ɢ/ by place of preceding consonant in /Cɢ/ clusters (shown in yellow) as well as word-initial control consonants

To ensure that the higher lenition for post-coronal /ɢ/ was not due to liquids (which were also characterized by higher intensity), a separate pairwise test by Place of the preceding segment was conducted including only post-obstruent /ɢ/. The results showed that there was still a significant difference between the post-coronal and post-labial /ɢ/ ($p < .001$), indicating a genuine place effect on lenition.

### 3.2 Model II: Lenition in clusters by voicing of preceding consonants

The second Mixed-Effects Model evaluated intRatio difference of /ɢ/ in different /Cɢ/ clusters, depending on the voicing of the preceding obstruent. The fixed effects were preceding segment's Voicing (2 levels: /ɢ/ after voiced obstruents and voiceless obstruents) and Gender (2 levels: female and male), and a random intercept for Speaker. The formula for the model was: intRatio.n.full <- lmer(intRatio.n ~ C_voicing + Gender + (1|speaker), data = q1, REML = F).

The results of Model II are presented in Table 4. These results revealed no significant effect of preceding obstruent's Voicing on the intRatio of /ɢ/. Likewise, no significant effect of Gender was observed. This means that /ɢ/ lenition was not affected by voicing of the preceding obstruent.

**Table 4.** Summary of the Linear Mixed-Effects Model II fit by maximum likelihood

| | Sum Sq | Mean Sq | NumDF | DenDF | F value | Pr(>F) |
|---|---|---|---|---|---|---|
| C_Voicing | 0.16 | 0.16 | 1 | 189.99 | 0.27 | 0.600 |
| Gender | 0.49 | 0.49 | 1 | 14.64 | 0.80 | 0.385 |

### 3.3 Pairwise tests between /ɢ/ and control consonants

Recall that word-initial /k/, /g/, /h/, were included as a reference for the relative constriction degree of /ɢ/. Non-lenited realization of /ɢ/ was expected to show no significant intRatio differences with /k/ and /g/, while the lenited realization of /ɢ/ would have insignificant intRatio differences with /h/.

Pairwise tests among /ɢ/ categorized by manner of the preceding consonant and controls showed insignificant difference between post-liquid /ɢ/ and the fricative control ($p > .05$) and significant differences with the stop controls, with greater intRatio values for the /ɢ/ ($p < .001$). This result indicates that post-liquid /ɢ/ had fricative-like realizations ([χ] ~ [ʁ] ≈ /h/). The pairwise tests results showed a significant difference between stop controls and the post-obstruent /ɢ/, with greater intRatio for the latter ($p < .001$). The pairwise tests between the fricative control and the post-obstruents were also significant, with greater intRatio values for the former ($p < .001$). These results indicate that the post-obstruents had intermediate realization between stop- and fricative-like realizations ([ɢ] ~ [χ], [ʁ]).

Pairwise tests were also conducted among /ɢ/ tokens categorized by the place of the preceding consonants and controls. The test results showed significant difference between post-coronal /ɢ/ and the stop controls with greater intRatio values for the former ($p < .001$). There were no significant intRatio differences between the post-coronal /ɢ/ and /h/ ($p > .05$) indicating the former was realized as more like fricative ([χ] ~ [ʁ] ≈ /h/). The results also revealed significant difference between post-labial /ɢ/ and /h/ with greater intRatio values for the latter ($p < .001$). The lack of differences between post-labial /ɢ/ and stop controls ($p > .05$) indicated that the former was realized as stop ([ɢ] ≈ /k/, /g/).

Another pairwise test among controls and the post-coronal obstruent /ɢ/ was conducted. The results showed that intRatio values of post-obstruent /ɢ/ were significantly higher than the intRatio of stop controls ($p < .001$), but intRatio values of /ɢ/ were significantly lower than the intRatio of /h/ ($p = .002$) revealing that post-coronal obstruent /ɢ/ had an intermediate condition between stop- and fricative-like realization. These results confirm that liquids were not fully responsible for the coronal effect.

## 4. Discussion

In this study, we examined the acoustic variation in the Persian uvular phoneme using a measure of relative intensity (IntRatio), as an acoustic correlate of lenition. We interpret the difference in this variable as reflecting the difference in constriction degree and hence lenition or lack of it. This was confirmed by the comparison of the target consonant's intRatio patterns to the control consonants.

Previous studies providing models of consonant lenition predict that the manner of the preceding consonant has a significant effect on lenition of the target stop (Kirchner 2001, 2004; Kingston 2008; Recasens 2016). There are also cross-linguistic observations which confirm the effect of this factor in languages such as Tamil, Catalan and Spanish (Lavoie 2001, Martínez-Celdrán and Regueira 2008, Carrasco, Hualde, and Simonet 2012, cf. Wheeler 2005). The results of the present study support the previous research by showing that the manner of the preceding consonant affects the lenition degree of the

uvular sound: in our Persian data, the lenition degree of post-liquid /ɢ/ was higher than the lenition degree of post-fricative and post-stop /ɢ/. Based on previous cross-linguistic observations (Lavoie 2001; Kirchner 2001, 2004; Kingston 2008; Ségéral and Scheer 2008; Recasens 2016), post-fricative target stops undergo lenition more than post-stop consonants, due to lesser constriction degree of fricatives compared to stops. However, no difference was observed between lenition degree of post-stop and post-fricative uvulars in our study. This result indicates that Hypothesis 1 is partially confirmed because the Persian uvular is sensitive to two broader manner categories of sonorants and obstruents only, and it is insensitive to the manner of the preceding obstruent.

The results showed that preceding consonant's place affects lenition of the uvular stop: post-coronal target consonants with fricative-like realization had higher degrees of lenition compared to post-labial /ɢ/ which had stop-like realization. This result confirms Hypothesis 2. The reason for more lenition after coronals than after labials is that among coronals in this study there are segments such as liquids (/l/, /ɾ/) and sibilants (/s/, /ʃ/, /z/) that are known to motivate lenition in their following stop consonants due to their lesser constriction degrees and higher intensity values compared to the labials used in this study (/b/, /f/) (Kirchner 2001, Kingston 2008, Ségéral and Scheer 2008, Recasens 2016).[7]

To the best of our knowledge, no other studies have reported lenition of stop consonants after an oral stop (see Honeybone 2001, Hammond, Chen, Bell, Carnie, Archangeli, Ussishkin and Fisher 2017, Tetzloff 2020). Ségéral and Scheer (2008) also posit that post-coda position, especially after an oral stop, is a strong position and no lenition is expected there. Yet, the Persian /ɢ/ after coronal stops undergoes lenition. Given this, lenition of the Persian /ɢ/ in our data presents an apparent counter-example. These results, in particular, showed that Persian /ɢ/ after coronal stops had lenition degrees between fricative- and stop-like realizations which could be due to the effect of two conflicting factors influencing the production of /ɢ/ after coronals: i) post-consonantal context disfavors lenition, as a strong position (Ségéral and Scheer 2008), while ii) word-medial position which favors lenition, as a weak position (Kingston 2008). Ultimately, the latter factor prevails indicating that word position has a greater effect on lenition of the /ɢ/ phoneme in Persian.

The post-consonantal /ɢ/ can also show greater lenition degree because of its place of articulation. As discussed in the Introduction section, previous literature shows that dorsal (velar) stops have a great tendency to undergo lenition compared to coronal or labial stops because the small air cavity behind the velar closure causes the air to accumulate below it and increase the supraglottal air pressure level (Ohala 1989, Recasens 2016) forcing velars to undergo lenition more. Since the uvular is more posterior than the velar stop, the former is even more subject to lenition due to smaller air cavity behind the uvular closure making it harder for the articulators to sustain the closure. Thus, it is expected to observe lenition in /ɢ/ even in the post-coda position which is cross-linguistically known as a strong position (Ségéral and Scheer 2008). Given this, the application of lenition in this context confirms

[7] Recall that the same result was obtained when the liquids were excluded from coronals.

previous accounts arguing for the high susceptibility of dorsal stops to lenition (Lavoie 2001, Wheeler 2005, Recasens 2016).

Previous studies (Recasens 2016, among others) predict that target stops show higher degrees of lenition after voiced consonants compared to voiceless ones since the former have higher intensity values presumably due to their weaker constrictions. Hence, in the present study it was hypothesized that /ɢ/ occurring after voiced obstruents would have a higher degree of lenition compared to post-voiceless obstruent /ɢ/. However, the results revealed that the voicing of the preceding obstruent did not have an effect on the uvular lenition. This result indicates that Persian /ɢ/ is insensitive to the voicing of their preceding obstruent, resulting in the rejection of Hypothesis 3. Note that the voicing results in this study should be taken with caution since the data were not completely balanced in terms of the voicing of the preceding consonant, due to the aforementioned lexical gap in Persian.

Our results revealed that the uvular phoneme showed a range of intensity values, and hence lenition degrees, depending on the nature of the preceding consonant. Some realizations were stop-like, while others were fricative-like, based on the comparison to word-initial velar stops and the glottal fricative. For instance, the stop allophone of /ɢ/ occurred after labial consonants (stops and fricatives) and the fricative allophone occurred after the coronal liquid /l/. Overall, our findings confirm the results of the previous studies which showed that the Persian /ɢ/ phoneme has stop and fricative allophones (Bijankhan and Nourbakhsh 2009, Nourbakhsh 2015, Reza Asa 2016). However, our results did not show any cases where the uvular phoneme would realize as an approximant. This was expected because previous studies (ibid) show that the approximant allophone most frequently occurs intervocalically or when it is the first consonant of a consonant cluster in word-medial position (recall that the uvular phoneme in our stimuli only occurred in post-consonantal position).

Note that the use of distinct stop/fricative allophones is an over-simplification since intensity values of /ɢ/ in different contexts were variable and continuous. This could suggest that the uvular consonant may not necessarily have categorically distinct allophones. That is, there could be one phoneme which realizes with different ranges of constriction degrees from fully occluded to highly lenited realizations on a continuum, rather than a categorical classification of lenited and non-lenited forms (Sproat and Fujimura 1993 on the English /l/). An investigation of the categorical or gradient status of the Persian /ɢ/ allophones is an interesting avenue for further research.

## 5. Conclusion

Extending the cross-linguistic typology of lenition to a new place of articulation, this study systematically investigated acoustics of Persian uvular stop lenition. The results of the study showed that various factors including word position, manner and place of articulation of the preceding consonant are at play in shaping lenition patterns of the uvular phoneme in Persian. These results also confirmed the high inclination of the uvular stop to lenition supporting the claim that dorsal stops across languages are highly prone to undergo this process.

**References**


Al-Khairy, Mohamed Ali. 2005. Acoustic characteristics of Arabic fricatives. Doctoral dissertation, University of Florida.

Alwan, Abeer Abdul-Hussain. 1986. Acoustic and perceptual correlates of pharyngeal and uvular consonants. Doctoral dissertation, Massachusetts Institute of Technology.

Anwyl-Irvine, Alexander L., Jessica Massonnié, Adam Flitton, Natasha Kirkham, and Jo K. Evershed. 2020. Gorilla in our midst: An online behavioral experiment builder. *Behavior Research Methods* 52(1): 388–407.

Ariyaee, Koorosh, Chahla Ben-Ammar, Talia Tahtadjian and Alexei Kochetov. 2021. The acoustics of guttural fricatives in three languages. In *Acoustics Week in Canada 2021*. Retrieved from https://awc.caa-aca.ca/index.php/AWC/AWC21/paper/view/795.

Babel, Molly, and Dasha Bulatov. 2012. The role of fundamental frequency in phonetic accommodation. *Language and Speech* 55(2): 231–248.

Bates, Douglas, Martin Mächler, Ben Bolker, and Steve Walker. 2015. Fitting linear mixed-effects models using lme4. *Journal of Statistical Software* 67(1): 1–48.

Bauer, Laurie. 2008. Lenition revisited. *Journal of Linguistics* 44(3): 605–624.

Bijankhan, Mahmood, and Mandana Nourbakhsh. 2009. Voice onset time in Persian initial and intervocalic stop production. *Journal of the International Phonetic Association* 39(3): 335–364.

Boersma, Paul, and David Weenink. 2019. Praat: doing phonetics by computer [Computer program]. Version 6.1.03, retrieved 22 December 2021 from http://www.praat.org.

Borgman, Donald M. 1990. Sanuma. In *Handbook of Amazonian languages*, ed. Pullum, Geoffrey K. and Desmond C. Derbyshire, 15–248. Berlin: Mouton de Gruyter.

Bouavichith, Dominique, and Lisa Davidson. 2013. Acoustic characteristics of intervocalic stop lenition in American English. *The Journal of the Acoustical Society of America* 133(5): 3565–3565.

Carrasco, Patricio, José I. Hualde, and Miquel Simonet. 2012. Dialectal differences in Spanish voiced obstruent allophony: Costa Rican versus Iberian Spanish. *Phonetica* 69(3): 149–179.

Cohen Priva, Uriel. 2017. Informativity and the actuation of lenition. *Language* 93(3): 569–597.

Dehkhoda Online Dictionary. Retrieved from http://www.jasjoo.com/books/wordbook/dehkhoda/ on April 6, 2022.

Ennever, Thomas, Felicity Meakins, and Erich R. Round. 2017. A replicable acoustic measure of lenition and the nature of variability in Gurindji stops. *Laboratory Phonology: Journal of the Association for Laboratory Phonology* 8(1): 1–32.

Foley, James. 1977. *Foundations of theoretical phonology*. Cambridge: Cambridge University Press.

Gurevich, Naomi. 2004. *Lenition and contrast: The functional consequences of certain phonetically conditioned sound changes*. Routledge: New York and London.

Gurevich, Naomi. 2011. Lenition. In *The Blackwell companion to phonology*, ed. Marc van Oostendorp, Colin J. Ewen, Beth Hume, and Keren Rice. Malden, MA: Blackwell. 1559–1575.

Hammond, Michael, Yan Chen, Elise Bell, Andrew Carnie, Diana Archangeli, Adam Ussishkin, and Muriel Fisher. 2017. Phonological restrictions on lenition in Scottish Gaelic. *Language*, 93(2): 446–472.

Honeybone, Patrick. 2001. Lenition inhibition in Liverpool English. *English Language and Linguistics* 5(2): 213–249.

Hualde, José Ignacio, and Marianna Nadeu. 2012. Lenition and phonemic overlap in Rome Italian. *Phonetica* 68(4): 215–242.

Hualde, José Ignacio, Miquel Simonet, and Marianna Nadeu. 2011. Consonant lenition and phonological recategorization. *Laboratory Phonology: Journal of the Association for Laboratory Phonology* 2(2): 301–329.

Kaplan, Abby. 2010. Phonology shaped by phonetics: The case of intervocalic lenition. Doctoral dissertation. University of California, Santa Cruz.

Kim, Eun-Sook, and Douglas Pulleyblank. 2009. Glottalization and lenition in Nuu-chah-nulth. *Linguistic Inquiry* 40(4): 567–617.

Kingston, John. 2008. Lenition. In *Selected Proceedings of the 3rd Conference on Laboratory Approaches to Spanish Phonology*, ed. Laura Colantoni and Jeffrey L. Steele, 1–31. Somerville, MA: Cascadilla Press.

Kirchner, Robert. 1998. An effort-based approach to consonant lenition. Doctoral dissertation. University of California, Los Angeles.

Kirchner, Robert. 2001. *An effort-based approach to consonant lenition*. London: Routledge.

Kirchner, Robert. 2004. Consonant lenition. In *Phonetically based phonology*, ed. Bruce Hayes, Robert Kirchner and Donca Steriade, 313–345. Oxford: Oxford University Press.

Lavoie, Lisa. 2001. *Consonant strength: Phonological patterns and phonetic manifestations*. Routledge.

Martínez-Celdrán, Eugenio, and Xosé Luís Regueira. 2008. Spirant approximants in Galician. *Journal of the International Phonetic Association*, 38(1): 51–68.

Moein Online Dictionary. Retrieved from http://www.jasjoo.com/books/wordbook/ on April 6, 2022.

Nourbakhsh, Mandana. 2015. Hamkhan-e malazi dar Farsi-e me'yar (Uvular consonant in standard Persian). *Journal of Zaban Pazhuhi* 15: 150–170.

Ohala, John. 1989. Sound change is drawn from a pool of synchronic variation. In *Language change: Contributions to the study of its causes*, ed. Leiv E. Breivik and Ernst H. Jahr, 173–198. Berlin: Mouton de Gruyter.

Parrell, Benjamin. 2010. Articulation from acoustics: Estimating constriction degree from the acoustic signal. *The Journal of the Acoustical Society of America* 128(4): 2289–2289.

Parrell, Benjamin. 2011. Dynamical account of how /b, d, g/ differ from /p, t, k/ in Spanish: Evidence from labials. *Laboratory Phonology: Journal of the Association for Laboratory Phonology* 2(2): 423–449.

Parrell, Benjamin. 2014. Dynamics of consonant reduction. Doctoral dissertation. University of Southern California.

R Core Team. 2016. R: A language and environment for statistical computing. Vienna, Austria. Retrieved from http://www.r-project.org.

Recasens, Daniel. 2016. The effect of contextual consonants on voiced stop lenition: Evidence from Catalan. *Language and Speech* 59(1): 139–161.

Reza Asa, Maryam. 2016. Barresi-e sowt-shentakhti-e shive-ye towlid-e hamkhan-e malazi-e /ɢ/ dar zaban-e Farsi-e me'yar (An acoustic study of the manner of articulation of the uvular consonant /ɢ/ in standard Persian). *Elm-e Zaban (The Science of Language)* 4(6): 101–130.

Scheer, Tobias, and Philippe Ségéral. 2008. Positional factors in lenition and fortition. In *Lenition and fortition*, ed. Joaquim Brandão de Carvalho, Tobias Scheer, and Philippe Ségéral, 131–172. Berlin: Mouton de Gruyter.

Shaw, Jason A., Christopher Carignan, Tonya G. Agostini, Robert Mailhammer, Mark Harvey, and Donald Derrick. 2020. Phonological contrast and phonetic variation: The case of velars in Iwaidja. *Language* 96(3): 578–617.

Sproat, Richard, and Osamu Fujimura. 1993. Allophonic variation in English /l/ and its implications for phonetic implementation. *Journal of Phonetics* 21(3): 291–311.

Tetzloff, Katerina. A. 2020. On the gradient lenition of Spanish voiced obstruents: A look at onset clusters. *Studies in Hispanic and Lusophone Linguistics* 13(2): 419–449.

Wheeler, Max. 2005. *The phonology of Catalan*. Oxford, UK: Oxford University Press.

Wickham, Hadley. 2011. ggplot2. *Wiley Interdisciplinary Reviews: Computational Statistics* 3(2): 180–185.