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# Acoustics of guttural fricatives in Arabic, Armenian, and Kurdish: A case in remote data collection

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Gutturals – uvulars, pharyngeals, and laryngeals – are relatively phonetically understudied, with previous acoustic investigations being limited to a handful of languages (and mainly Arabic). The goal of this paper is twofold: (i) to provide an acoustic documentation of guttural fricatives /χ, ʁ, (ħ, ʕ,) h/ in three under-documented languages/dialects: Emirati Arabic, Iraqi Central Kurdish, Lebanese Western Armenian, and (ii) through this to test the reliability of remote data collection for the analysis of fricatives. Fifty-nine participants residing in United Arab Emirates, Iraq, and Lebanon (18–21 speakers per language) completed an online audio-recording experiment. Word-initial, -medial, and -final fricatives in real words, embedded in carrier phrases, were measured for four spectral moments, relative intensity, and duration. The results showed consistent place and voicing differences in all three languages. Specifically, center of gravity and standard deviation of fricative noise were higher for uvulars and lower for pharyngeals and /h/. Voicing was consistently distinguished by duration, among other variables. Some positional and gender differences were also observed. Overall, the results obtained for fricatives in three languages are remarkably similar to those previously reported for Arabic and other languages, providing evidence for shared acoustic properties of gutturals, despite their very different phonological patterning in each language. The results also confirm the validity of the remote audio recording method.

# 1. Introduction

Guttural fricatives are produced in the posterior region of the vocal tract and include uvulars (/χ, ʁ/), pharyngeals (/ħ, ʕ/), and, by some accounts, laryngeal /h/ and /ɦ/ (McCarthy, 1991, 1994). Apart from /h/, these consonants are relatively under-represented in phonemic inventories of world languages. Uvular continuants, for example, have been reported to occur in less than 13% of world languages (59 out of sampled 470 languages in WALS; Maddieson, 2013). Even less common are pharyngeals, occurring in only 4% (19 of 451 languages in UPSID-PC; Maddieson & Precoda, 1991; 89 out of 2186 languages/dialects in Phoible; Moran & McCloy, 2019).

Guttural consonants as a class have attracted considerable attention in the phonological literature, serving as a testing ground for theories of distinctive features and models of assimilation and dissimilation (Herzallah, 1990; McCarthy, 1991, 1994; Bessell, 1993; Rose, 1996; Zawaydeh, 1999; Shahin, 2003; Bin-Muqbil, 2006; Sylak-Glassman, 2014). Much of this work was made possible due to pioneering phonetic – primarily articulatory – investigations of Arabic gutturals (e.g., Al-Ani, 1970; Delattre, 1971; Ghazeli, 1977; Bukshaisha, 1985). Not as much work, however, has been done on the acoustics of guttural fricatives, and the available research has largely focused on Arabic (e.g., Norlin, 1983; Alwan, 1986; see below). Even less is known about acoustic properties of guttural fricatives in other languages and how these may differ from the corresponding Arabic sounds. Even for Arabic, most phonetic studies have typically examined gutturals in a subset of positions (e.g., word-initial) and often involved a handful of speakers, representative of different dialects. The primary goal of this study is to provide an acoustic analysis of spectral and durational properties of voiceless and voiced guttural fricatives across word positions by relatively large groups of speakers of three phonologically different languages – Emirati Arabic, Iraqi Central Kurdish, and Lebanese Western Armenian, with the results potentially contributing to our better understanding of cross-language phonetic and phonological variation in this class of sounds. The secondary goal of the study is to test the reliability of online data collection from participants residing in their home country communities and using a range of recording devices and settings.

## 1.1. Acoustics of guttural fricatives in Arabic

As mentioned above, most previous acoustic work on guttural fricatives has been conducted on Arabic, which has a set of five relevant phonemes – voiceless and voiced uvulars /χ, ʁ/ (realized as velars or post-velars in some dialects), voiceless and voiced pharyngeals /ħ, ʕ/, and the voiceless glottal /h/ (Watson, 2007). In terms of their articulation, the Arabic uvular fricatives have been described as produced with the tongue dorsum making a narrow constriction against the uvula, with a secondary constriction at the upper pharyngeal wall (Zawaydeh, 1999). The pharyngeals typically involve a retraction of the tongue root and/or the epiglottis towards the lower pharyngeal wall and some raising of the larynx. While the voiced pharyngeal /ʕ/ is typically classified as fricative, it is often produced with an approximant-like constriction (and occasionally as an epiglottal stop; see McCarthy, 1994; Khattab, Al-Tamimi, & Alsiraih, 2018; Shosted, Fu, & Hermes, 2018 for reviews). The articulation of the laryngeal /h/ is more controversial, as some studies have described it as lacking a supralaryngeal constriction (Zawaydeh, 1999), while others inferring a pharyngeal constriction (Shahin, 2003; Bin-Muqbil, 2006), thus corroborating the sound's phonological behavior (cf. McCarthy, 1991, 1994).

Acoustic studies of Arabic sounds (Obrecht, 1961; Ghazeli, 1977; Nartey, 1982; Norlin, 1983; Alwan, 1986) found that voiceless guttural fricatives are characterized by a strong non-periodic noise, yet with some formant structure. The latter property is more evident in the voiced sounds and, particularly, in the pharyngeal /ʕ/ (given its frequent approximant-like realization). Voiceless and voiced uvulars were observed to have relatively compact spectra with prominent narrow peaks at mid frequencies, as well as secondary peaks further up. Spectra of pharyngeals were less compact, showing broad peaks at somewhat higher frequencies and a more abrupt decrease in energy at higher frequencies (Obrecht, 1961; Nartey, 1982; Norlin, 1983; Alwan, 1986; Bin-Muqbil, 2006). The laryngeal /h/ showed the flattest shape, with relatively low energy spread at low and mid frequencies (Obrecht, 1961; Norlin, 1983).

To quantitatively capture spectral differences in fricatives, many researchers employed measurements of spectral moments, such as center of gravity (COG, or centroid, in Hz), standard deviation (SD), skewness, and kurtosis (see Forrest, Weismer, Milenkovic, & Dougall, 1988). COG, which reflects the mean concentration of frication noise across frequencies, is known to correlate with place of articulation: the further back the constriction is in the mouth (and thus the larger the front cavity is), the lower is the COG of the sound (Gordon, Barthmaier, & Sands, 2002). Not surprisingly, studies of Arabic fricatives found COG to be lower for gutturals as a class (as opposed to e.g. coronals), as well as lower for pharyngeals than uvulars (Obrecht, 1961; Norlin, 1983; Al-Khairy, 2005; Abu-Al-Makarem, 2005; Bin-Muqbil, 2006; Al-Tamimi & Khattab, 2015), lower for the laryngeal /h/ than the uvular /χ/ (Obrecht, 1961; Abu-Al-Makarem, 2005; Al-Tamimi, & Khattab, 2015) and – in some cases – the pharyngeal /ħ/ (Norlin, 1983). Similar place differences were found for voiced uvulars and pharyngeals. In addition, COG was found to be lower for voiced than voiceless fricatives (Obrecht, 1961; Norlin, 1983; Al-Khairy, 2005; Abu-Al-Makarem, 2005; Al-Tamimi & Khattab, 2015), likely reflecting the prominence of formants in the former sounds.

Other spectral moments were also found useful in distinguishing the contrast. SD, which reflects the range of energy distribution around the mean (COG), was observed to be higher for uvulars than pharyngeals, at least for the voiceless set (Norlin, 1983; Al-Khairy, 2005; Abu-Al-Makarem, 2005; Al-Tamimi, & Khattab, 2015; but see Bin-Muqbil, 2006 on the reverse difference). The laryngeal /h/ was similar to either voiceless uvulars (Norlin, 1983; Al-Khairy, 2005) or pharyngeals (Abu-Al-Makarem, 2005; Al-Tamimi & Khattab, 2015). Skewness, which compares the energy distribution below and above the mean, was found to be higher for pharyngeals than uvulars, while yielding inconsistent results for /h/ (Al-Khairy, 2005; Abu-Al-Makarem, 2005; Bin-Muqbil, 2006). These findings reflect the earlier mentioned abrupt fall-off of energy at higher frequencies for pharyngeals and a relatively flat spectrum for /h/. Finally, place and voicing differences were also observed for kurtosis, a measure of the relative peakedness of the spectrum. Specifically, pharyngeals showed a higher kurtosis than uvulars, and so did voiced fricatives compared to voiceless ones (Al-Khairy, 2005; Abu-Al-Makarem, 2005; Bin-Muqbil, 2006).

Studies that examined relative intensity of fricative noise found that the measure was generally higher for voiceless than voiced fricatives, except for /h/ which had the lowest intensity (Norlin, 1983; Al-Khairy, 2005). Most studies have examined duration of fricative noise, reporting it to be much shorter for /h/ than the other fricatives (Obrecht, 1961; Al-Khairy, 2005; Abu-Al-Makarem, 2005; but see Al-Ani, 1970 and Alwan, 1986 for no difference), and – in some cases – shorter for voiced than voiceless uvulars and pharyngeals (Al-Khairy, 2005).

## 1.2. Acoustics of guttural fricatives in other languages

Considerably less phonetic work has been done on gutturals in other languages. Most of the studies we are aware of examined uvular fricatives in comparison to either more anterior fricatives (velars, if contrastive, or coronals) or the laryngeal /h/. Gordon et al. (2002) studied the acoustics of the uvulars /χ, χʷ/ in Montana Salish and Western Aleut (where these sounds contrast with the velars /x, xʷ/). The authors reported that the uvulars in Montana Salish were characterized with an acute noise peak at a low frequency and additional peaks at higher frequencies. The velar fricatives showed a similar low-frequency peak (although slightly higher in frequency), while lacking any prominent higher frequency peaks. Despite these differences, COG failed to distinguish the fricatives in both Montana Salish and Western Aleut (while showing significant differences in formant transitions). Hargus, Levow, and Wright (2021) compared /χ/ to /h/ in Deg Xinag (Athapaskan), finding that the uvular was characterized by higher COG, SD, and intensity, and by lower kurtosis. Skewness did not distinguish the two fricatives. Nartey (1982) examined the voiceless uvular fricative /χ/ (among other fricatives) in Hebrew, characterizing its spectrum as having a low-frequency primary peak and a medium-frequency secondary peak. Frequencies of these peaks appeared similar to those of the Egyptian Arabic /χ/ and Navajo /x/, also examined in the study. No quantitative comparisons of within or between languages, however, were performed. While some – albeit relatively limited – literature exists on uvular fricatives, we are not aware of any spectral investigations of pharyngeals in languages other than Arabic. A few studies that have looked at the acoustics of pharyngeals in Interior Salish languages (Bessell, 1993; Shahin, 2003; Flemming et al., 2008) focused on these consonants' formant patterns – likely due to these consonants' typically approximant-like realizations. Similarly, there is a lack of acoustic data (apart from a few spectrograms) on pharyngeals in languages of the

Caucasus, where these sounds have also been reported and noted to contrast with uvulars and laryngeals (cf. Ladefoged & Maddieson [1996] on Abkhaz, Agul, and Dargi).

## 1.3. Goals of the study and the choice of target languages

The previous studies of guttural fricatives in Arabic reviewed above have established that spectral measurements of fricative noise, and primarily COG and SD, can relatively reliably differentiate the relevant place contrasts, while intensity and duration are particularly relevant to distinguishing the fricative voicing. To some extent, these findings were corroborated by studies of similar fricatives (mainly uvulars) in other languages. It should be mentioned that most studies reviewed above typically examined fricatives in either word-initial (e.g., Norlin, 1983; Al-Khairy, 2005; Abu-Al-Makarem, 2005) or word-medial positions (e.g., Alwan, 1986). Hardly any work has been done on fricatives in word-final position, or across positions (with Al-Ani [1970] being an exception). Therefore, we chose to examine possible acoustic variation of fricatives as a function of position.[1] It has been observed that fricatives are generally more resistant to positional effects than other consonants, likely due to the higher articulatory precision required to generate noise turbulence (Byrd, 1996). Some positional effects, however, have been observed as, for example, a longer duration and higher COG for fricatives in word-initial position, compared to word-medial and word-final positions (Kochetov, 2017 on Russian).

The studies reviewed above have examined specific varieties of Modern Standard Arabic, as spoken primarily in Egypt (Norlin, 1983), Iraq (Alwan, 1986), Lebanon (Obrecht, 1961; Al-Tamimi & Khattab, 2015), and Saudi Arabia (Al-Khairy, 2005). Less is known about the acoustic realization of gutturals in Emirati Arabic, a relatively phonetically understudied variety of Persian Gulf Arabic (Leung, Ntelitheos, & Al-Kaabi, 2020). One exception to this is Abu-Al-Makarem's (2005) study of fricatives in the Al-Khat colloquial variety of Persian Gulf Arabic spoken in Saudi Arabia. Even less is known about guttural fricatives in other languages of the broader Middle East region. Therefore, the research gap in the phonetic study of gutturals in this region was a major motivating factor for our choice of Iraqi Central Kurdish and Lebanese Western Armenian. Both languages are phonetically understudied, particularly with regards to fricatives. In addition, Western Armenian is of interest due to its endangered status in Anatolia and the Middle East (UNESCO World Atlas of Languages, n.d.). Importantly, a comparison of guttural fricatives of these two languages with the much more studied sounds of Arabic would

[1] The phonetic variables discussed above – spectral moments, intensity, and duration – are certainly not the only possible cues to guttural fricatives. Some previous studies have observed consistent place differences in formant transitions to or from these consonants, reflecting their different front/back cavity resonances (e.g., Al-Ani, 1970; Alwan, 1986 on Arabic). Furthermore, some more recent studies have explored other methods to investigate spectral noise of fricatives (including gutturals), such as mel-frequency cepstral coefficients (MFCCs; e.g., Chelali & Djeradi, 2012 on Arabic; Ghaffarvand Mokari & Mahdinezhad Sardhaei, 2020 on Azerbaijani). Such analyses were not employed in the current study yet would be useful to consider in the future cross-language comparisons of gutturals.

allow us to identify cross-linguistically common patterns or differences in the phonetic realization of these sound categories.

## 1.4. Background on investigated languages and fricatives

### 1.4.1. Emirati Arabic

Arabic is a Semitic language belonging to the Afro-Asiatic family and is spoken predominantly in the countries of Northern Africa and the Middle East (Eberhard, Simons, & Fennig, 2023; Holes, 2004). While there exists a general standard variety of the language, Modern Standard Arabic (MSA), vernacular varieties differ based on the country they are spoken in, with the major dialects being Egyptian, Levantine (e.g., Syria and Lebanon), Mesopotamian (e.g., Iraq and Anatolia), Maghrebi (e.g., Morocco and Algeria), and Peninsular (e.g., Saudi Arabian) (Eisele, 1987; Versteegh, 1997; Holes, 2021). In this paper, we study the Arabic spoken in the United Arab Emirates (UAE), particularly the variety of the Emirate of Abu Dhabi, with around 3.7 million speakers (Eberhard, Simons, & Fennig, 2023). This regional variety of Peninsular Arabic, indicated in **Figure 1**, is known to be mutually intelligible with varieties spoken in other Emirates (e.g., Fujairah, Sharjah, Ras Al Khaima, Dubai, Ajman, and Umm AlQuwain; Feghali, 2008). For simplicity, we will refer to the examined variety as Emirati Arabic (EA).

As discussed earlier, Arabic guttural fricatives include voiceless and voiced uvulars and pharyngeals, as well as the voiceless laryngeal /h/, as summarized in **Table 1** below. It should be noted that although /χ, ʁ/ have been traditionally described as uvular, these sounds are realized in some varieties as velars or post-velars (Watson, 2007). Recent descriptive accounts of Emirati Arabic and Persian Gulf Arabic more generally classify the sounds as velars (Feghali, 2008; Leung et al., 2020). Phonetic investigations of the corresponding sounds in other varieties of Persian Gulf Arabic, however, refer to these sounds as uvulars (e.g., Abu-Al-Makarem, 2005 on the Al-Khat dialect of Saudi Arabia, and Bukshaisha, 1985; Al-Ansari & Kulikov, 2022 on Qatari Arabic). Our auditory impressions of the Emirati Arabic recordings also suggest that these sounds are more likely uvular than velar. We will, therefore, refer to them as uvular in the paper.

### 1.4.2. Iraqi Central Kurdish

Kurdish is an Iranian (Indo-European) language spoken in Iran, Iraq, Syria, Turkey, and Central Asia (Hamid, 2016). While there is no consensus on the Kurdish dialects and subdialects, there is general agreement that this language has three main varieties of Northern Kurdish, Central Kurdish, and Southern Kurdish (Haig and Öpengin, 2014; Hamid, 2016). In this paper, we study the Central Kurdish dialect spoken in the Sulaymaniyah region of Iraq (also known as Sorani Kurdish), which is highlighted in **Figure 1**, and further referred to as Iraqi Kurdish (IK). This variety is mainly spoken in northeastern Iraq and northwestern Iran (Hamid, 2016). While there is no accurate number of Central Kurdish speakers, this variety is estimated to have around 5.3 million speakers in total (Eberhard, Simons, & Fennig, 2023; cf. Hamid, 2016).

As Arabic, Iraqi Kurdish has five guttural fricative phonemes, as shown in **Table 1**. While the voiceless uvular fricative /χ/ frequently occurs in the Iraqi Kurdish vocabulary, its voiced counterpart /ʁ/ is less frequent and appears mainly in Arabic loanwords (Hamid, 2021; Anonby, 2022). The place of /χ, ʁ/ is also debatable, with some sources (Hamid, 2016; Ahmed, 2019; Anonby, 2022) describing them as uvular and others as velar (Thackston, 2006; Öpengin, 2013). The pharyngeals /ħ, ʕ/ in Kurdish varieties occur predominantly in Arabic loanwords (e.g., Haig & Matras, 2002), while also being found in some high frequency native vocabulary (e.g., [ħawt] 'seven', [ħawtɑna] 'weekly'; Barry, 2019; Qazzaz, 2000; Anonby, 2022) and showing phonotactic preferences distinct from Arabic (Kahn, 1976; Barry, 2019; see below). Given the extensive adaptation of the sounds in the language (as well as the currently diminished influence of Arabic; see below), we may not necessarily expect these sounds to be identical to Arabic in terms of their acoustic properties.

### 1.4.3. Lebanese Western Armenian

Armenian is an isolate within the Indo-European language family. It has two standard dialects: Eastern Armenian (EA) and Western Armenian (WA). Eastern Armenian is the dialect mainly spoken in Armenia, Russia, and Iran (around 3.85 million speakers), while Western Armenian is the dialect spoken mainly in the diaspora (around 1.4 million speakers total; around 336,000 speakers in Lebanon) (Eberhard, Simons, & Fennig, 2023). As shown in **Figure 1** below, our focus here is on Western Armenian spoken in Lebanon; this variety will be referred to as Lebanese Armenian (LA). It should be noted that Lebanon has been traditionally one of the centers of the West Armenian population and served as a primary destination for Armenian refugees escaping Anatolia during the genocide circa 1918 (World directory of minorities and indigenous peoples, 2020; Chahinian & Bakalian, 2016).

Unlike Emirati Arabic and Iraqi Kurdish, Lebanese Armenian has three fricatives that can be classified as guttural: the uvular /χ, ʁ/ and the laryngeal /h/ (Vaux, 1998; Sakayan, 2012; Tahtadjian, 2023). The place of /χ, ʁ/ has been debated, with some researchers transcribing the fricatives as uvular (Vaux, 1998; Sakayan, 2012), while others as velar (i.e., /x, ɣ/; Baronian, 2017; Kelly & Keshishian, 2021). To date, two phonetic investigations of Armenian uvulars have been conducted. In an X-ray imaging study, Xacatryan (1988) showed that for Eastern Armenian, while both uvulars were produced with the tongue dorsum raised toward the uvula, the dorsum for /ʁ/ was found to be more posterior and made closer contact with the passive articulator than /χ/. In an ultrasound study comparing both varieties, Tahtadjian (2023) found that Western Armenian speakers tended to produce a smaller place of articulation differences between velar stops and uvular fricatives compared to Eastern Armenian speakers. This suggests that uvulars in the former variety are more fronted. As Arabic is the dominant second language for Armenians living in the Middle East, these speakers' bilingualism could influence the phonetic realization of various Armenian sounds (as has been previously noted for laryngeal contrast: Kelly & Keshishian, 2021; Tahtadjian, 2021; Seyfarth et al., 2023), including the uvular fricatives. How the potential influence would be manifested, however, is unclear, given the contradictory phonetic accounts of similar sounds in Lebanese Arabic (as uvulars by Obrecht, 1968 and as velars by Al-Tamimi & Khattab, 2015).


**Figure 1:** Map of Western Asia and regions where Emirati Arabic (EA), Iraqi Kurdish (IK), and Lebanese Western Armenian (LA) are spoken. Armenia is highlighted to show that LA is spoken outside of the homeland.

| | **Uvular** | **Pharyngeal** | **Laryngeal** |
|---|---|---|---|
| Emirati Arabic | χ ʁ<br>(or x, ɣ) | ħ ʕ | h |
| Iraqi Central Kurdish | χ ʁ<br>(or x, ɣ) | ħ ʕ | h |
| Lebanese Western Armenian | χ ʁ<br>(or x, ɣ) | — | h |

**Table 1:** Guttural fricatives in the investigated languages.

### 1.5. Predictions, possible challenges, and phonological differences

Based on results of previous studies (mainly on Arabic), we can make several predictions about the differentiation of fricatives in place and voicing. Specifically, uvulars should be distinguished from pharyngeals by a higher COG and SD, and a lower skewness and kurtosis. Compared to the other voiceless fricatives, the laryngeal /h/ would be expected to show a lower COG (at least compared to /χ/), and lower intensity and duration, with possible other spectral differences. Voiced uvular and pharyngeal fricatives, in their turn, would be expected to show lower COG, intensity, and duration, and higher kurtosis values than their voiceless counterparts. Based on results of Tahtadjian's (2023) ultrasound study on Armenian dorsal consonants, the laryngeal /h/ in Lebanese Western Armenian should have a lower COG than the uvulars. No specific predictions are made about between-language differences for specific fricative types, given the near-lack of previous phonetic research on these sounds in Central Kurdish.

While many previous studies of fricatives made use of quality recorders and acoustic chambers, in this study we are evaluating the segment classification method based on data collected online, the acoustic quality of which may be variable due to different recording conditions (see Section 2). An advantage of this method, on the other hand, is the ability to record multiple speakers residing in their home countries. This is in contrast to much of the previous works where fricatives were recorded from a handful of speakers, typically residing in the United States. It remains to be seen, however, whether results obtained from online recordings are comparable to previous studies. This is one of the questions our study will address.

Easier access to technological devices (such as smartphones) with the ability of audio recording on the one hand, and the COVID-19 pandemic on the other, motivated many researchers to adopt online methods to collect phonetic data remotely and analyze compressed audio files. While the use of such devices facilitates the process of data collection and shows to be reliable (Freeman & Decker, 2021), there are limitations to this method. For instance, Ge, Xiong, and Mok (2021) and Sanker, Babinski, Burns, Evans, Johns, Kim, Smith, Weber, and Bowern (2021) suggest that the reliability of remote data collection might be affected due to the variation in values of some acoustic parameters including vowel formants (cf. Freeman & Decker, 2021) and the COG of fricatives with energies concentrated at higher frequencies (sibilants). This variation, which could result in confusion for listeners and in general degrade the quality of recordings, is greater than what is observed in recordings conducted in a sound-attenuated booth. Another important factor affecting the quality of remotely collected data is the variation in the use of devices participants used for audio recording (phones or laptops). Additionally, audio recordings conducted via popular video conference apps (e.g., Skype, Zoom, Microsoft Teams) have been shown to affect certain acoustic parameters, such as formants values of vowels as well as degrees of vowels nasalization (Freeman & Decker, 2021). However, despite these challenges and limitations of the remote data collection, the method, with some considerations, is concluded to be a worthwhile medium to obtain data for the acoustic analysis of various phonetic variables (particularly F0 and duration; Bulgin, De Decker, & Nycz, 2010; Freeman & Decker, 2021). As our focus in this paper is on guttural fricatives that are typically characterized by energy at lower frequencies, we expect the limitations of the online method to be relatively moderate.

It is important to note that although the three selected languages have a set of what seems to be phonetically similar guttural phonemes (cf. **Table 1**), the phonological patterning and historical sources of these sounds are different in each language. In Arabic, for example, gutturals are part of a larger class of segments including uvular stops, the glottal stop, and pharyngealized consonants (emphatics) (Watson, 2007). These sounds share the common behavior of lowering adjacent vowels (McCarthy, 1991); they also pattern together in lexical co-occurrence restrictions (exhibiting the Obligatory Contour Principle as a similarity avoidance effect; Frisch, Pierrehumbert, & Broe, 2004). In contrast, there is no evidence, as far as we know, for the common phonological patterning of pharyngeals, uvulars, and laryngeals in Kurdish (Kahn, 1976; Barry, 2019). Similarly, no evidence exists for the uvulars and /h/ forming a natural class in Armenian (Vaux, 1998). Moreover, the set of gutturals in Armenian is much smaller compared to the other two languages. If language-specific sets of contrasts and phonological patterning have any say in how sounds are realized phonetically, we should expect considerable differences in the realizations of guttural contrasts across the three languages. There may also be some phonologically-based similarities. For example, in Arabic, uvulars have been observed to lower or back vowels in varieties of Armenian (Vaux, 1998). Somewhat similar height effects were also reported for (Northen) Kurdish pharyngeals: Barry (2019) observed that these sounds have a strong tendency to occur next to low vowels,[2] while Kahn (1976) reported that pharyngeals actively lower and back following vowels. Thus, the three selected languages exhibit robust phonological differences, as well as some similarities with respect to their guttural phonemes. Whether these factors play a role in the phonetic realization of sounds is an interesting question, to which we will return in the Discussion.

## 2. Method

### 2.1. Participants

The study involved 59 participants: 18 speakers of Emirati Arabic (10 females, 8 males), 20 speakers of Iraqi Kurdish (10 females, 10 males), and 21 speakers of Lebanese Armenian (12 females, 9 males), residing predominantly in Abu Dhabi and Dubai (UAE), Sulaymaniyah and Kirkuk (Iraqi Kurdistan), and Beirut (Lebanon), respectively. The participants were mainly in

[2] A similar situation appears to exist in Sorani Kurdish, the variety examined in this study. Based on our review of words with initial pharyngeals in Hakem’s (2012) dictionary, pharyngeals followed by low vowels /a/ and /ɑ/ account for 73–82% of entries.

their 20s, with the mean age being 22.2 for Emirati Arabic, 22.5 for Iraqi Kurdish, and 28.6 for Lebanese Armenian. All 18 EA participants identified Arabic as their first language (L1) and English as their second language (L2). Among them, three individuals stated that they spoke fluent French, while one participant mentioned proficiency in Korean, and another in Spanish. Regarding educational backgrounds, the language of instruction varied during elementary and secondary schooling, with some receiving education in Arabic and others in English. However, at the tertiary level, all participants were educated in English, except for one individual who pursued studies in French. All Iraqi Kurdish speakers reported this language to be their L1. Nine of them mentioned to be able to speak Arabic as well. All the other participants indicated Kurdish as their preferred language of speaking, reading, and writing. This is not surprising as the language of education in this autonomous region is Kurdish, and the use of Arabic has declined there over the last two decades (Procházka, 2019). Four participants were educated in Arabic, besides Kurdish. Finally, for Lebanese Armenian, 19 of 21 speakers reported Arabic as their L2, while the two of them as L1 alongside Armenian.

The participants were recruited through the authors' personal networks and local contacts in respective countries, and all participants were paid an equivalent of 15 CAD for their participation.

## 2.2. Materials

The materials were real words with the fricatives /χ, ʁ, (ħ, ʕ,) h/ appearing in initial, medial and (when phonotactically possible) final positions. The target consonants were immediately adjacent to a low vowel. The full list of the stimuli is presented in **Table 2**. The word lists for each language were prepared by the first three authors who are native speakers of the respective languages (albeit the first and the second authors being speakers of different dialects of Kurdish and Arabic). For Iraqi Kurdish, this was done in consultation with a native language informant. Recall that Lebanese Armenian lacks pharyngeal fricatives, while Iraqi Kurdish does not permit /h/ in final position. This gave us 15 words for Emirati Arabic, 14 for Iraqi Kurdish, and 9 for Lebanese Armenian.[3]

The target words were embedded in a carrier phrase, provided for each language in **Table 3**. In all cases care was taken to select meaningful phrases where the target word receives primary focus. It was not possible, however, to control for the length of the phrases and some variation in

[3] While our goal was to select words where fricatives occurred in stressed syllables and in words of similar length, it was not always possible (and for Iraqi Kurdish in particular) due to lexical gaps. With respect to stress, the Emirati Arabic and Lebanese Armenian sets contained a single word with a target fricative in an unstressed syllable (with initial /ʁ/ for both), while the Kurdish set had four such words (with initial /χ, h/ and medial /ħ, ʕ/). The stimuli consisted of either monosyllabic or disyllabic words, except for occasional trisyllabic words: one in Arabic (with final /ʕ/) and Armenian (with initial /ʁ/), and two in Kurdish (with medial /ħ, ʕ/). This prosodic and word length variation could in principle affect the results, with fricatives in unstressed syllables, for example, having lower intensity and shorter duration. We will return to this question when presenting the results.

prosodic patterns across the languages.[4] In terms of phonetic contexts, target words in each case were preceded and followed by a bilabial stop (/b/, /p/, or /pʰ/) in order to minimize lingual coarticulation with fricatives. The words were presented in the respective language script.

| Position | Fricative | EA | IK | LA |
|---|---|---|---|---|
| Initial | /χ/ | /χasː/ 'lettuce' | /χaˈtɑ/ 'mistake' | /χatʧʰ/ 'cross' |
| | /ʁ/ | /ʁaˈsuːl/ 'soap' | /ʁam/ 'sadness' | /ʁazarˈjan/ 'Ghazarian' (Proper noun) |
| | /ħ/ | /ħasː/ 'he felt' | /ħaz/ 'like to' | -- |
| | /ʕ/ | /ˈʕasal/ 'honey' | /ʕaʃq/ 'affection' | -- |
| | /h/ | /hazː/ 'vibration | /haˈnɑr/ 'pomegranate' | /haz/ 'cough' |
| Medial | /χ/ | /ˈdaχal/ 'he entered' | /jaˈχa/ 'collar' | /gaˈχartʰ/ 'witch' |
| | /ʁ/ | /ˈraʁad/ 'Raghad' | /baˈʁam/ 'unhappy' | /gaˈʁantʰ/ 'Christmas' |
| | /ħ/ | /ˈlaħas/ 'he licked' | /baħasˈrat/ 'eager' | -- |
| | /ʕ/ | /ˈlaʕan/ 'he cursed' | /baʕaraˈbi/[5] 'in Arabic' | -- |
| | /h/ | /ˈsahar/ 'to stay up' | /baˈhaʃt/ 'heaven' | /vaˈhan/ 'shield' |
| Final | /χ/ | /ʔawˈsaːχ/ 'litter' | /doˈzaχ/ 'hell' | /tsʰaχ/ 'left (adj.)' |
| | /ʁ/ | /faˈraːʁ/ 'gap' | /sɑʁ/ 'safe' | /baʁ/ 'cold' |
| | /ħ/ | /timˈsaːħ/ 'crocodile' | /waħ/ 'revelation' | -- |
| | /ʕ/ | /itːiˈsaːʕ/ 'enlargement | /jaʕ/ 'yuck' | -- |
| | /h/ | /ɪkˈraːh/ 'coercion' | -- | /vəsˈdah/ 'sure' |

**Table 2:** Full lists of words with fricatives used in the study by position and by language with primary stress marked for polysyllabic words.

[4] Note that given the overall shorter carrier phrase in Arabic, we may expect longer duration of target fricatives than in the other two languages. As some Lebanese Armenian speakers pronounced utterances with a short pause before the target word, one may expect initial fricatives in such cases to be more prominent (showing longer duration, higher intensity, and/or COG).

[5] Note that due to lexical gaps in Kurdish, there were no common monomorphemic words in which /ʁ/, /ħ/ and /ʕ/ would occur between two identical, low vowels. Instead, common bimorphemic words that begin with these consonants were selected that host the /ba-/ prefix (as in /ba-ʕarabi/) rendering the target phoneme intervocalic.

| | |
|---|---|
| Emirati Arabic | اِكتب سهر برصاص<br>[aktɪb sah̲ar brasˤaːsˤ]<br>“Write ‘he stayed up’ in pencil.” |
| Iraqi Kurdish | له ڕێی دەزگای چاپ بەهەشت پرێنت کرا بوو<br>[la ri dazgɑj ʧɑp bah̲aʃt pɾint keɾɑ bo]<br>“The word ‘heaven’ was printed via a printer.” |
| Lebanese Armenian | Յակոբ, վահան բառը հի՛մա գրէ<br>[hagopʰ, vah̲an pʰaɾə hima kʰəɾɛ]<br>“Jacob, write the word ‘shield’ now!” |

**Table 3:** Sample sentences with target words used in the study by language.

## 2.3. Procedure

The sentences were randomized, and each sentence was presented three times to each participant. Audio recordings were performed using an online experiment platform, Gorilla (Anwyl-Irvine, Massonnié, Flitton, Kirkham, & Evershed, 2020). A sample Gorilla display with a stimulus is presented in **Figure 2**. The total number of collected tokens was 2424[6] (1032 for Emirati Arabic, 828 for Iraqi Kurdish, and 564 for Lebanese Armenian).

Participants were allowed to use a recording device of their choice. The experiment records showed that 24 participants used a computer (Emirati Arabic: 13 participants; Iraqi Kurdish: 3 participants; Lebanese Armenian: 8 participants) and 35 used a cell phone (Emirati Arabic: 5 participants; Iraqi Kurdish: 17 participants; Lebanese Armenian: 13 participants). The resulting sound files were saved as mp3 files, separately for each utterance.


**Figure 2**: A sample screenshot of a Gorilla display for the Iraqi Kurdish word /ʁam/ ‘sadness’.

[6] This number is somewhat higher than the expected 2217 tokens (38 words x 3 repetitions x 59 speakers), since some of the Emirati Arabic speakers produced more than three repetitions.

## 2.4. Annotation

The data were manually annotated in Praat (Boersma & Weenink, 2023), with boundaries set to indicate onsets and offsets of fricatives and adjacent vowels. A fricative onset was taken to be a clear appearance of random frication noise above 1000 Hz based on a spectrogram, with reference to the waveform; a fricative offset was taken to be the cessation of such noise. The voiced pharyngeal produced by Emirati Arabic and Iraqi Kurdish speakers, however, frequently lacked fricative noise, being realized as an approximant (91% of tokens for Emirati Arabic and 88% for Iraqi Kurdish; cf. Khattab et al., 2018). In this case, the consonant boundaries were estimated based on dips in intensity observed in the waveform. Sample annotations for the voiceless uvular in each language are shown in **Figure 3**. (Examples of annotations for all fricatives are given in the Appendix.)

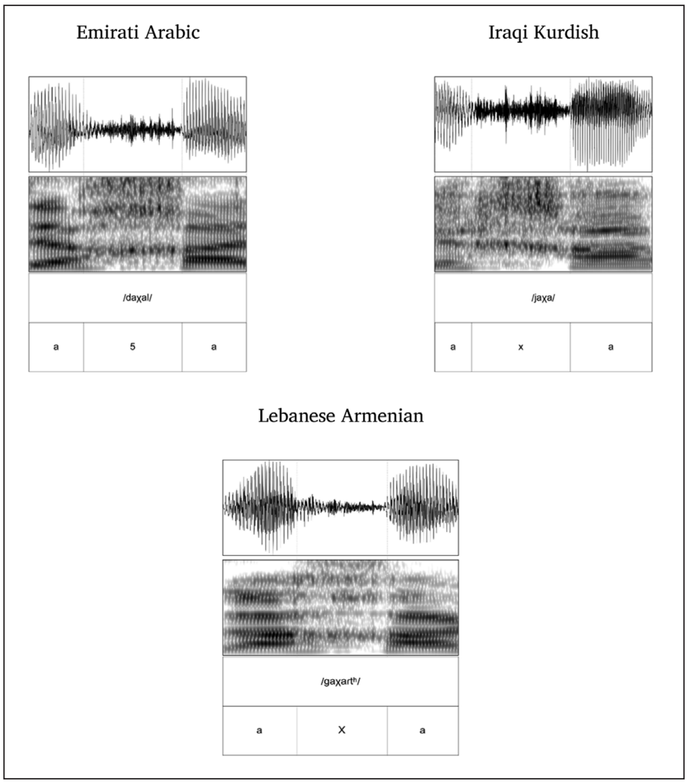


**Figure 3**: Sample annotations for medial /χ/ in three languages (speakers EAf01, IKf02, LAf19); the spectrogram frequency range is 0–7000 Hz.

## 2.5. Acoustic analysis

As mentioned above, one downside of collecting data online and having no control over speakers' choice of recording devices is that data would vary with respect to the frequency range of individual recordings. Our examination of all recordings revealed that the upper cut-off of frequency was between 7500 Hz and 15000 Hz (7500–15000 Hz for Emirati Arabic, 7850–15000 Hz for Iraqi Kurdish, and 7600–15000 Hz for Lebanese Armenian), with the average being 11411 Hz (12007 Hz for Emirati Arabic, 12099 Hz for Iraqi Kurdish, and 10126 Hz for Lebanese Armenian). This is in contrast to conventional in-person recordings (in the lab or in the field) using the upper limit of at least 22100 Hz (given the sampling rate of 44200 Hz). However, since the focus of this study is on fricatives characterized by concentrations of energy in low and mid frequencies, having less reliable higher frequency information was not considered to be a major drawback. Nevertheless, we decided to make the frequency range uniform for all speakers by filtering out the signal above 7500 Hz. (A comparison of filtered and unfiltered high frequency fricative noise data is further discussed in Section 4.3). We also filtered out the signal below 1000 Hz for spectral moments measurements (see below) in order to reduce their dependence on formants (cf. Lorenc, Żygis, Mik, Pape, & Sóskuthy, 2023), which can be relatively strong for voiced fricatives and /h/.

Measurements were automatically extracted from the middle 20% of each annotated fricative and included four spectral moments (using a pass Hann band 1000–7500 Hz; see above):

- Spectral center of gravity (COG, in Hz; also called centroid or the first spectral moment), which shows the mean frequency of the spectrum of the fricative weighted by its intensity and is known to correlate negatively with fricative place of articulation (with lower COG reflecting a more posterior place; Gordon et al., 2002).
- Standard Deviation (SD, in Hz; also called variance), which indicates how much frequencies in a spectrum deviate from COG (that is, a range of energy concentration for the sound).
- Skewness, which shows how much the shape of the spectrum below its COG is different from the shape above it, thus reflecting the tilt of the energy distribution (with positive values indicating a negative tilt, or more energy at lower frequencies).
- Kurtosis, which shows how much the shape of the spectrum around COG is different from the Gaussian shape, thus representing the relative peakedness of the spectrum (with positive values indicating higher peakedness or less flat distribution. (See the Praat manual for more details; Boersma & Weenink, 2023.)

Two other measurements were performed: relative intensity (in dB) and fricative duration (in sec). The former measurement was calculated as a difference between the intensity of adjacent vowels (preceding, following, or both) and the intensity of the fricative, with both taken at the mid 20% of the segment duration. Overall, all six measurements were performed on all annotated fricative tokens (n = 2424; see above), giving a total of 14544 data points for the analysis.

## 2.6. Statistical analysis

Data were analyzed using two kinds of linear mixed effects regression (LMER) models, performed using the lme4 package (Bates, Mächler, Bolker, & Walker, 2015) for R (R Core Team, 2022). The first set of models examined within-language differences in fricatives and included the fixed factors Consonant (five levels for Emirati Arabic and Iraqi Kurdish: /χ/, /ʁ/, /ħ/, /ʕ/, /h/; three levels for Lebanese Armenian: /χ/, /ʁ/, /h/), Position (initial, medial, final), and Gender (female, male). No interactions of Consonant with other factors were included, given the above-mentioned phonotactic gaps (in the case of Position) and in order to keep the outputs reasonably interpretable (in the case of Gender). The factors Consonant and Position were crucially related to our research questions. This is not the case for Gender, however, given the lack of clarity about its effects on guttural fricative noise (Gordon et al., 2002). We nevertheless decided to include this factor for exploratory reasons. Speaker was set as a random effect in these models, with a random intercept and a random slope by Consonant. Each model was performed separately for each variable (and separately by language), with a sample model being lmer(COG ~ Consonant + Position + Gender + (1 | Speaker), data_ea).[7] In each case, likelihood ratio tests were used to compare a full model to a nested model excluding the factor of interest, employing the Anova function of the lmerTest package (Kuznetsova, Brockhoff, & Christensen, 2017). Posthoc tests with a Bonferroni correction for multiple comparisons were performed for Consonant and Position using the phia package (De Rosario-Martinez, 2015). In pairwise Consonant comparisons, our focus will be on place contrasts for fricatives of the same voicing and voicing contrasts for fricatives of the same place (e.g. /χ/ vs. /ħ/ and /χ/ vs. /ʁ/, leaving out contrasts like /χ/ vs. /ʕ/).

The second set of models was performed separately for each place category (uvular, pharyngeal, and laryngeal /h/), comparing their realizations across the languages. The fixed factor was Language (three levels for uvulars and /h/: Emirati Arabic, Iraqi Kurdish, Lebanese Armenian; two levels for pharyngeals: Emirati Arabic, Iraqi Kurdish). Random factors were Voicing, Position, and Speaker — Voicing and Position were included as random factors given our primary focus at this stage on language differences. Again, each model was performed separately for each variable (and separately by place category), with a sample model being lmer (COG ~ language + (1 | voicing) + (1 | position) + (1 | speaker), data_uvular). Results of all LMER models were visualized using the ggplot2 package (Wickham, 2011).

We further used random forest analyses (Breiman, 2001) to determine the relative importance of acoustic variables for each language. This was done using the package party (Strobl, Malley, & Tutz, 2009) in R (R Core Team, 2022). The random forests method produces large sets ('forests') of conditional inference trees seeking to predict which variables (adjusted for collinearity) are most probable in accounting for the data (see Tagliamonte & Baayen, 2012 for a detailed

[7] Our initial attempt to include by-speaker random slopes for Consonant and/or Position produced errors. Note also that no random intercepts or slopes for Word were included, since we only had one word item per consonant.

description). Each conditional inference tree provides estimates of the likelihood of the value of the response variable (e.g., uvular vs. laryngeal) based on a series of binary questions about the values of predictor variables (e.g., COG, SD, duration). Predictions for each tree are made based on a random subset of the data and are further generalized to a final tree. An example of such a tree is shown in **Figure 4**, based on a subset of our data (Lebanese Armenian /χ/ vs. /h/). It shows that the algorithm recursively splits the data into clusters finding SD, duration, and – to a lesser extent – kurtosis (based on *p*-values) as useful predictors for distinguishing the contrast. A sample full model for a random forest analysis is la.cforest = cforest(C ~ COG + SD + skewness + kurtosis + rel_intensity + duration, data = data_la). The random forests analyses were run on the same data as for LMER models (a total of 14544 tokens).

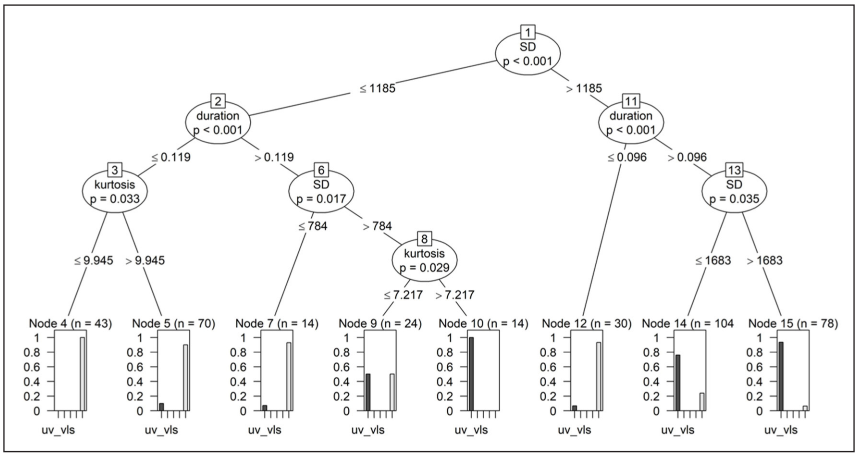


**Figure 4**: A sample conditional inference recursive partitioning tree for a subset of the data: The Lebanese Armenian voiceless uvular (uv_vls) vs. laryngeal (lar_vls) contrast.

## 3. Results

We will begin this section with an illustration of spectral patterns for each fricative in the data. This is followed by quantitative analyses across fricatives separately for each language in Section 3.1 and across languages for specific fricative categories in Section 3.2. The section is concluded with an evaluation of relative importance of variables in Section 3.3.

### 3.1. An overview of spectral patterns

**Figure 5** presents Fast Fourier Transform (FFT) spectra of representative tokens for each fricative by language (measured around the midpoint). Beginning with voiceless fricatives, we can see that the uvular /χ/ in all three languages shows a very prominent low-frequency peak, as well as lesser defined concentrations of energy at higher frequencies. The voiceless pharyngeal /ħ/ in Emirati Arabic and Iraqi Kurdish is characterized by two peaks of similar intensity towards lower frequency, with some energy at medium frequency and a drop-off at higher frequency.

The spectra for the laryngeal /h/ in Emirati Arabic and Lebanese Armenian are generally flat, apart from the intensity boost at the lowest frequency. The /h/ in Iraqi Kurdish, however, shows more prominence in low-to-medium frequencies. Voiced fricatives show overall similar patterns to their voiceless counterparts. Of note is a more abrupt decrease in energy at higher frequencies for the pharyngeal /ʕ/ (compared to /ħ/). How these spectral differences are manifested in terms of spectral moments across the full dataset will be examined in the next sections.

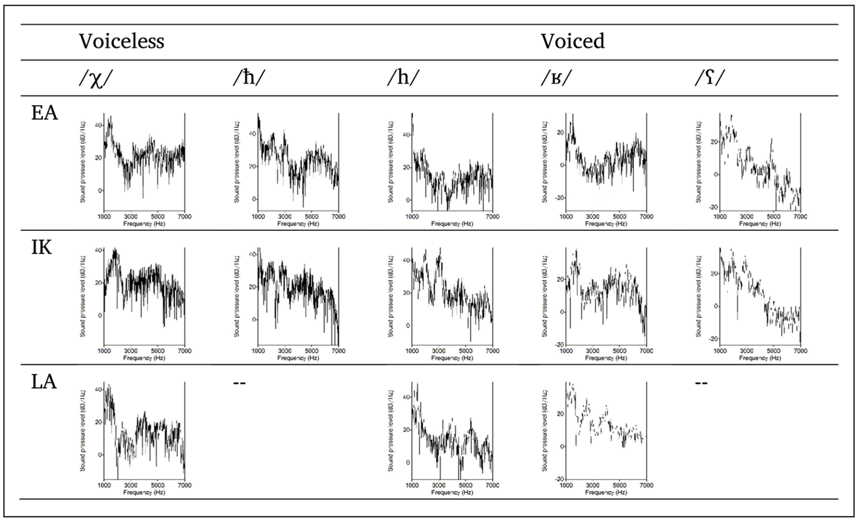


**Figure 5:** Sample FFT spectra for fricatives in three languages by voicing and place (speakers EAf01, IKf02, LAf19).

## 3.2. Fricative contrasts by language

### 3.2.1. Emirati Arabic

LMER models with fixed factors Consonant, Position, and Gender (without interactions) and random factors Speaker (with random slopes by Consonant) were performed for each of the six variables. Significant effects of Consonant were obtained for all of them: COG, SD, kurtosis, skewness, relative intensity, and duration (all $p < 0.001$). Pairwise comparisons for consonant pairs were examined using t-tests with a Bonferroni correction. The results of these in terms of Place (for either voiceless or voiced fricatives) and Voicing (for fricatives of the same place) are summarized in **Table 4**. These and other differences can be observed in **Figure 6**. (For full outputs of model comparisons, see the Supplementary Materials file.)

Considering place differences first, uvulars were distinguished from pharyngeals by a higher COG and SD, and a lower skewness and lower kurtosis (for voiced only). The voiceless uvular /χ/ was distinguished from the voiceless laryngeal /h/ by a higher COG and SD, a lower skewness, and a shorter duration. The voiceless pharyngeal /ħ/ was distinguished from /h/ by a higher SD and a longer duration. That is, the COG and SD differences showed a reduction in values from the more anterior to the more posterior fricatives; uvulars in general showed lower skewness and kurtosis, as well as a lower intensity than the more posterior fricatives. There were no other significant differences in Place.

Considering voicing, voiceless uvulars and pharyngeals were characterized by a higher COG, kurtosis, and skewness, a longer duration, and a lower SD, compared to their voiced counterparts. There were no other significant differences in Voicing. Significant effects of Position were limited to COG ($p < 0.05$), relative intensity ($p < 0.001$), and duration ($p < 0.001$). Posthoc tests revealed that fricatives in medial position had a lower COG and duration, and a higher intensity than their initial counterparts.[8] In addition, final fricatives had a lower intensity and longer duration than their counterparts in the other two positions. There was no significant effect of Gender for any of the variables, indicating that Consonant and Position differences described above were in general shared by female and male speakers.

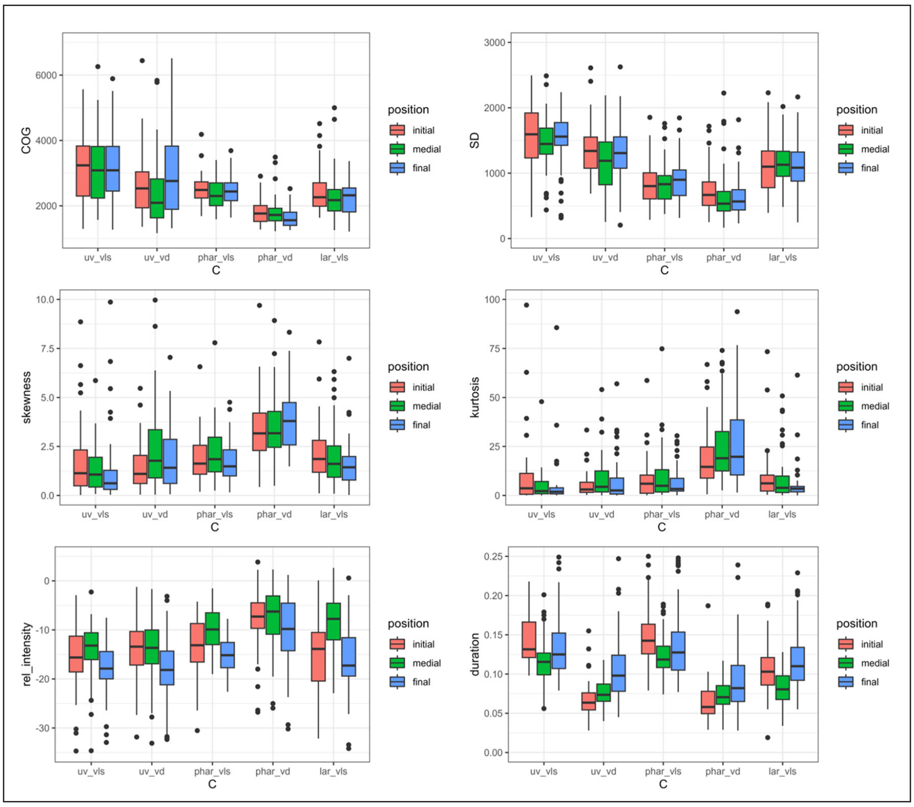


**Figure 6**: Boxplots for fricatives produced by Emirati Arabic speakers: COG (Hz), Standard Deviation (SD, Hz), skewness, kurtosis, relative intensity (dB), and duration of fricative noise by consonant (uvular voiceless /χ/, uvular voiced /ʁ/, pharyngeal voiceless /ħ/, pharyngeal voiced /ʕ/, and laryngeal voiceless /h/) and position (initial, medial, and final).

[8] Note that unlike the other fricatives, initial /ʁ/ in our stimuli occurred in an unstressed syllable (see footnote 4). This did not, however, seem to affect its patterning compared to the other uvular or voiced fricatives. For example, initial /ʁ/ showed lower duration than its medial and final counterparts – the pattern that was similar to initial /ʕ/. Similarly, there is no evidence of the higher number of syllables in the target word with medial /ʕ/ resulting in a shorter duration of the sound.

| Variable | Place | | | | Voicing | |
|---|---|---|---|---|---|---|
| | uv. vs. phar. | | uv. vs. lar. | phar. vs. lar. | vls. vs. vd. | |
| | vls. | vd. | vls. | vls. | uv. | phar. |
| COG (Hz) | χ > ħ*** | ʁ > ʕ*** | χ > h*** | -- | χ>ʁ*** | ħ > ʕ*** |
| SD (Hz) | χ > ħ*** | ʁ > ʕ*** | χ > h*** | h > ħ*** | χ>ʁ*** | ħ > ʕ*** |
| skewness | ħ > χ*** | ʕ > ʁ*** | h > χ*** | -- | ʁ>χ*** | ʕ > ħ*** |
| kurtosis | -- | ʕ > ʁ*** | -- | -- | -- | ʕ > ħ*** |
| rel. intensity (dB) | ħ > χ*** | ʕ > ʁ*** | -- | -- | -- | ʕ > ħ*** |
| duration (sec) | -- | -- | χ > h*** | h > ħ*** | χ>ʁ*** | ħ > ʕ*** |

**Table 4:** Results of pairwise consonant comparisons for Emirati Arabic by place and voicing; vls.: voiceless, vd.: voiced, uv.: uvular, phar.: pharyngeal, lar.: laryngeal; >: greater than; ***: $p < 0.001$, **: $p < 0.01$, *: $p < 0.05$, --: not significant.

### 3.2.2. Iraqi Kurdish

LMER models similar to those for Emirati Arabic were performed for each of the six variables of fricatives produced by Iraqi Kurdish speakers. Significant effects of Consonant were obtained for all of them: COG, SD, kurtosis, skewness, relative intensity, and duration (all $p < 0.001$). Results of pairwise comparisons in terms of Place and Voicing are summarized in **Table 5**. These and other differences can be observed in **Figure 7**. (See the Supplementary Materials file for further details.)

For place, uvulars were distinguished from pharyngeals by a higher COG and SD, and a lower skewness (voiced only), kurtosis (voiced only), and relative intensity, as well as by shorter duration. The voiceless uvular /χ/ was distinguished from the voiceless laryngeal /h/ by a higher COG and SD, and a longer duration. The voiceless pharyngeal /ħ/ was distinguished from /h/ by a lower SD and a longer duration. That is, the COG and SD differences showed a reduction in values from the more anterior to the more posterior fricatives, with the exception of SD for the /ħ/ vs. /h/ contrast. Uvulars tended to show a lower relative intensity than pharyngeals. The laryngeal /h/ showed the shortest duration among voiceless fricatives.

In terms of voicing, differences mostly involved pharyngeals: The voiceless /ħ/ had a higher COG, a lower skewness, kurtosis, and relative intensity, as well as a longer duration than /ʕ/. Significant differences between the two uvulars were limited to duration, with the voiceless /χ/ being longer than /ʁ/. Significant effects of Position were observed only for duration: final fricatives were longer than initial ($p < 0.001$) and medial fricatives ($p < 0.05$).[9] Significant

[9] Recall that, in contrast to the other consonants/positions, initial /χ, h/ and medial /ħ, ʕ/ occurred in our stimuli in unstressed syllables, while medial /ħ, ʕ/ occurred in trisyllabic words (see footnote 4). It is not clear from **Figure 6** if stress and the number of syllables had any influence on the realization of fricatives.

Gender effects were found for skewness and duration. Values for the former variable were higher for male speakers ($p < 0.01$), while the reverse was observed for the latter one ($p < 0.05$).

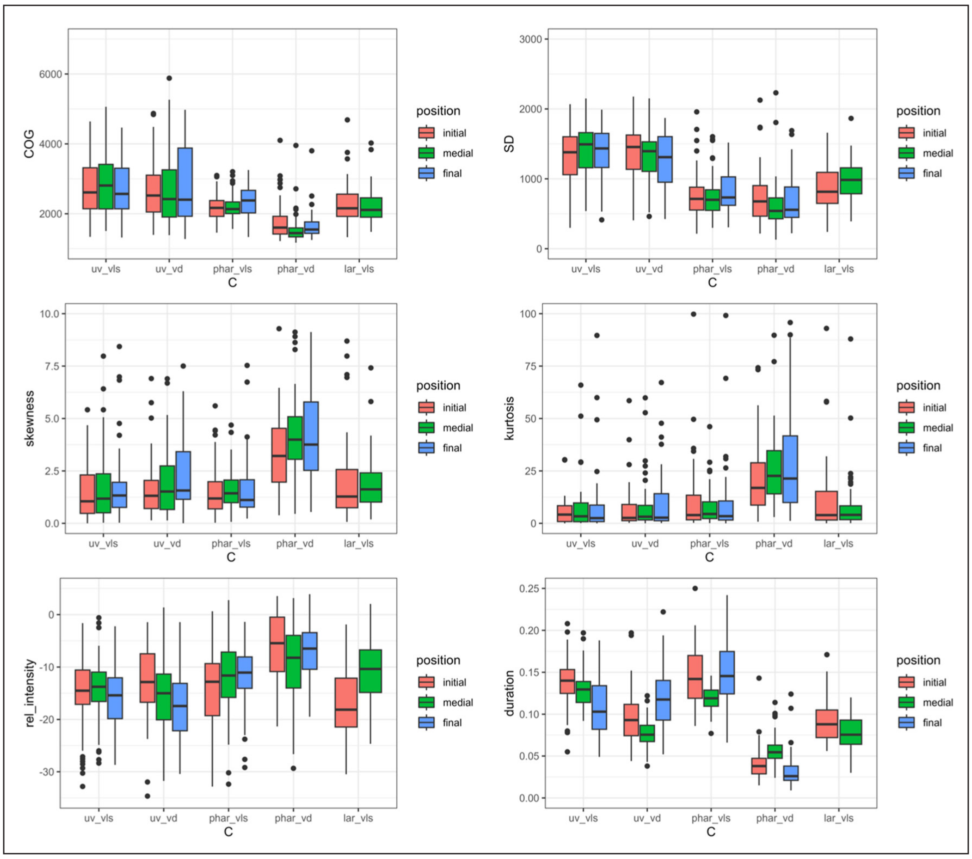


**Figure 7**: Boxplots for fricatives produced by Iraqi Kurdish speakers: COG (Hz), Standard Deviation (SD, Hz), skewness, kurtosis, relative intensity (dB), and duration of fricative noise by consonant (uvular voiceless /χ/, uvular voiced /ʁ/, pharyngeal voiceless /ħ/, pharyngeal voiced /ʕ/, and laryngeal voiceless /h/) and position (initial, medial, final).

The results for Iraqi Kurdish fricatives were, in many respects, similar to those consonants in Emirati Arabic. Specifically, uvulars and pharyngeals in both languages were distinguished by COG, SD, and relative intensity, with voiced fricatives also showing differences in kurtosis and skewness. The laryngeal /h/ in both languages was differentiated from the other voiceless fricatives by SD and, in the case of uvulars, by COG and duration. Both languages distinguished the voicing contrast by duration. Unlike Emirati Arabic, however, Iraqi Kurdish showed additional duration differences (for voiceless uvular vs. pharyngeal and laryngeal), while not showing significant differences in skewness for some of the contrasts, and showing hardly any voicing contrasts in uvulars. Iraqi Kurdish also showed fewer positional differences than Emirati Arabic.

| Variable | Place | | | | Voicing | |
|---|---|---|---|---|---|---|
| | uv. vs. phar. | | uv. vs. lar. | phar. vs. lar. | vls. vs. vd. | |
| | vls. | vd. | vls. | vls. | uvul. | phar. |
| COG (Hz) | χ > ħ*** | ʁ > ʕ*** | χ > h*** | -- | -- | ħ > ʕ*** |
| SD (Hz) | χ > ħ*** | ʁ > ʕ*** | χ > h*** | h > ħ* | -- | -- |
| skewness | -- | ʕ > ʁ*** | -- | -- | -- | ʕ > ħ*** |
| kurtosis | -- | ʕ > ʁ*** | -- | -- | | ʕ > ħ*** |
| relative intensity (dB) | ħ > χ* | ʕ > ʁ*** | -- | -- | -- | ʕ > ħ*** |
| duration (sec) | ħ > χ*** | -- | χ > h*** | ħ > h*** | χ > ʁ*** | ħ > ʕ*** |

**Table 5:** Results of pairwise consonant comparisons for Iraqi Kurdish by place and voicing; vls.: voiceless, vd.: voiced, uv.: uvular, phar.: pharyngeal, lar.: laryngeal; >: 'greater than'; ***: p < 0.001, **: p < 0.01, *: p < 0.05, --: not significant.

### 3.2.3. Lebanese Armenian

Finally, we ran similar LMER models for Lebanese Armenian fricatives. Recall that these involved only one place contrast (of the same voicing, /χ/ vs. /h/) and one voicing contrast (of the same place, /χ/ vs. /ʁ/). Significant effects of Consonant were obtained for all variables (all $p < 0.001$) except for relative intensity. Results of pairwise comparisons in terms of Place and Voicing are summarized in **Table 6**. These and other differences can be observed in **Figure 8**. Considering place, the uvular /χ/ was distinguished from /h/ by a higher COG and SD, a lower skewness and kurtosis, and a longer duration. Among the two uvulars, the voiceless /χ/ was distinguished from its voiced counterpart /ʁ/ by a higher COG and SD, a lower skewness, and a longer duration. Finally, all variables exhibited significant effects of Position. Fricatives in medial position showed a lower COG and SD, a higher skewness and relative intensity, and a shorter duration than their initial and/or final counterparts ($p < 0.05$–$0.001$).[10] In addition, final fricatives showed a lower kurtosis, a higher relative intensity, and a longer duration than initial fricatives ($p < 0.05$–$0.001$). Significant Gender effects were found for several variables. Compared to males, females showed higher COG and SD, and lower skewness and kurtosis values (all $p < 0.05$).

[10] Recall that initial /ʁ/ was the only case of a fricative occurring in an unstressed syllable and in a trisyllabic word (see footnote 4). This did not seem to matter in terms of the sound's acoustic characteristics, as it was similar overall to either its medial or final counterpart. Similarly, there was no clear acoustic effect of occasional pauses before the target word in Armenian utterances (see footnote 6).

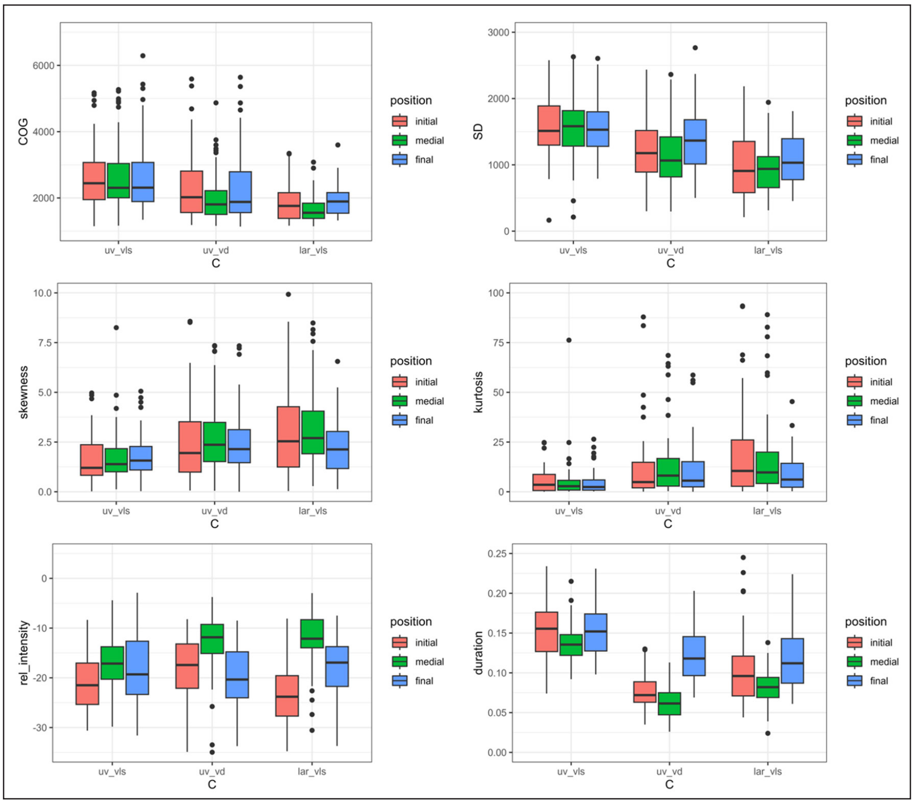


**Figure 8**: Boxplots for fricatives produced by Lebanese Armenian speakers: COG (Hz), Standard Deviation (SD, Hz), skewness, kurtosis, relative intensity (dB), and duration of fricative noise by consonant (uvular voiceless /χ/, uvular voiced /ʁ/, and laryngeal voiceless /h/) and position (initial, medial, final).

| Variable | Place | Voicing |
|---|---|---|
| | **uv. vs. lar.** | **vls. vs. vd.** |
| | **vls.** | **uv.** |
| COG (Hz) | χ > h*** | χ > ʁ*** |
| SD (Hz) | χ > h*** | χ > ʁ*** |
| skewness | h > χ*** | ʁ > χ*** |
| kurtosis | h > χ* | -- |
| relative intensity (dB) | -- | -- |
| duration (sec) | χ > h*** | χ > ʁ*** |

**Table 6**: Results of pairwise consonant comparisons for Lebanese Armenian by place and voicing; vls.: voiceless, vd.: voiced, uv.: uvular, lar.: laryngeal; >: 'greater than'; ***: $p < 0.001$, **: $p < 0.01$, *: $p < 0.05$, --: not significant.

Like Emirati Arabic and Iraqi Kurdish, Lebanese Armenian distinguished the voiceless uvular and laryngeal using COG, SD, skewness (Emirati Arabic only), and duration, while also showing an additional difference in kurtosis. The voicing difference in Lebanese Armenian was manifested by the same variables as for Emirati Arabic: COG, SD, skewness, and duration (which differed from Iraqi Kurdish that showed only the duration difference).

Similar to the other two languages, Lebanese Armenian showed positional differences in duration differences, with final fricatives for all three languages being the longest and medial ones being the shortest. Like Emirati Arabic, Lebanese Armenian showed a higher COG and lower relative intensity for initial fricatives and higher relative intensity for medial fricatives. In addition, Lebanese Armenian showed positional differences in SD, kurtosis, and skewness, indicative of the overall greater positional variation compared to the other two languages.

## 3.3. Fricatives across languages

LMER models with the fixed factor Language and random factors Voicing, Position, and Speaker (with random slopes by Consonant) were performed separately for each consonant place, separately for each of the six variables. The analyses for uvulars (combined /χ/ and /ʁ/) and /h/ were based on three languages, while the analyses for pharyngeals were based on two languages (Emirati Arabic and Iraqi Kurdish).

A summary of the results is provided in **Table 7**. The results for uvulars showed no significant Language differences apart from relative intensity ($p < 0.05$): fricatives in Lebanese Armenian were less loud (compared to the adjacent vowels) than their counterparts in the other two languages (both $p < 0.05$). It should be noted that although COG differences were not significant, values for voiceless uvulars in Emirati Arabic were, on average, higher than for the other languages (by about 150–200 Hz). The results for pharyngeals showed significant effects of Language for COG ($p < 0.05$) and Duration ($p < 0.001$): Emirati Arabic speakers produced these fricatives with a higher COG and longer duration than Iraqi Kurdish speakers. Finally, the results for the laryngeal /h/ showed significant effects of COG ($p < 0.05$), skewness ($p < 0.001$), kurtosis ($p < 0.01$), and relative intensity ($p < 0.001$). This fricative produced by Lebanese Armenian speakers showed lower COG (both $p < 0.001$) and relative intensity ($p < 0.05$–$0.001$), as well a higher skewness (both $p < 0.001$) and kurtosis (both $p < 0.001$) than /h/ produced by Emirati Arabic and Iraqi Kurdish speakers. There were no other significant effects.

In summary, most language differences were found in the realization of the laryngeal /h/ and juxtaposed Lebanese Armenian speakers with the Emirati Arabic and Iraqi Kurdish speakers. There were hardly any language differences in the realization of uvulars, apart from the lower intensity of these consonants for Lebanese Armenian speakers. Pharyngeals in Emirati Arabic and Iraqi Kurdish were also relatively similar, yet with some differences in COG and duration.[11]

| Variable | uvulars | pharyngeals | laryngeals |
|---|---|---|---|
| | /χ/ and /ʁ/ | /ħ/ and /ʕ/ | /h/ |
| COG | -- | EA > IK* | EA > LA***, IK > LA*** |
| SD | -- | -- | -- |
| skewness | -- | -- | LA > EA***, LA > IK*** |
| kurtosis | -- | -- | LA > EA***, LA > IK*** |
| relative intensity (dB) | EA*, IK* > LA | -- | EA > LA***, IK > LA* |
| duration (sec) | -- | EA > IK*** | -- |

**Table 7:** Results of pairwise consonant comparisons for fricative categories across languages; EA: Emirati Arabic, IK: Iraqi Kurdish, LA: Lebanese Armenian; >: greater than; ***: $p < 0.001$, **: $p < 0.01$, *: $p < 0.05$, --: not significant.

### 3.4. Relative importance of variables

Random forests analyses were performed separately for each language, as well as across the three languages. The results of variable importance are illustrated in **Figure 9**. We can see that the most important (i.e., most informative, capable of distinguishing most contrasts) variable for Emirati Arabic was Standard Deviation (SD), followed by duration (sec) and then COG (Hz). The other variables – relative intensity, skewness, and kurtosis – were considerably less important. For Iraqi Kurdish, duration was most important, followed by SD, and at a considerable distance by skewness and the other variables. For Lebanese Armenian, duration and SD were also the top two variables, followed at a distance by COG and the other two variables. For the entire dataset (where Emirati Arabic tokens were most numerous), SD and duration were the top two predictors of the fricative contrasts, followed – in reducing importance – by COG, relative intensity, skewness, and kurtosis.

It should be noted that these analyses were performed to predict consonant categories, some of which involved place and some voicing. Running a random forests analysis for place categories (on the full data set) showed a greater importance of COG and relative intensity (while still distant in importance from SD) compared to duration. A random forests analysis for voicing, on the other hand, showed a dominance of duration, followed distantly by COG, SD, and then the other variables. Thus, overall, we can conclude that SD, duration, and COG were most crucial

[11] We expected Emirati Arabic fricatives in our data to be somewhat longer given the overall shorter utterances (see Table 4; footnote 6). This effect, however, was not found in most of the comparisons.

to distinguishing fricatives across three languages, with SD and COG being more important for place, and duration being more important for voicing.

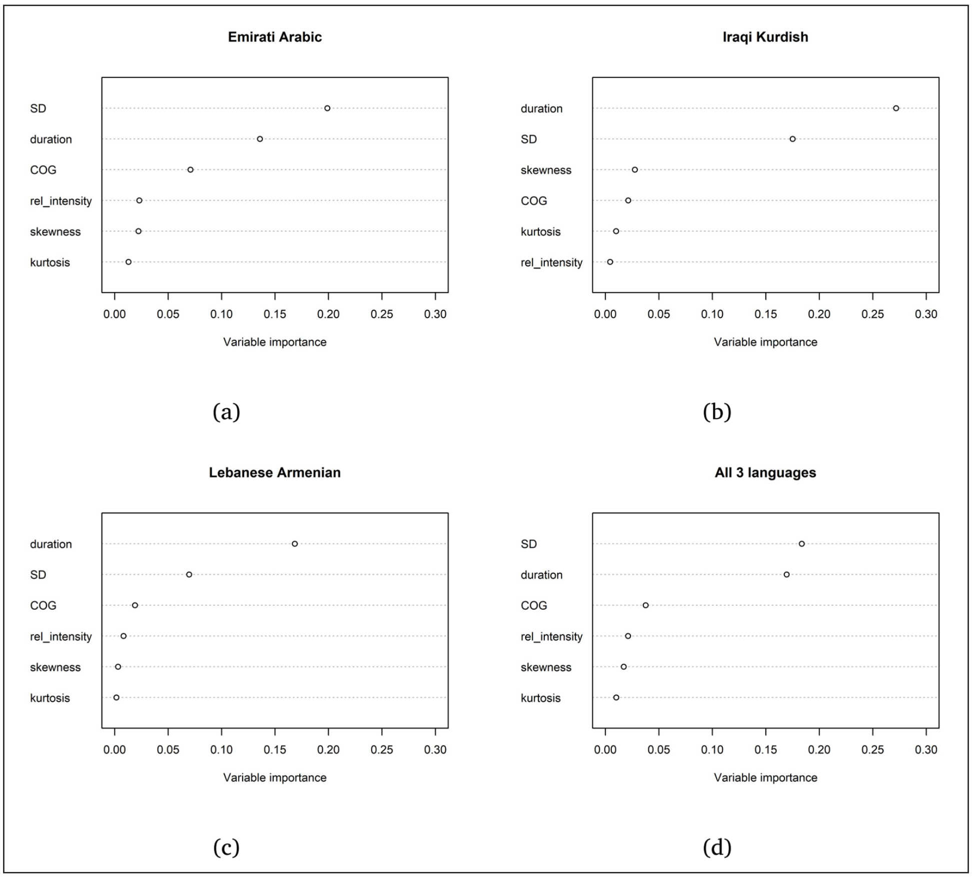


**Figure 9:** Conditional permutation variable importance for random forest analyses predicting consonant categories for (a) Emirati Arabic, (b) Iraqi Kurdish, (c) Lebanese Armenian, and (d) for the entire data set.

# 4. Discussion and conclusion

## 4.1. Summary of results

The main goal of this study was to provide a cross-language investigation of guttural fricatives across different positions in three languages – Emirati Arabic, Iraqi Central Kurdish, and Lebanese Western Armenian – in order to contribute to a better understanding of the cross-linguistic typology and phonological patterning of these sounds. A secondary goal was to assess the validity of the online data collection for the acoustic analysis of fricatives. Our analysis of fricative contrasts involved measurements of four spectral moments, relative intensity, and duration, evaluated statistically using linear mixed effects regression models and random forests.

The results revealed that all place and voicing contrasts in fricatives across the languages were reliably differentiated by the selected acoustic variables. In terms of place, the uvular-pharyngeal contrast was consistently distinguished by COG, SD, and relative intensity, as well as partly by skewness (for Emirati Arabic and for voiced fricatives in Iraqi Kurdish), kurtosis (for voiced fricatives), and duration (for voiceless fricatives in Iraqi Kurdish). The uvular-laryngeal contrast was consistently distinguished by COG, SD, and duration, as well as partly by skewness (for Emirati Arabic and Lebanese Armenian), and kurtosis (for Lebanese Armenian). The pharyngeal-laryngeal contrast was consistently distinguished by SD and duration.

In terms of voicing, this contrast in uvulars was consistently distinguished by duration, and partly by COG, SD, and skewness (all for Emirati Arabic and Lebanese Armenian). Voicing in pharyngeals was consistently distinguished by COG, kurtosis, skewness, relative intensity, and duration, as well as partly by SD (for Emirati Arabic). This can be at least partly attributed to the frequent approximant-like realization of /ʕ/.

Based on LMER models, the variables SD, COG, and duration were most informative for differentiating fricative contrasts, while relative intensity, kurtosis, and skewness were considerably less informative. This was consistent with our evaluation of acoustic variables using random forests: COG, duration, and particularly SD were most successful at predicting consonant categories. Interestingly, SD did not differentiate the languages from each other (while the other variables did, at least for some contrasts). This suggests that SD is the most suitable variable for characterizing the examined fricative contrasts.

With respect to differences among the languages, most of those involved /h/ in Lebanese Armenian, which unlike Emirati Arabic and Iraqi Kurdish, was produced with a lower COG and relative intensity and a higher skewness and kurtosis. Lower intensity was also observed for the Lebanese Armenian uvulars. The source of these differences is unclear, but perhaps they reflect a weaker, more vocalic realization of /h/ and a more posterior location of the uvulars in Lebanese Armenian. Remarkably, the way uvulars and pharyngeals were produced in Emirati Arabic and Iraqi Kurdish was very similar, at least based on our measurements. The only language differences were in COG and duration for pharyngeals, indicating a more posterior and longer constriction in Iraqi Kurdish.

Some positional differences were also found. Namely, word-medial fricatives in Emirati Arabic and Lebanese Armenian showed higher relative intensity, lower COG, and shorter duration than their counterparts in initial and/or final positions. Positional differences were minimal in Iraqi Kurdish, being limited to duration; they were most extensive in Lebanese Armenian, involving almost all phonetic variables. It should be noted that many of these differences are indicative of lenition of fricatives in medial or final positions, thus confirming the cross-linguistic tendencies in this process (e.g., Hualde, Lujanbio & Zubiri, 2010; Henriksen

& Harper, 2016). Gender differences in the production of fricatives were rather inconsistent, being absent in Emirati Arabic, present for just two variables (skewness and duration) in Iraqi Kurdish, and manifested by almost all variables (except relative intensity and duration) in Lebanese Armenian. It appears that gender differences in the production of guttural fricatives are largely language-specific.

## 4.2. Comparison with previous studies

The results obtained in this study are remarkably similar to many previous findings for Arabic (see Section 1.1). Taking voiceless fricatives, for example, we see in **Figure 10** that COG values reported in several previous studies of Arabic fricatives (Norlin, 1983; Al-Khairy, 2005; Abu-Al-Makarem, 2005; Al-Tamimi & Khattab, 2015) were lower for pharyngeals and laryngeals; the same was observed for a previous investigation of Eastern and Western Armenian by Tahtadjian (2023). The results obtained for Emirati Arabic, Iraqi Kurdish, and (in part) Lebanese Armenian in this study showed essentially the same effects. The lower COG for /h/ in our results is also consistent with the findings of Abu-Al-Makarem (2005). Note also that there is considerable agreement in mean values for the fricatives across the studies, despite the very different recording conditions and signal filtering procedures. Similarly, our results for general spectral patterns, SD, and duration, and to some extent those for skewness and kurtosis, are in line with previous studies of gutturals in Arabic and other languages (Nartey, 1982; Gordon et al., 2002; Hargus et al., 2021).

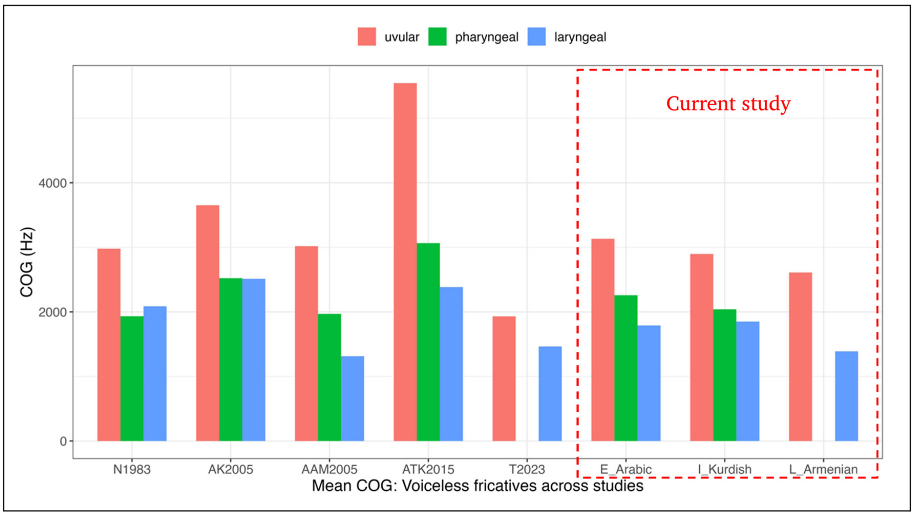


**Figure 10:** A comparison of mean COG (Hz) values across previous studies of Arabic voiceless fricatives (see text) and current results (N1983: Norlin, 1983; AK2005: Al-Khairy, 2005; AAM2005: Abu-Al-Makarem, 2005; ATK2015: Al-Tamimi & Khattab, 2015; T2023: Tahtadjian, 2023).

The current results, therefore, provide evidence for the overall similar acoustic properties of guttural consonants in three different languages – Emirati Arabic, Iraqi Central Kurdish, and Lebanese Western Armenian – thus contributing to the phonetic typology of fricative contrasts. Having said that, we cannot discount the possibility that the production of fricatives by our Iraqi Kurdish and Lebanese Armenian speakers had been influenced by local varieties of Arabic. This may be the case particularly for the latter group, given their extensive use of Lebanese Arabic. Further work is needed to tease apart possible language contact effects by examining the production of Iraqi Kurdish and Western Armenian fricatives vis-à-vis similar consonants in Iraqi and Lebanese Arabic, by both bilingual and monolingual speakers.

One outstanding question is whether the Emirati Arabic, Iraqi Kurdish, and Lebanese Armenian fricatives referred here as uvulars (/χ, ʁ/) are indeed produced at the uvula or the velum, as suggested in some previous works (see Section 1.4). Based on our spectral analyses, these fricatives (/χ, ʁ/) are comparable to uvulars in other languages (cf. Hargus et al., 2021); furthermore, uvular fricatives examined in this study have auditory properties similar to those in other languages. Yet, it is worth noting that differences between uvulars and velars were not always successfully established through spectral analysis (Gordon et al., 2002). As the next step, it would be useful to examine formant transitions for uvulars in the three languages and compare those to other uvular (the stop /q/) and velar sounds. Future work should also extend speech materials to other vowel contexts and multiple lexical items. In addition, more can be done for examining cross-language variation in guttural fricatives by combining acoustic analysis with ultrasound tongue imaging (cf. Tahtajian, 2023).

## 4.3. Phonetics vs. phonology of gutturals

Our finding that guttural fricatives in three languages are largely similar phonetically runs against the fact that these sounds do not pattern the same way in each of these languages. As mentioned in Section 1.5, the Arabic /χ, ʁ, ħ, ʕ, h/ are part of a larger segmental class including the stops /q, ʔ/ and coronal pharyngealized consonants (Watson, 2007). As McCarthy (1994) shows, gutturals in Arabic (and Semitic in general) pattern together in multiple processes, including the lowering adjacent vowels, avoiding coda position, and exhibiting strong co-occurrence restrictions in roots (OCP) (cf. Frisch et al., 2004). This shared behavior is attributed to these segments being specified for the same place feature, [pharyngeal] or [RTR] (McCarthy, 1994; Shahin, 2003; Watson, 2007). While somewhat similar consonant-to-vowel assimilatory effects have been reported for Kurdish varieties (as vowel lowering and backing: Kahn, 1976; as a phonotactic preference: Barry, 2019), these involve pharyngeals only. Uvulars (which also include /q/) do not pattern with pharyngeals as a class, showing no assimilatory effects on vowels. Pharyngeals do, however, exhibit some affinity with laryngeals (/h, ʔ/), appearing with those in free variation under certain conditions (Kahn, 1976). In contrast to Kurdish uvulars (but similarly to uvulars in Arabic), these sounds in Armenian can lower and/or back adjacent vowels (as been reported for some dialects). This prompted Vaux (1998) to specify these consonants for the features [+back, -high, -ATR]. These sounds do not pattern together with the laryngeal /h/, which acts as placeless. Furthermore, there have been no reports of lexical co-occurrence restrictions involving gutturals in either Kurdish[12] or Armenian, thus additionally pointing to the relative phonological dissimilarity of the respective places of articulation. Altogether, what this shows is that there is a mismatch between the phonetics and phonology of guttural sounds: Their relatively similar phonetic realizations across three languages correspond to rather different phonological sets of contrasts and behaviors. This, in turn, underscores the relative independence of phonetics and phonology, and particularly the indirect mappings between distinctive features and acoustic properties of sounds. This state of affairs, however, may not be surprising if we assume that features represent emergent language-particular generalizations over acoustic/articulatory sensory maps and patterns in the lexicon (cf. Mielke, 2008).

## 4.4. Advantages and limitations of online data collection

One clear advantage of the online data collection adopted in this study was being able to target speakers of lesser studied languages residing in their home countries. It would have been clearly difficult, if not impossible, to find dozens of speakers of the examined languages (and reasonably control for age, gender, and dialect) anywhere in North America. One disadvantage of this method, however, is the reduced quality and variability of recordings obtained online, as has been previously observed in a number of studies (Ge, et al., 2021; Freeman & Decker, 2021; Sanker et al., 2021).

As mentioned in Section 2.5, our speakers used their own devices to make recordings, with over half of the speakers making recordings on their cell phones. Given the different settings for different device types, frequency ranges for the recorded data were inevitably different. For our analysis, we chose to adopt the lowest frequency cut-off in our sample to all speakers' data (7500 Hz). One question arises is how this could have affected the results, specifically for spectral moments. To examine this, we compared the currently used values for COG and SD for each fricative (separately for each language) to the corresponding original values of these moments prior to the upper limit frequency filtering. These results are summarized in **Table 8** in the Appendix. As one would expect, both COG and SD averages were reduced by the filtering procedure. The COG reduction was on average 253 Hz for Emirati Arabic, 250 Hz for Iraqi Kurdish, and 168 Hz for Lebanese Armenian (where the frequency range was originally the lowest). In all cases, the reduction was greater for uvulars, which are in general characterized

[12] An exception to this is a restriction on having two pharyngeal(ized) consonants within a word, as reported by Kahn (1976) for Northern Kurdish.

by a higher COG. The SD reduction was on average 434 Hz for Emirati Arabic, 497 Hz for Iraqi Kurdish, and 329 Hz for Lebanese Armenian. This reduction affected voiceless fricatives to a greater extent than voiced ones. Overall, this shows that the use of devices with lower frequency cut-off has a tangible effect on spectral moments measurements, and this effect can be different depending on the fricative's place and voicing. Nevertheless, it is important to note that even with a reduced frequency range, we obtained significant results for most fricative contrasts, and these effects were similar to those reported in previous studies. One would expect an even greater differentiation of these sounds if we had selected participants using devices with the largest frequency range (0–15000 Hz). Future work should aim to ensure the use of higher frequency devices, particularly if the focus is on more anterior fricatives, such as sibilants.

To conclude, the increasing availability of online platforms has a clear potential to facilitate data collection from participants residing in diverse geographical locations, allowing for a broader representation of speakers and linguistic varieties. This study serves as an initial contribution to a more extensive cross-linguistic phonetic documentation of guttural fricatives by covering new languages/varieties and using relatively large speaker samples. This study also serves to confirm the validity of the online audio recording method for acoustic analysis, which has been increasingly used in phonetics since the pandemic of COVID-19.

## Appendix

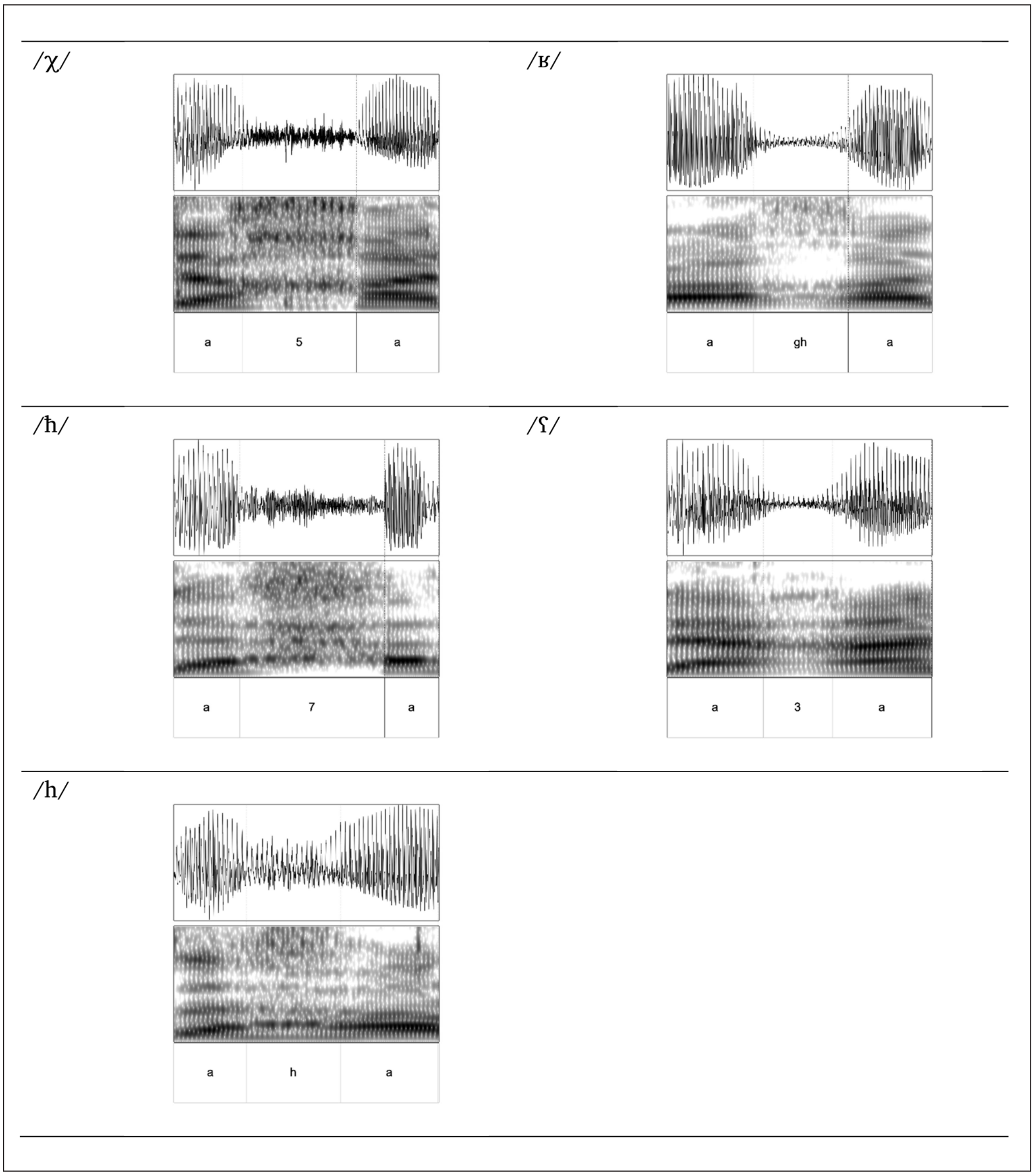


**Figure 11:** Sample annotations for the Emirati Arabic fricatives in medial position (speaker EAF01).

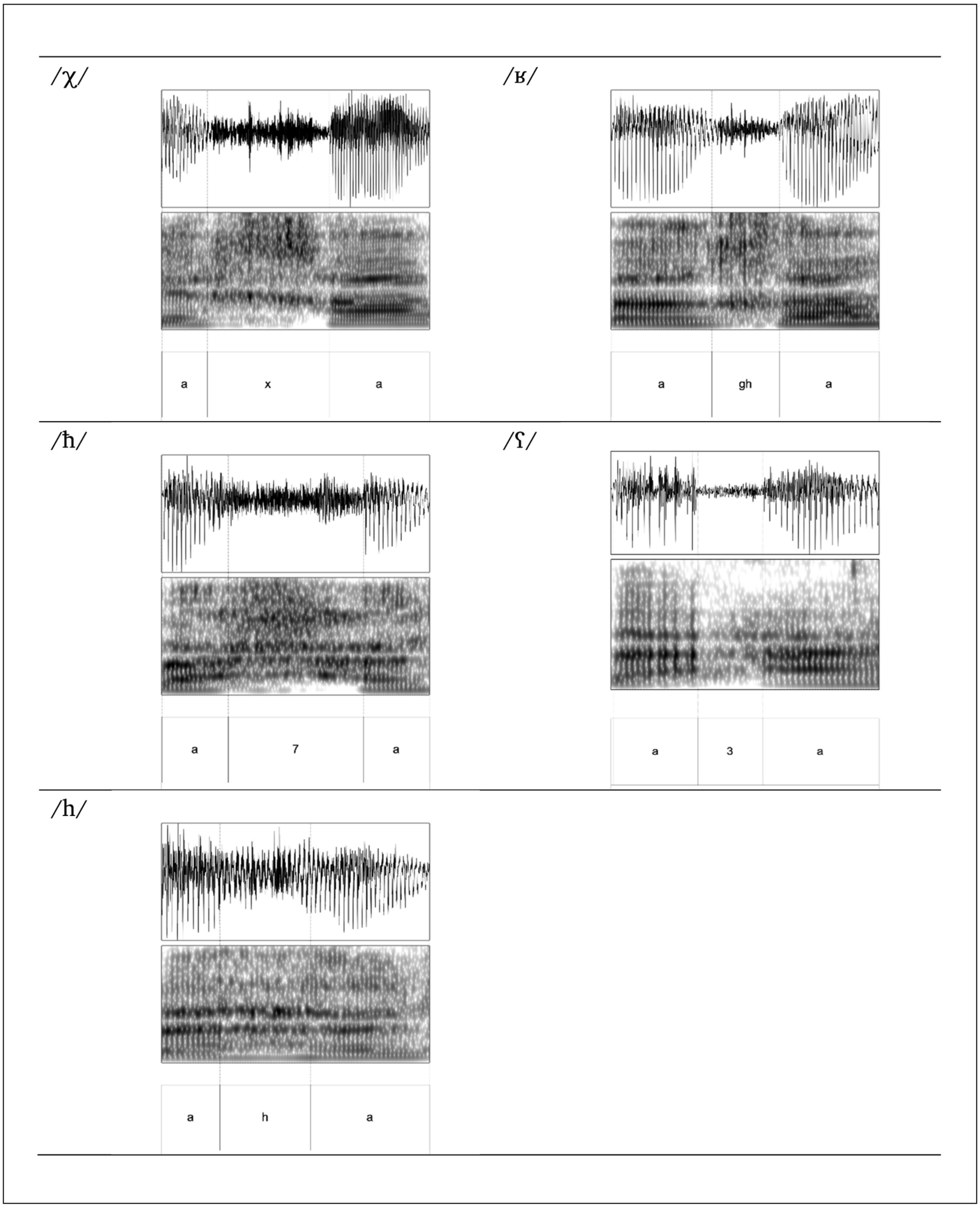


**Figure 12:** Sample annotations for the Iraqi Kurdish fricatives in medial position (speaker IKF02).

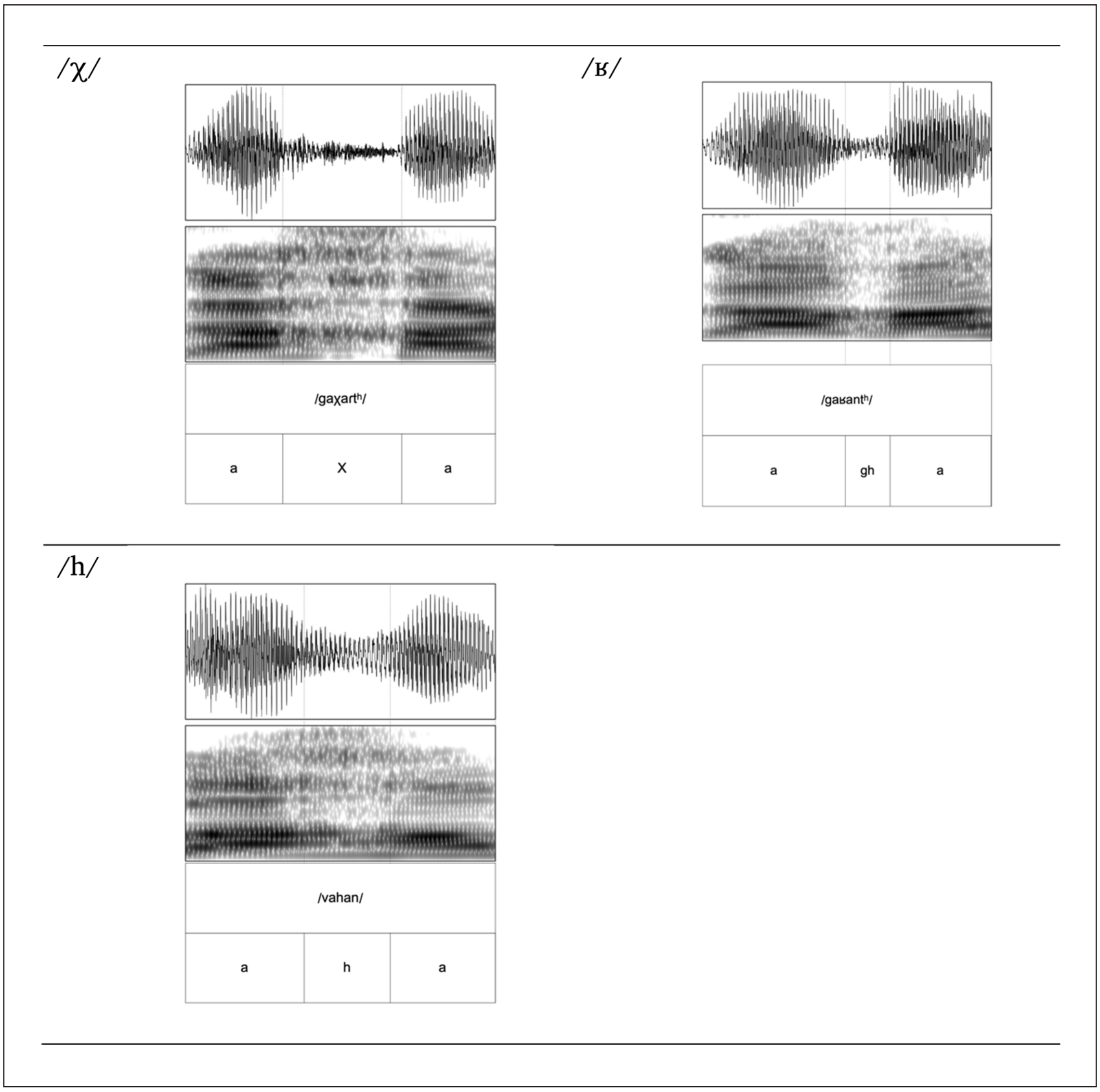


**Figure 13:** Sample annotations for the Lebanese Armenian fricatives in medial position (speaker LAF19).

| Language | C | COG (filtered) | COG (raw) | *Diff.* | SD (filtered) | SD (raw) | *Diff.* |
|---|---|---|---|---|---|---|---|
| Emirati Arabic | /χ/ | 3116 | 3576 | *460* | 1510 | 2011 | *501* |
| | /ʁ/ | 2670 | 3183 | *513* | 1286 | 1991 | *705* |
| | /ħ/ | 2438 | 2491 | *53* | 854 | 1024 | *169* |
| | /ʕ/ | 1742 | 1900 | *158* | 666 | 1211 | *545* |
| | /h/ | 2316 | 2399 | *83* | 1119 | 1367 | *248* |
| | *mean* | *2456* | *2710* | *253* | *1087* | *1521* | *434* |
| Iraqi Kurdish | /χ/ | 2797 | 3209 | *412* | 1381 | 1943 | *563* |
| | /ʁ/ | 2733 | 3238 | *505* | 1313 | 2070 | *757* |
| | /ħ/ | 2238 | 2277 | *39* | 781 | 931 | *150* |
| | /ʕ/ | 1666 | 1828 | *162* | 677 | 1293 | *616* |
| | /h/ | 2246 | 2367 | *121* | 927 | 1328 | *401* |
| | *mean* | *2336* | *2584* | *248* | *1016* | *1513* | *497* |
| Lebanese Armenian | /χ/ | 2653 | 2877 | *224* | 1568 | 1772 | *204* |
| | /ʁ/ | 2213 | 2400 | *188* | 1250 | 1695 | *445* |
| | /h/ | 1817 | 1892 | *75* | 1007 | 1343 | *336* |
| | *mean* | *2228* | *2390* | *162* | *1275* | *1603* | *329* |

**Table 8:** Means for COG and SD obtained for guttural fricatives in three languages with and without filtering out frequencies above 7500 Hz.

## Additional File

The additional file for this article can be found as follows:

- **Supplementary Materials.** Tables S1 and S2. DOI: https://doi.org/10.16995/labphon.10542.s1

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## Competing Interests

The authors have no competing interests to declare.

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