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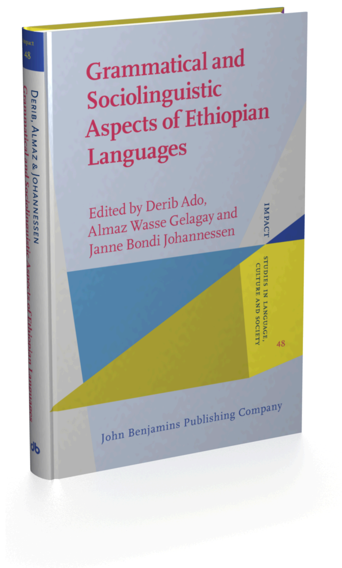
https://doi.org/10.1075/impact.48.13ado



Pages 303–344 of
Grammatical and Sociolinguistic Aspects of Ethiopian Languages
Edited by Derib Ado, Almaz Wasse Gelagay and Janne Bondi Johannessen †
[**IMPACT: Studies in Language, Culture and Society**, 48]
2021. viii, 415 pp.

An acoustic analysis of Amharic fricatives

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This study presents an acoustic analysis of Amharic fricatives, an Ethio-Semitic language spoken in Ethiopia. The study aimed to identify acoustic correlates for place of articulation and airstream mechanism, and investigate the effects of position within a word and window location on acoustic measurements. Duration of the fricative noise, spectral moments, zero-crossing rate, intensity and voice measurements were taken in CV and VCV contexts in real Amharic words. The results showed that frequency of peak intensity, maximum intensity, mean intensity, normalised intensity and spectral COG were found to be robust acoustic correlates of place of articulation. The effect of airstream was seen clearly with the ejective fricative /s'/ having higher intensity values, spectral peak location, spectral mean and zero-crossing values than the alveolar fricative /s/ for both male and female speakers. Voice measurements (H1-H2, H1-A1, H1-A2, and H1-A3) were affected significantly by airstream, with the values indicating a creaky phonation of the vowel following the ejective fricative. Position also contributed in differences in durational and spectral measures with fricatives in the CV position having higher values than fricatives in the VCV position. The results showed that duration was not an important acoustic correlate for place of articulation.

Keywords: Amharic, fricative, acoustic analysis, pulmonic, ejective

1. Introduction

A South Ethio-Semitic language, Amharic is spoken in the central and northern parts of Ethiopia and in all towns of the country (Girma 2009; Meyer & Richter 2003). The 2007 census put the number of Amharic native speakers more than 21 million (FDRE Population Census Commission, 2010). Amharic is also spoken as a second language by more than 4 million speakers (Hudson 1999). Functionally, Amharic is the official working language of Ethiopia, as well as the official language of four of the ten regional states (Amhara, the South Nations, Nationalities and Peoples, the Gambela and the Benishangual Gumuz regional states) and the two chartered cities, namely Addis Ababa and Dire Dawa.

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Amharic has 7 vowels and 30 consonant phonemes (Baye 2008, 2010; Derib 2011), which include five ejectives */p', t', k', s' and tʃ'/* and labialised consonants */k^w, g^w and k'^w /*.[1] Gemination is phonemic in the language, and all phonemes except /h/ and /ʔ/ can occur as geminates in word medial and final positions. The language has seven fricative phonemes: /f/, /s/, /s'/, /z/, /ʃ/, /ʒ/ and /h/.

Acoustic studies of fricatives examined include duration of frication noise and normalised duration, spectral peak location, spectral moments (spectral mean, spectral standard deviation, skewness, and kurtosis) and zero-crossings. In the following section, a review of previous works that aimed at identifying acoustic features related to pulmonic and ejective fricatives is discussed.

This study investigated the effects of place of articulation, position within a word, gender, voice, window location, airstream and voice on different acoustic measures, mainly durational, intensity, spectral moments, zero-crossing points and voice measurements. The study aimed to answer the following specific questions:

a. What are the acoustic correlates of place of articulation?
b. What are the acoustic correlates of airstream that differentiate between /s/ and /s'/?
c. Which acoustic measures are affected by position within a word, gender, window location and voice?

Amharic has seven fricative consonants, which can be singleton or geminate. This study considered only singleton fricatives. The study presents previous works on acoustics of fricatives (Section 2), previous studies on Amharic fricatives (Section 3), methods (Section 4), results (Section 5), discussion (Section 6) and conclusions (Section 7).

2. Previous studies on acoustics of fricatives

2.1 Durational measurements

The research on duration of the fricative noise has been inconclusive in whether it is a robust acoustic correlate of voicing for fricatives. Several studies showed that there is a significant difference in fricative duration between voiceless and voiced fricatives, the former being longer than the latter. Cole & Cooper (1975) conducted perceptual experiments by shortening the fricative duration and reported that reducing the frication duration resulted in the perception of English syllables /fa/ as

1. The number of labialised phonemes in Amharic is now open for debate with the latest proposal to be as much as 19 (Derib 2020).

/va/, /sa/ as /za/ and /tʃa/ as /dʒa/. Acoustic studies on English (Crystal & House 1988a, b; Pirello, Blumstein & Kurowski 1997; Stevens et al. 1992) and Argentine Spanish (de Manrique & Massone 1981) showed that there is a significant difference in fricative duration between voiceless and voiced fricatives, the former being longer than the latter. However, the classification of voiced versus voiceless based only on frication duration has not been achieved specifically for fricatives produced in initial position in English (Baum & Blumstein 1987).

Frication duration has also been found to be an important acoustic correlate in distinguishing sibilant fricatives from non-sibilant ones (in English: Jongman 1989; Jongman, Wayland & Wong 2000; Nissen & Fox 2005; in Oromo: Dejene 2019). In these studies, sibilants were found to have longer duration than non-sibilants. Duration of the frication noise has been contested in its role as a robust acoustic correlate in classifying fricatives. While studies such as that of Jongman (1989) and Shobha (2012) reported that it is not an important cue in classifying fricatives into sibilant and non-sibilant, as well as between the sibilant fricatives, the entire fricative noise duration has been reported as a robust cue in the perception of sibilants (Whalen 1981). The lesser contribution of frication duration in the differentiation of sibilants was reported by Gordon et al. (2002) in a study on seven languages.

In addition to noise duration and normalised duration, duration of the vowel following fricatives has been investigated but was not found to be a robust cue in identifying place of articulation (Dejene 2019).

2.2 Amplitude

Amplitude of the fricative noise was found to be an important cue in identifying sibilant fricatives from non-sibilant fricatives. Heinz and Stevens (1961) conducted an experiment by synthesising fricative signals and reported that the relative amplitude of fricative noise to the following vowel at −15 and −25 dB contributed to the better identification of /f/ and /θ/. Gurlekian (1981) presented synthetic /fa/ and /sa/ syllables to speakers of Spanish and American English and found that listeners identified syllables with low fricative noise amplitude to be /fa/ and syllables with high fricative noise amplitude to be /sa/. Jongman, Wayland and Wong (2000) reported a significant effect of normalised amplitude in differentiating place of articulation of fricatives in English. Nissen (2003) on English, and Dejene (2019) on Oromo, however, reported a significant effect of normalised amplitude only for the categorisation of fricatives into sibilants and non-sibilants. The contribution of amplitude has been described not to be robust in perceptual studies. Behrens and Blumstein (1988) reported that the manipulation of amplitude has little effect in the differentiation of fricatives, provided that spectral properties and formant transitions remain the same.

2.3 Spectral properties

The shape of the spectrum of a fricative is determined by the size and shape of the oral cavity before the point of constriction (Jongman, Wayland & Wong 2000: 1253). The length and volume of the vocal tract before the point of constriction affect the spectral shape of a fricative: labial fricatives have flat spectral shapes because the vocal tract filter has a shorter length and smaller area, whereas alveolar and palatal fricatives have 'well-defined, distinct spectral shapes' (Jongman, Wayland & Wong 2000: 1253).

Spectral peak location and spectral moments (spectral mean, spectral standard deviation, spectral skewness, spectral kurtosis) have been explored in search of correlates for place categorisation of fricatives. Spectral peak location was identified as a prominent feature of fricatives in earlier acoustic studies. Sibilant fricatives had been reported to have higher frequency for their spectral peak location, whereas non-sibilant had lower frequency as a location of their spectral peak (Jongman, Wayland & Wong 2000; Jongman, Wayland & Sereno 2000). Differences in spectral peak location as a function of place of articulation were reported for English (Jongman, Wayland & Wong 2000; Jongman, Wayland & Sereno 2000) and Spanish (de Manrique & Massone 1981; Gurlekian 1981). The spectral peak location was found to differ by gender: male subjects having lower spectral peak location frequencies than female subjects (Jongman 1989; Jongman, Wayland & Wong 2000; Fox & Nissen 2005).

The size and configuration of the vocal tract in the production of fricatives is mainly reflected in the four spectral moments (spectral mean, spectral standard deviation (SD), spectral skewness, and spectral kurtosis). Spectral mean, which is also referred to as centre of gravity, and spectral skewness are associated negatively with the length of the vocal tract filter before the point of constriction (Stevens 1998; Li, Edwards & Beckman 2009). Spectral standard deviation and spectral kurtosis are associated with the body of the tongue (apical or laminal) that is involved in the making of constriction (Li, Edwards & Beckman 2009).

Spectral moments have been studied using various methods and were found to be major acoustic correlates in the identification of place of articulation of fricatives. Forrest et al. (1988) reported the result of a discriminant analysis using the four spectral moments (spectral mean, skewness, kurtosis and variance). The postalveolar fricative /ʃ/ was discriminated with higher score (95%), followed by /s/ (85%) and /f/ (75%). A very low identification was scored for /θ/ (58%).

Spectral mean was found to be higher for females than males for adults; children had higher spectral mean than adults (Nissen 2003; Fox & Nissen 2005). Males also had lower spectral kurtosis values than females (Fox & Nissen 2005).

In addition to spectral mean and kurtosis, Jongman, Wayland and Wong (2000) reported males had lower values of spectral variance than females. In terms of place of articulation, the spectral mean for /*s*/ was found to be higher than the values for other fricatives (Jongman, Wayland & Wong 2000).

2.4 Zero-crossing rate

Zero-crossing measurements have been studied as a measure of periodicity of speech signal. Gurlekian, Franco and Santagada (1989) reported different zero-crossing rate range values for groups of consonants. Santagada and Gurlekian (1989) examined the allophones of /b/, /d/ and /g/ in Spanish to see whether they are fricatives or approximants and concluded that the allophones are approximants because they had lower zero-crossing rates compared to the fricatives. Weigelt, Sadoff and Miller (1990) reported that using an algorithm employing zero-crossing rate, the logarithm of the root mean-square (RMS) energy and the derivative of the log RMS energy with respect to time [termed rate of rise(ROR)], they were able to discriminate between voiceless fricatives from voiceless stops and affricates. Zero-crossing rate was identified as an acoustic correlate that differentiates between voiced and voiceless fricatives, as voiced fricatives have lower values than the voiceless ones (Fernández 2010). Zero-crossing points have not been investigated as a potential acoustic correlate of place, airstream or gender for fricatives or other consonants, as far as the author knows.

2.5 Voice measurements

The difference between ejective and plain obstruents has been explained in the voice quality of the following vowel: the vowel following ejectives had a creaky phonation (Robins & Waterson 1952; Wysocki 2004; Vicenik 2010). The measurements used to see the phonation differences include H1-H2 (relative amplitude of the first two harmonics, H1-A1 (relative amplitude of the first harmonic and the most robust harmonic in the region of first formant frequency); H1-A2 (relative amplitude of the first harmonic and the most robust harmonic in the region of second formant frequency) and H1-A3 (relative amplitude of the first harmonic and the most robust harmonic in the region of third formant frequency).

3. Previous studies on Amharic fricatives

The earliest acoustic study on Amharic was done by Sumner (1957). Using an electrokymograph, he collected data from a single male speaker. Nevertheless, the analysis was made for a group of consonants such as ejectives (including the ejective stops /p'/, /t'/, /k'/; the ejective affricate /tʃ'/ and the ejective fricative /s'/. The only fricative that was investigated by itself was the glottal fricative /h/, which was reported to have 16 cycles (7cs).

Among the fricative phonemes in Amharic, the ejective fricative /s'/ had got attention because of the acoustic and aerodynamic properties involved in its production. The ejective fricative /s'/ has been reported to have shorter duration than the pulmonic fricative /s/ (Demolin 2004). This result, however, was not confirmed by Derib (2017), as he reported /s'/ had longer duration than /s/. Both studies used three native speakers and recorded real words at normal speaking rate, putting the fricatives in VCV context both as singleton and geminate. However, there were differences in the vowels preceding and following the fricatives: in Demolin (2004) they were either /ɨ/, /ə/ or /a/ but Derib (2017) used /a/ only preceding and following the fricatives. The difference could also be attributed to the number of participants in both studies.

Demolin (2002) characterised /s'/ to have constant amplitude and the intraoral pressure to show high and short pressure peak and rapid rise. The electropalatography results for the ejective fricative showed a wider area of contact than for the pulmonic fricative (Demolin 2002).

4. Methods

4.1 Subjects

Five male and five female subjects were recorded in a quiet room saying words aloud. The subjects were between the ages of 20 and 32 and were all born and raised in Addis Ababa with no history of speech or hearing disorders.

4.2 Recording

All the recordings were made using Sennheiser e-815 dynamic microphone attached to CSL 4400 by Kay Elemetrics. The microphone was placed approximately 10 cm from the mouth of the speaker to avoid clipping of the amplitude. The audio recording was sampled a 44100 Hz and quantised at 16 bits. The word lists were presented in the Amharic writing system (in the Ethiopic script). The subjects were given time to practice reading the words and test recorded before the actual recording took place. The words were put in randomised lists, and five randomised repetitions were recorded, of which the middle three repetitions were annotated and analysed. A total of 420 tokens (10 subjects * 7 fricatives * 2 positions * 3 repetitions) were used for this study.

4.3 Stimuli

All the words were real Amharic words that contain the target fricatives in a CV and VCV contexts in which the vowel is the low central vowel /a/. All the fricatives appeared only as singleton in the words. They are presented in the table below.

Table 1. List of Amharic words used for recording

Words containing the target fricative in CV context	Words containing the target fricative in VCV context
/s'adɘk'/ 'righteous'	/nas'af/ '[you, M) come and write
/safa/ 'bucket made of aluminium'	/asama/ 'pig'
/ʃata/ 'container used to catch fish'	/aʃara/ 'finger print, mark'
/ʒagre/ 'one who carries the spear, and sword of a royalty'	/aʒara/ 'gravel found near rivers and cliffs'
/zagol/ 'bead'	/azaba/ 'cow dung'
/fata/ 'a moment of relief'	/afaʃ/ 'one who gathers up crops or flour'
/hagɜr/ 'country'	/ahad/ 'item'

4.4 Measurements

The following measurements were taken for the fricatives in both CV and VCV contexts: fricative noise duration, normalised duration, following vowel duration, spectral peak location, maximum and mean intensity, normalised intensity, spectral centre of gravity, spectral standard deviation, spectral skewness, spectral kurtosis, zero-crossing, normalised zero-crossing and voice measurements (H1-H2, H1-A1, H1-A2, H1-A3).

Fricative duration was measured from the beginning to the end of the fricative noise, and vowel duration from the beginning to the end of the vowel, following the fricatives aided by wave and spectrographic displays on Praat (version 6.0.3.7) (Boersma & Weenink 2018). Intensity measurements were made for the entire fricative duration, for the first 30 ms of the vowel and for the entire vowel duration. Normalised intensity was calculated as the difference between the maximum intensity of the fricative and the first 30 ms.

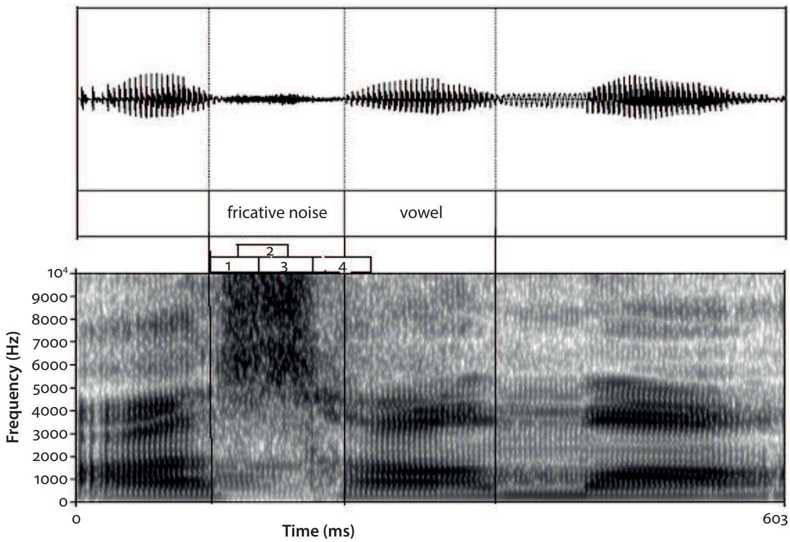


Figure 1. Increments in the measurement of fricative and vowel duration in the word /asama/ 'pig' produced by female speaker F1. W1-W4 represent the four windows used in the measurement of spectral moments

Measurements of spectral moments were made using a 40 ms Gaussian window at the beginning, mid and end of the fricative noise, and at the boundary of the fricative-vowel transition using Praat and a script by Elvira-García (2014), following similar procedures outlined by Jongman, Waylan & Wong (2000). The first three windows had a 20 ms overlap. The audio recording was hann band-pass filtered at 1000 and 11000 Hz prior to the spectral and intensity measurements. The FFT power spectral analysis, which uses calculations to the power of 2, was employed in the spectral analysis.

Zero-crossing was measured for the first 30 ms of the fricative duration as well as for the entire duration. The zero-crossings for the whole interval were multiplied by 10 and divided by the interval duration as a means of normalisation, which is referred to as normalised zero-crossing in this study.

Voice measurements were made using the script by Chad Vicenik, which makes a similar analysis with VoiceSauce (Shue, Keating & Vicenik 2009). The measurements were made first by dividing the duration of the vowel into three parts and calculating the voice measurements (H1-H2, H1-A1, H1-A2, H1-A3) for the first one-third section of the vowel following each of the fricatives.

4.5 Statistical analysis

A four-way, three-way and univariate analysis of variance were made on the values of the measurements of the three repetitions using R version 3.6.1. Place of articulation, gender, position within a word, window location, airstream and voice were taken as independent variables, whenever appropriate. In order to see where the significant effects of variables lie, Bonferroni post hoc test was used whenever a significant result was found on the analysis of variance.

5. Results

Before the analysis on different measurements was made, the spectrograms were inspected to see if there were differences within the instances of the fricative ejective, as there were reports that stated that the first part of the fricative ejective may have a closure component, such as the one reported for Tigrinya by Shosted and Rose (2011). The results of this study showed that there is no affrication of the ejective fricative in Amharic. In this study, a post frication lag until the glottal opening (mean duration = 39 ms) in CV and (mean duration = 34 ms) in VCV position was found, which is similar to the finding for Arabic (Al-Khairy 2005).

5.1 Durational measurements

Mean noise duration of each of the fricatives averaged across gender and position within word are presented in Table 2.

Table 2. Mean and SD values of fricative duration of vowel following the fricatives and normalised duration averaged across genders and position in a word

Fricative	Noise duration		Vowel duration		Normalised duration	
	Mean	SD	Mean	SD	Mean	SD
z	79.05	20.83	154.77	18.07	0.335	0.060
ʒ	79.95	24.99	156.72	19.82	0.334	0.071
h	88.33	24.29	146.65	28.12	0.374	0.072
f	98.25	25.12	150.17	21.39	0.392	0.068
s’	99.58	26.98	158.35	22.58	0.383	0.069
s	105.90	21.70	139.48	25.52	0.432	0.064
ʃ	112.97	23.57	157.38	21.74	0.416	0.054

The overall mean of fricative noise in Amharic shows the postalveolar fricative /ʃ/ had the longest duration, followed by alveolar fricatives /s/ and /s'/. The glottal fricative /h/ had the shortest duration among the voiceless fricatives.

Duration of the fricative noise and normalised duration did not show statistically significant differences due to place of articulation. Place had a significant effect on the duration of the vowel following the fricatives, but the effect was seen mainly due to the significant differences between /s/ and /ʒ/, which differ in voice. Neither was the difference between sibilant and non-sibilant fricative significant for all durational measurements, though for voiceless pulmonic fricatives, sibilant fricatives had higher values for fricative noise duration and normalised duration.

Gender had a significant effect on the duration of the fricative noise and the duration of the vowel following the fricative: female values were higher than male values, which were statistically significant, as presented in Table 3 below. In the case of frication duration for all the fricatives, female values were higher than male values by 11 ms, on average.

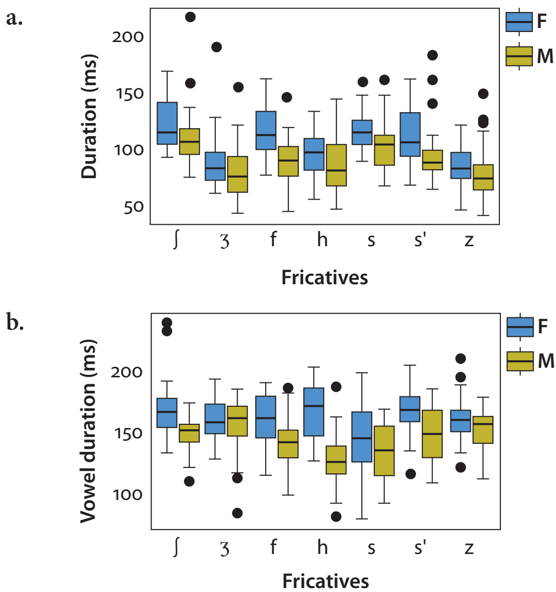


Figure 2. Box plot of fricative noise duration and vowel duration:
(a) Fricative duration and (b) duration of the vowel following the fricatives for male and female speakers of Amharic

The effect of position was significant only on the duration of the vowel following the fricatives (Cf. Table 3). Fricatives in the CV position were followed by longer vowels than fricatives in the VCV position, except for /h/ and /ʒ/.

Table 3. Results of a three-way analysis of variance on the effects of place, gender and position within a word on durational measurements: (a) frication duration, (b) duration of the vowel following the fricatives and (c) normalised duration

a. Frication duration

	Sum Sq	DF	F value	Pr(>F)	Part. eta sq
Place	3552	3	27.352	0.14003	0.0119
Gender	17641	1	26.31	0.0000002728 ***	0.0592
Position	1478	1	2.2923	0.13080	0.0050
Gender:Position	3661	1	5.676	0.01766 *	0.0123
Residuals	296414	418			0.9950

b. Vowel duration

	Sum Sq	Df	F value	Pr(>F)	Part. eta sq
Place	5209	3	4.407	0.0045781 **	0.0227
Gender	29854	1	75.791	2.48e-14 ****	0.1299
Position	9007	1	22.866	0.000439 ***	0.0392
Gender:Place	7544	3	6.383	0.0003103 ***	0.0328
Gender:Position	5180	1	13.15	0.0003242 ***	0.0225
Place:Position	13063	3	11.054	0.0000005463 ***	0.0569
Residuals	159135	404			0.9608

* For all p values henceforth, * represents statistically significant at $p < 0.005$, ** represents statistically significant at $p < 0.05$, and *** represents statistically significant at $p < 0.001$. The p value <2e-16 *** represents the smallest larger than zero. The p value 2.48e-14 is the same as 2.48×10^{-14}, which is 0.0000000000000248.

c. Normalised duration

	Sum Sq	Df	F value	Pr(>F)	Part. eta sq
Place	0.01541	3	1.1951	0.4016692	0.0067
Gender	0.00626	1	1.1951	0.2749461	0.0027
Position	0.00842	1	1.6086	0.2054202	0.0037
Gender:Position	0.06361	1	12.145	0.0005461 ***	0.0277
Residuals	2.11586	404			0.9608

Voice had a significant effect on the duration of fricatives and the normalised duration, but not on the duration of the vowel following the fricatives (Cf. Table 4): voiced fricatives had shorter duration than their voiceless counterparts.

Table 4. Results of a univariate analysis of variance of the effects of voice and airstream on (a) fricative duration, (b) duration of the vowel following the fricatives and (c) normalised duration

a. Duration of the fricatives

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	Part. eta sq
Voice	1	51136	51136	88.93	<2e-16 ***	0.2298
Residuals	298	171347	575			0.7702
Airstream	1	1197	1197	1.997	0.16	0.0166
Residuals	118	70734	599.4			0.9834

b. Vowel duration

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	Part. eta sq
Voice	1	1154	1153.6	2.254	0.134	0.0075
Residuals	298	152518	511.8			0.9925
Airstream	1	10679	10679	18.39	0.000037	0.1348
Residuals	118	68523	581			0.8652

c. Normalised duration

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	Part. eta sq
Voice	1	0.415	0.415	96.1	<2e-16 ***	0.2438
Residuals	298	1.287	0.0043			0.7562
Airstream	1	0.0721	0.0721	16.23	0.0000996 ***	0.1209
Residuals	118	0.5241	0.00444			0.8791

As Table 4 shows, the effect of airstream was significant for the duration of the vowel following the fricatives and the normalised duration, but not the duration of the fricatives themselves. The vowel following /s'/ was longer than the vowel following /s/.

5.2 Spectral peak location

Mean and SD of spectral peak location values for Amharic fricatives are presented in Appendix 1. Place of articulation had a statistically significant effect on the spectral peak location of Amharic fricatives (Cf. Table 5.) Alveolars had the highest value of frequency of spectral peak location, followed by postalveolars. The glottal fricative /h/ had the lowest value of frequency of spectral peak location. Bonferroni post hoc test revealed that alveolar versus the rest of the three places, and the postalveolar versus the labiodental were significantly different at $p < 0.0001$. The difference between postalveolar and glottal place was slightly significant, at $p < 0.05$.

The only non-significant difference in the frequency of peak intensity was between the non-sibilants /f/ and /h/. Thus, the difference between sibilant and non-sibilant fricatives was statistically significant at $p < 0.0001$.

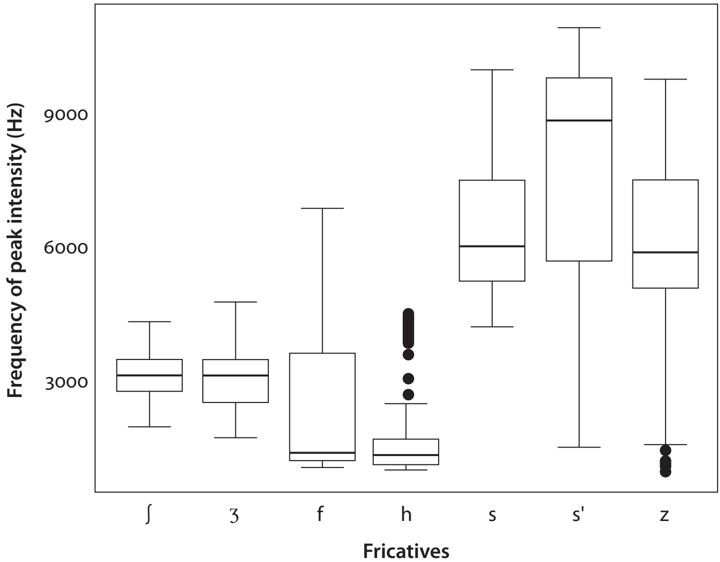


Figure 3. Box plot of frequency of peak intensity

Sibilants had maximum intensity at higher values than non-sibilants, as can be seen in Figure 3, and the differences were statistically significant (Cf. Table 5). /s'/ had higher values than /s/, which was statistically significant (Cf. Table 5).

Table 5.

a. Results on the three-way analysis of variance of the effects of place of articulation, gender and position within a word on spectral peak location

	Sum Sq	Df	F value	Pr(>F)	Part. eta sq
Place	1923783065	3	300.089	< 2.2e-16 ***	0.6423
Gender	70594620	1	33.036	1.785e-08 ***	0.0236
Position	20586215	1	9.633	0.002045 **	0.0069
Residuals	863307991	404			0.2882

b. Results on analysis of variance of airstream on spectral peak location of Amharic fricatives

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	Part eta sq.
Airstream	1	75595163	75595163	21.08	0.0000111 ***	0.1516
Residuals	118	423096005	3585559			0.8484

The effect of gender on the frequency of peak intensity was significant (Cf. Table 5). The difference in the frequency of peak intensity of Amharic fricatives had different patterns for sibilants and non-sibilants. For sibilant fricatives, the values for females were lower than the values for males. The result was the opposite for sibilant fricatives: the values for females were higher than the values for males, as can be seen in Figure 4a, b.

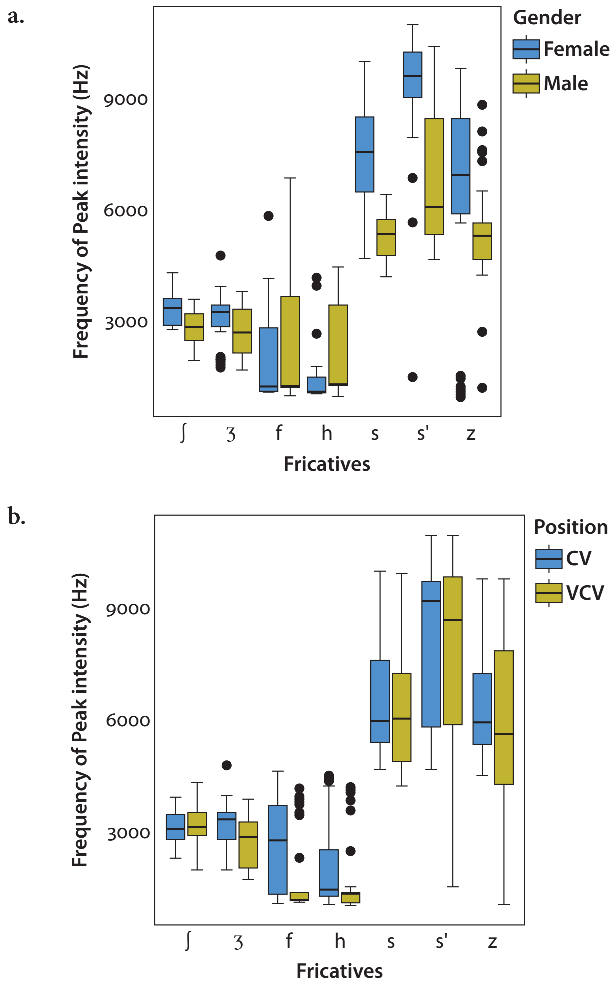


Figure 4. Box plot of frequency of peak intensity for Amharic fricatives (a) by gender and (b) by position within a word

Position also had a statistically significant effect on the frequency of peak intensity: the values in the CV position were higher than those in the VCV position, except for /ʃ/.

The effect of airstream on spectral peak location was statistically significant: /s'/ had higher values than /s/ and the rest of the fricatives.

5.3 Intensity

Mean and SD of intensity measurements for Amharic fricatives are presented in Appendix 1. Figure 5 presents the boxplot of the three types of measurements of intensity: maximum intensity, mean intensity, and normalised intensity (the maximum intensity of the frication relative to the intensity of the first 30 ms of the vowel). In all of the three measurements, the postalveolar fricatives had the highest values, followed by the alveolars and the glottal fricative. The labiodental fricative had the lowest values on the intensity measurements.

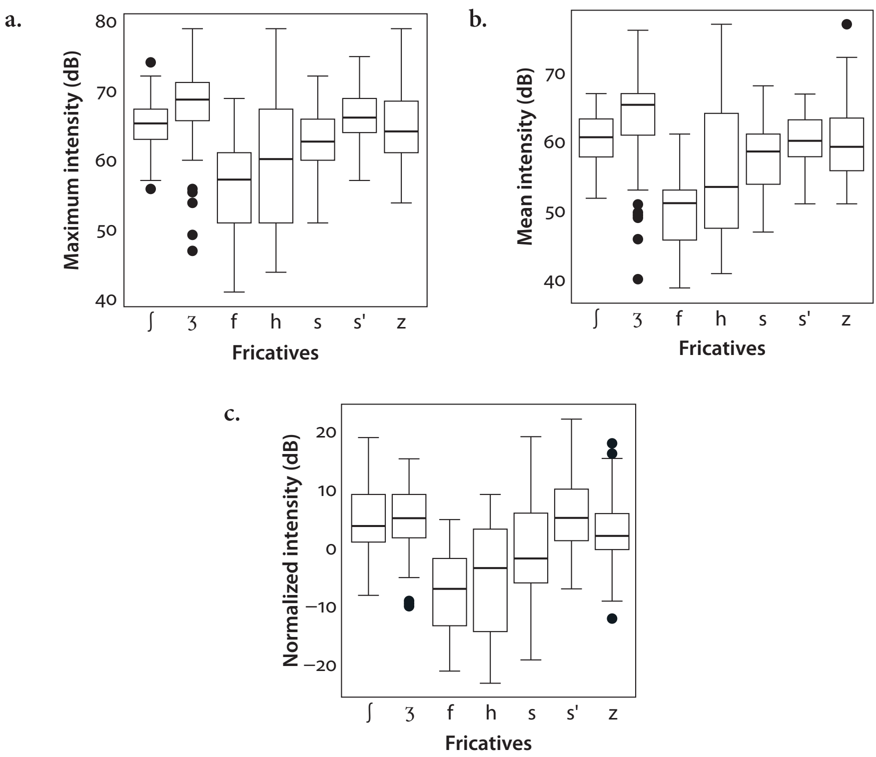


Figure 5. Box plot of intensity measurements for Amharic fricatives: (a) maximum intensity, (b) mean intensity and (c) normalised intensity

The effect of place of articulation on all three intensity measurements was statistically significant. Sibilant fricatives had higher values on all intensity measurements than the non-sibilant fricatives, and the differences were statistically significant on Bonferroni post hoc test at $p < 0.0001$. The post hoc test showed the differences in place of articulation within the sibilants and within the non-sibilants were also statistically significant at $p < 0.05$. Thus, intensity measurements were able to differentiate the four places of articulation.

Table 6. Results on the univariate analysis of variance on the effect sibilance on different intensity measurements: (a) maximum intensity, (b) mean intensity, (c) overall normalised intensity and (d) normalised intensity

a. Maximum intensity

	Sum Sq	Df	F value	Pr(>F)	Part eta sq
Place	5463.0	3	83.6156	<2e-16 ***	0.2755
Gender	107.3	1	4.9270	0.0270*	0.0054
Position	3181.8	1	146.0966	<2e-16 ***	0.1605
Gender:Place	54.0	3	0.8265	0.4798	0.0027
Gender:Position	3.1	1	0.1411	0.7074	0.0002
Place:Position	2198.2	3	33.6450	<2e-16 ***	0.1109
Gender:Place:Position	22.0	3	0.3367	0.7988	0.0011
Residuals	8798.5	404			0.4437

b. Mean Intensity

	Sum Sq	Df	F value	Pr(>F)	Part eta sq
Place	6211.1	3	102.98	<2.2e-16 ***	0.0076
Gender	156	1	7.759	0.005594 **	0.3026
Position	3828.2	1	190.414	<2.2e-16 ***	0.1865
Gender:Place	65.8	3	1.091	0.352552	0.0032
Gender:Position	11.6	1	0.5772	0.447868	0.0006
Place:Position	2090.2	3	34.654	<2e-16 ***	0.1018
Gender:Place:Position	44	3	0.728	0.535	0.0021
Residuals	8798.5	404			0.3956

c. Normalised Intensity

	Sum Sq	Df	F value	Pr(>F)	Part. eta sq
Place	8639	3	78.986	0.004406 **	0.3027
Gender	299	1	8.2	< 2.2e-16 ***	0.0105
Position	2166.9	1	59.437	9.916e-14 ***	0.0759
Gender:Place	118.3	3	1.081	0.356479	0.0041
Gender:Position	0	1	0	0.994739	0
Place:Position	2561.3	3	23.418	5.393e-14 ***	0.0898
Gender:Place:Position	21.7	3	0.198	0.897505	0.0008
Residuals	14728.9	404			0.5162

The effect of gender was significant for all intensity measurements, but it was consistent only for mean intensity, which showed that the values for males were higher than the values for females.

Position had significant and consistent effect only on maximum intensity. The fricatives in VCV position had higher maximum intensity than those in the CV position, as can be seen in Figure 6, and the differences were statistically significant.

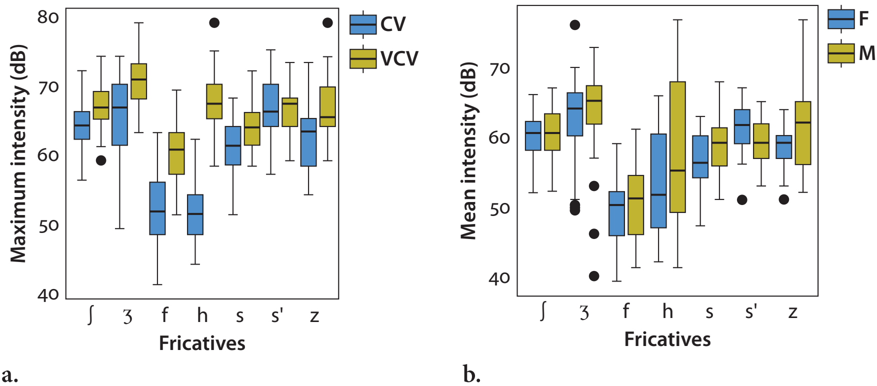


Figure 6. Boxplot of (a) maximum intensity of Amharic fricatives by position and (b) mean intensity of Amharic fricatives by gender

Table 7. Results on the univariate analysis of variance on the effect airstream and voice on different intensity measurements: (a) maximum intensity, (b) mean intensity and (c) normalised intensity

a. Maximum intensity

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	Part. eta sq
Airstream	1	476	476	30.84	0.000000176 ***	0.2072
Residuals	118	1822	15.4			0.7928
Voice	1	126	126.41	5.147	0.024 *	0.0170
Residuals	298	7318	24.56			0.9830

b. Mean intensity

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	Part. eta sq
Airstream	1	165.7	165.68	10.79	0.00134 **	0.0838
Residuals	118	1810.9	15.35			0.9162
Voice	1	308	308.35	12.36	0.000508 ***	0.0398
Residuals	298	7436	24.95			0.9602

c. Normalised intensity

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	Part. eta sq.
Airstream	1	935	935.2	19.53	0.0000221 ***	0.1420
Residuals	118	5650	47.9			0.8580
Voice	1	16	16.06	0.382	0.537	0.0013
Residuals	298	12522	42.02			0.9987

As presented in Table 7, airstream had a statistically significant effect on all measurements: the ejective fricative /s'/ had higher values on all of the intensity measurements than pulmonic alveolar voiceless fricative /s/ (Cf. Figure 5).

The effect of voice was more visibly significant on mean intensity than on maximum intensity. Relative intensity values were not affected by voice. Nevertheless, in all three intensity measurements, /z/ had higher values than /s/ and /ʒ/ had higher values than /ʃ/.

5.4 Spectral moments

Mean and SD of the four spectral measurements for Amharic fricatives are presented in Appendix 2.

5.4.1 *Spectral centre of gravity (COG)*

Box plot of COG values for Amharic fricatives averaged across genders, position and windows are presented in Figure 7. The results show that the alveolar fricatives had the highest mean COG values followed by the postalveolars and then the labiodental fricative. The glottal fricative had the smallest value of mean COG.

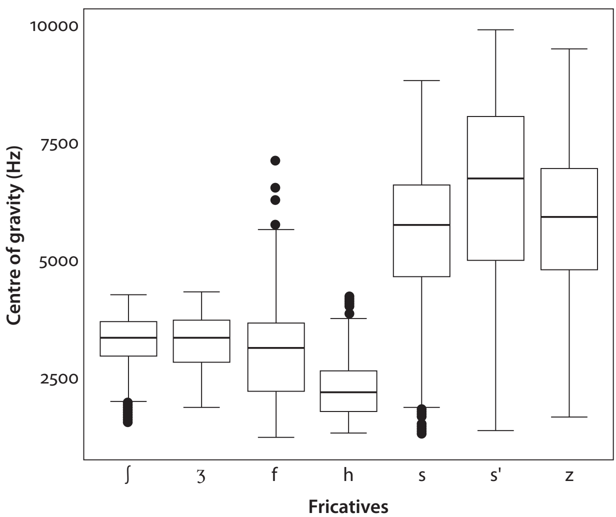


Figure 7. Box plot of COG values for Amharic fricatives averaged across genders, position within a word and window location

Place of articulation had a statistically significant effect on spectral COG values as presented in Table 8. A post-hoc test showed that all place contrasts, except the postalveolar vs labiodental, were significant at $p < 0.0001$. Sibilants had higher values of spectral COG than non-sibilants, but the differences between sibilant and non-sibilant fricatives were not statistically significant, just as the difference between postalveolars and the labiodental were not statistically significant.

Table 8.

a. Results of a four-way analysis of variance of the effects of place of articulation, gender, position and window location on spectral COG

Response= Spectral COG	Sum Sq	Df	F value	Pr(>F)	Part. eta sq.
Place	3468386152	3	1228.9974	< 2.2e-16 ***	0.5087
Gender	28759416	1	30.5721	3.745e-08 ***	0.0042
Position	74004328	1	78.6687	< 2.2e-16 ***	0.0109
Window	1031674633	3	365.5664	< 2.2e-16 ***	0.1513
Gender:Place	97937393	3	34.7034	< 2.2e-16 ***	0.0144
Gender:Position	9933487	1	10.5596	0.001180 **	0.0015
Place: Position	13101135	3	4.6423	0.003085 **	0.0019
Gender:Window	59088926	3	20.9377	2.620e-13 ***	0.0087
Place:Window	409744125	9	48.3966	< 2.2e-16 ***	0.0601
Position:Window	10143390	3	3.5942	0.013156 *	0.0015
Gender:Place:Position	995286	3	0.3527	0.787222	0.0001
Gender:Place:Window	74053500	9	8.7468	6.274e-13 ***	0.0109
Gender:Position:Window	4452534	3	1.5777	0.192856	0.0007
Place:Position:Window	10583971	9	1.2501	0.259857	0.0016
Gender:Place:Position:Window	4882695	9	0.5767	0.817139	0.0007
Residuals	1520185540	1616			0.2230

b. Results of analysis of variance of the effects of airstream on spectral COG

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	Part. eta sq.
Airstream	1	80002447	80002447	18.31	0.0000227 ***	0.0369
Residuals	478	2088368709	4368972			0.9631

Window location had a significant effect on COG values. However, the differences were significant only between the fourth window against the rest of the three windows at $p < 0.001$, as revealed by Bonferroni post hoc test. Amharic fricatives had lower spectral COG values in the fourth window than in the rest of the three windows, as shown in Figure 8.

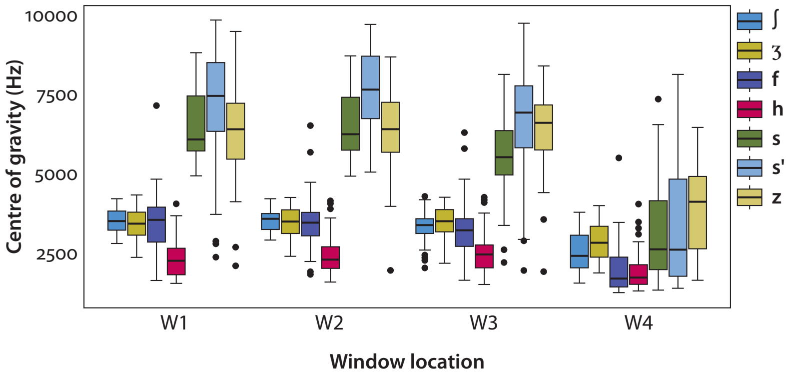
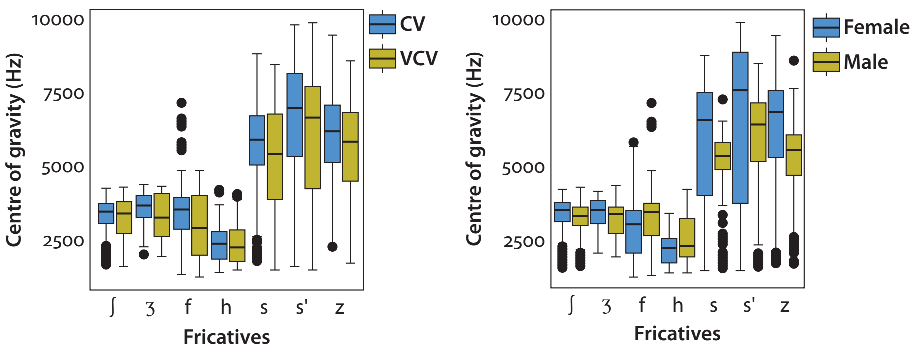


Figure 8. Box plot of COG values for Amharic fricatives plotted against window location

The effect of gender was slightly significant, as can be seen in Table 8. The mean spectral COG values for females were higher than the values for males, except for the glottal fricative, as can be seen in Figure 9.

The effect of position was significant. Fricatives in the CV position had higher spectral COG values than fricatives in the VCV position.



a. b.

Figure 9. Box plot COG values of Amharic fricatives (a) by position in a word and (b) by gender

The interactions of the place with gender, place with position and place with window location were all statistically significant. The interactions of position with gender and position with window location yielded statistically significant differences, though the level of significance was much lower for the latter one. The only statistically significant three-way interaction was between place, gender and window location.

The effect of airstream was statistically significant: /s’/ had higher spectral COG values than /s/.

5.4.2 *Spectral standard deviation*

Spectral standard deviation (SD) shows that the postalveolar and glottal fricatives had lower values than the alveolar and labiodental fricatives, as can be seen in Figure 10.

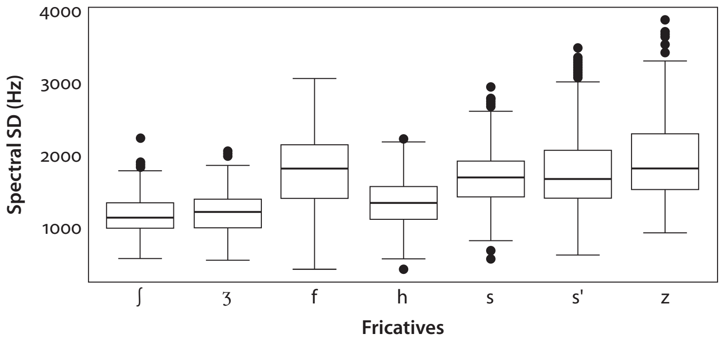


Figure 10. Box plot of spectral SD of Amharic fricatives

A four-way analysis of variance (place X gender X position X window location) showed that place of articulation had a statistically significant effect on spectral SD values of Amharic fricatives as presented in Table 9. Bonferroni post hoc test for the spectral SD values of the four places of articulation revealed that the glottal fricative and the postalveolar fricatives had significant differences with the alveolar and labiodental fricatives at $p < 0.001$. Though position and window location had slightly significant p values, spectral SD values were not affected by them as the results were not consistent across the fricatives.

Table 9.

a. Results of a four-way analysis of variance of the effects of place, gender, position within a word and window location on spectral SD values

Response= Spectral SD	Sum Sq	Df	F value	Pr(>F)	Part. eta sq
Place	133480436	3	265.7612	< 2.2e-16 ***	0.2760
Gender	102566	1	0.6126	0.4339141	0.0002
Position	751153	1	4.4867	0.0343126 *	0.0016
Window	2075139	3	4.1316	0.0062714 **	0.0043
Residuals	270549166	1616			0.5595

b. Results of a univariate analysis of variance of the effects of airstream on spectral SD values

Response= Spectral SD	Df	Sum Sq	Mean Sq	F value	Pr(>F)	Part. eta sq
Airstream	1	566287	566287	2.251	0.134	0.0047
Residuals	478	120274246	251620			0.9953

The effect of airstream was not statistically significant: /s'/ and /s/ had very close values, as can be seen in Figure 10.

5.4.3 *Spectral skewness*

Spectral skewness values for Amharic fricatives averaged across window location, position in a word and gender are presented in Figure 11. Alveolars had the lowest skewness values than the rest of the fricatives produced at the other places of articulation.

The effect of place of articulation was statistically significant but this was mainly caused by the alveolars, which had lower spectral skewness values than the rest of the fricatives, and which showed significant differences with the rest of places of articulation at $p < 0.0001$ in Bonferroni post hoc test. The difference between sibilant and non-sibilant fricatives was also significant, which was caused by the lower values for alveolar fricatives.

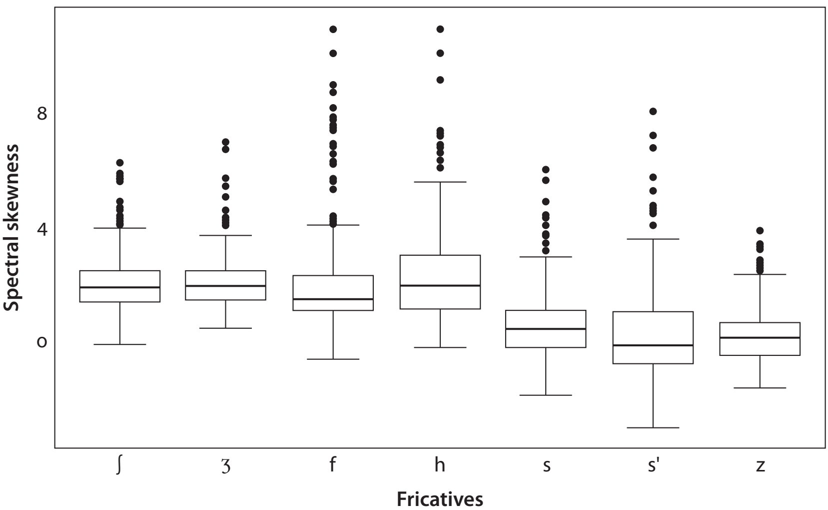


Figure 11. Box plot of spectral skewness values of Amharic fricatives averaged across genders, position within a word and window location. Note the outliers due to the effect of the fourth window (Cf. Figure 12).

Though position within a word had a slightly significant p value, the results were not consistent across all fricatives.

Table 10.

a. Results of a four-way univariate analysis of variance of the effects of place, gender, position within a word and window location on spectral skewness

Response= Spectral Skewness	Sum Sq	Df	F value	Pr(>F)	Part. eta sq
Place	1276.28	3	292.2227	<2.2e-16 ***	0.2568
Gender	1.14	1	0.7843	0.375976	0.0002
Position	7.23	1	4.9634	0.026026 *	0.0015
Window	713.92	3	163.4616	< 2.2e-16 ***	0.1436
Place: Window	172.64	9	13.1760	<2.2e-16 ***	0.0347
Residuals	2352.6	1616			0.4733

b. Results of a univariate analysis of variance of the effects of airstream on spectral skewness

Response= Spectral skewness	Df	Sum Sq	Mean Sq	F value	Pr(>F)	Part. eta sq
Airstream	1	24.4	24.387	8.77	0.00327	0.0179
Residuals	478	1334.2	2.791			0.9821

Window location had a significant effect on skewness values. Nevertheless, Bonferonni post hoc test revealed that the difference due to window location was significant only for the fourth window against the rest of the windows at $p < 0.001$. The skewness values for the fourth window were significantly higher than the values for the rest of the windows.

The interaction of place and window location was statistically significant, and this is true specifically for three of the four places of articulation (except the post-alveolars) that showed higher values for the fourth window.

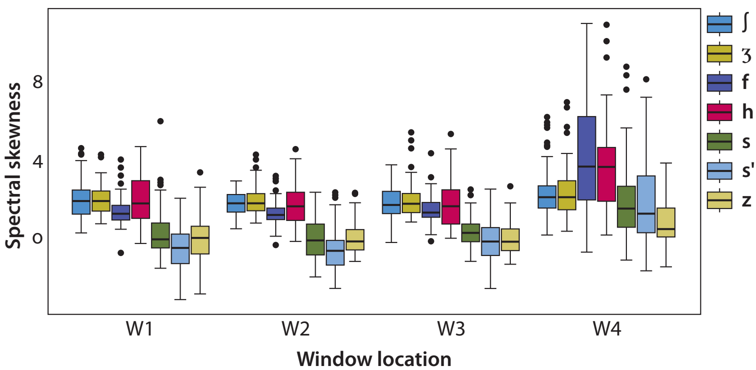


Figure 12. Box plot of skewness values of Amharic fricatives by window location

Gender and airstream had no effect on spectral skewness values of Amharic fricatives.

5.4.4 *Kurtosis*

Spectral kurtosis values for Amharic fricatives collapsed across genders, window location and position within a word showed that alveolar fricatives had the lowest kurtosis values compared to the rest of the fricatives, as can be seen in Figure 13. The difference between the values for kurtosis of Amharic fricatives was significant for place of articulation. However, Bonferroni post hoc test showed that the differences were significant only for the alveolars against the rest of the fricatives at $p < 0.001$, showing that there were no sibilant versus non-sibilant differences.

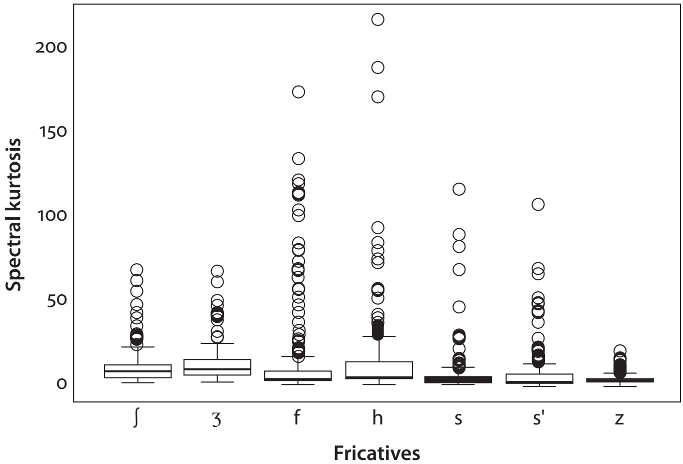


Figure 13. Box plot of spectral kurtosis values of Amharic fricatives. Note the outliers due to the fourth window (Cf. Figure 14 and Figure 15)

Though gender and position had significant p values, the results were consistent only for the fourth window across all fricatives: values for females were higher than for males, and values for fricatives in VCV position had higher values than fricatives in the CV position, as presented in Figure 14. a, b.

The differences in value of spectral kurtosis due to gender and position in the fourth window were prominent mainly for the non-sibilant fricatives rather than the sibilant fricatives, as can be seen in Figure 14a, b.

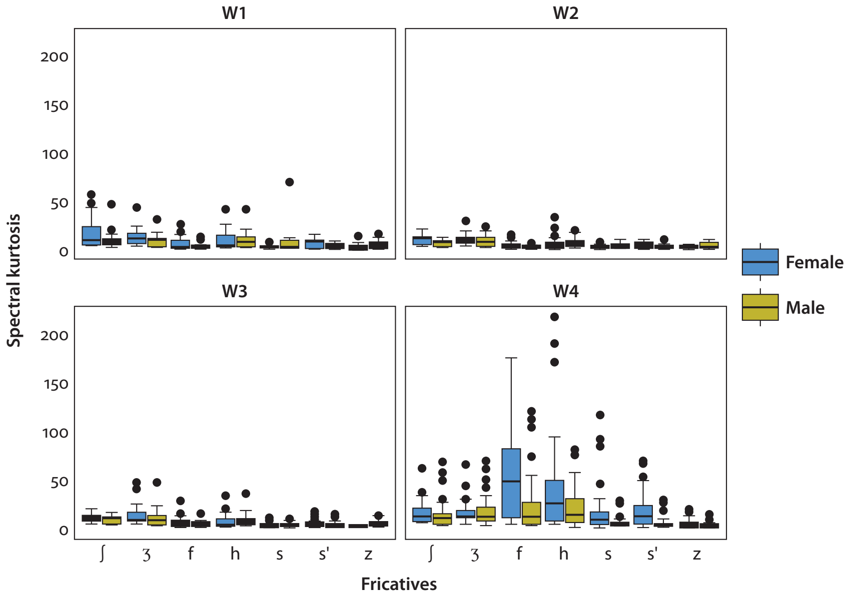


Figure 14a. Box plot of spectral kurtosis values for Amharic fricatives by gender and window location

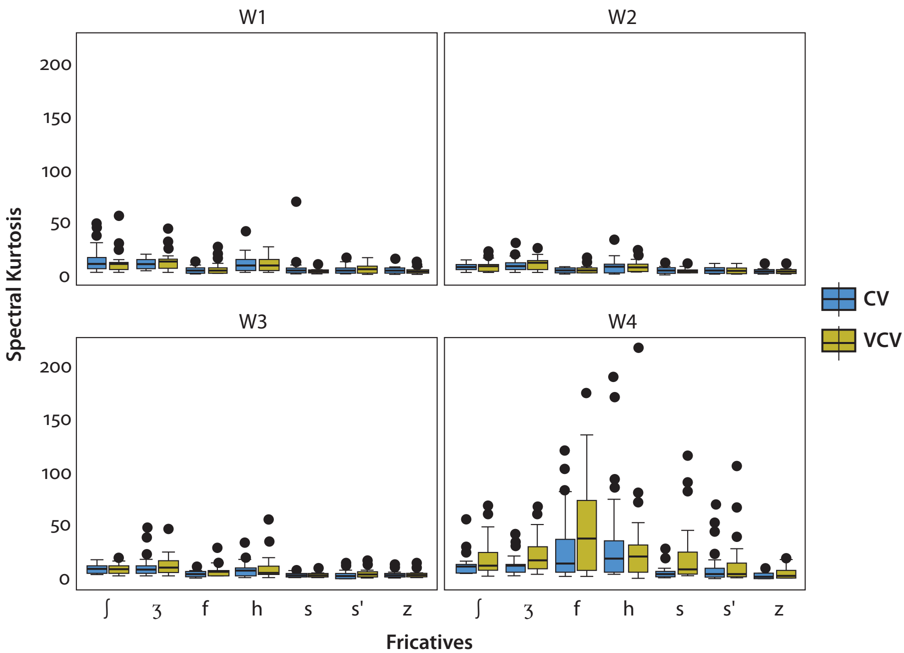


Figure 14b. Box plot of spectral kurtosis values for Amharic fricatives by context and window location

Table 11.

a. Results of a four-way analysis of variance of the effects of place, gender, position within a word and window location on spectral kurtosis

	Sum Sq	Df	F value	Pr(>F)	Part. eta sq
Place	24191	3	43.0204	< 2.2e-16 ***	0.0530
Gender	5174	1	27.6037	0.000000168702 ***	0.0113
Position	1352	1	7.2129	0.007312 **	0.0030
Window	50914	3	90.5448	< 2.2e-16 ***	0.1115
Gender:Window	8694	3	15.4609	0.000000000643 ***	0.0190
Place:Window	37576	9	22.2749	< 2.2e-16 ***	0.0823
Position:Window	3734	3	6.6412	0.000186 ***	0.0082
Gender:Place:Window	8908	9	5.2806	0.000000402479 ***	0.0195
Place:Position:Window	2668	9	1.5817	0.115268	0.0058
Residuals	302898	1616			0.6632

b. Results of a univariate analysis of variance of the effects of airstream on spectral kurtosis

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	Part. eta sq
Airstream	1	5	4.51	0.033	0.856	0.0001
Residuals	478	65753	137.56			0.9999

Window location had a significant effect on kurtosis values. The effect of window, however, was seen between the fourth window and the rest of the windows, which was significant at $p < 0.001$ in Bonferroni post hoc test.

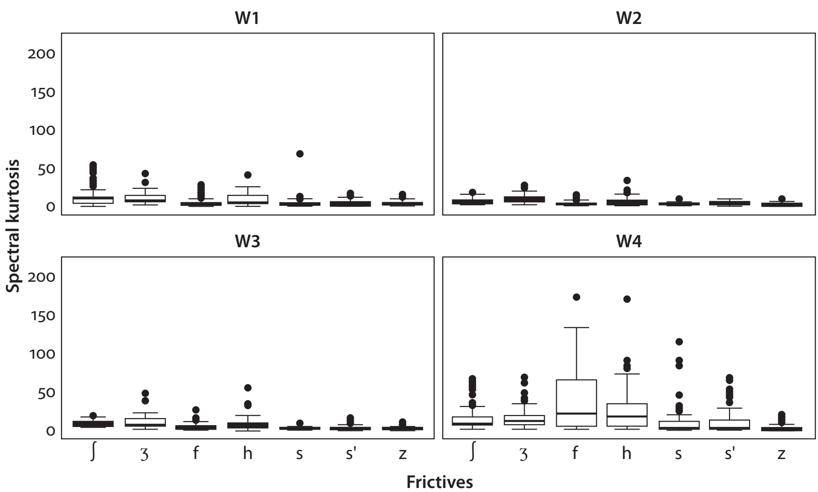


Figure 15. Box plot of spectral kurtosis values of Amharic fricatives by window location

Airstream had no significant effect on spectral kurtosis values.

5.5 Zero-crossing points

Mean and SD of zero-crossing measurements for Amharic fricatives are presented in Appendix 2. The results show that alveolars had the highest values, whereas the glottal fricative had the lowest values among the voiceless group. Though the effect of place of articulation on zero-crossing values was statistically significant, Bonferroni post hoc test results showed that place differences were significant between the alveolars and the rest at $p < 0.001$. As a result, there were no significant differences between the sibilants and the non-sibilants. The box plot of zero-crossing points (for the first 30 ms) for Amharic fricatives is presented in Figure 16.

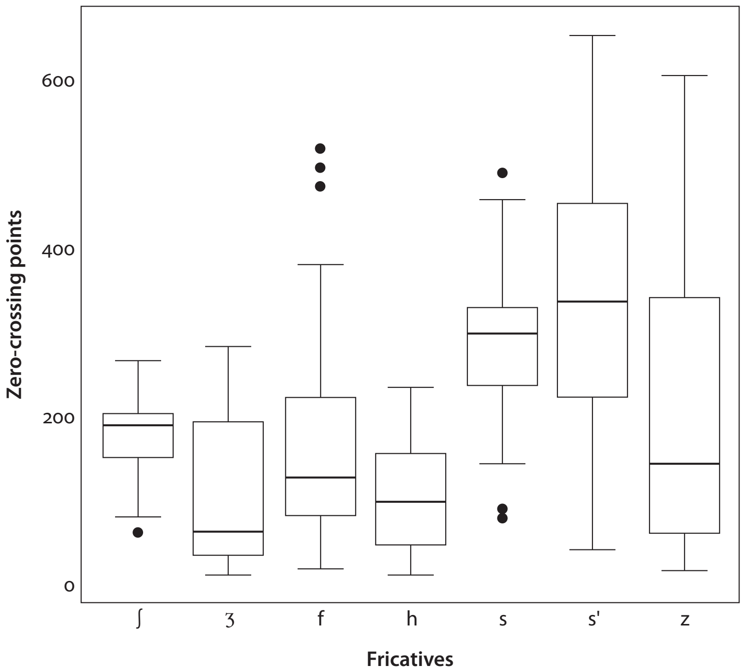


Figure 16. Box plot of zero-crossing points of Amharic fricatives averaged across genders and positions in a word

The effect of gender on zero-crossing points was slightly significant, but not consistent across all fricatives.

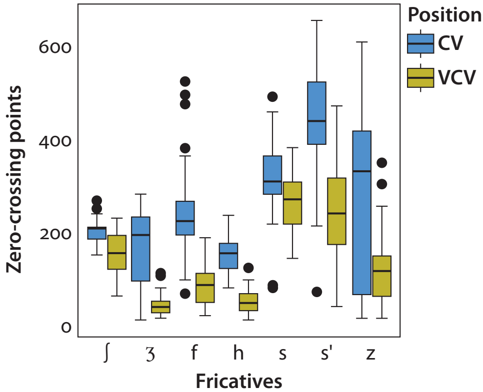


Figure 17. Box plot of zero-crossing points of Amharic fricatives by position

The effect of position within a word was significant. The zero-crossing values for those in CV position were consistently higher than the values in the VCV position for all the fricatives, as presented in Figure 17.

Table 12.

a. Results of a three-way analysis of variance of the effects of place, gender and position on zero-crossing points

	Sum Sq	Df	F value	Pr(>F)	Part. et sq
Gender	53901	1	5.5594	0.01886 *	0.0069
Place	2198779	3	75.5941	< 2e-16 ***	0.2806
Position	1482386	1	152.8935	< 2e-16 ***	0.1892
Gender:Place	80849	3	2.7796	0.04086 *	0.0103
Gender:Position	1656	1	0.1708	0.67961	0.0002
Place:Position	92688	3	3.1866	0.02376 *	0.0118
Gender:Place:Position	9727	3	0.3344	0.80048	0.0012
Residuals	3917002	404			0.4998

b. Results of a univariate analysis of variance of the effects of airstream and voice on zero-crossing points

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	Part. eta sq
Airstream	1	82635	82635	5.4	0.0218 *	0.0438
Residuals	118	1805705	15303			0.9562
Voice	1	988840	988840	58.47	2.87e-13 ***	0.1640
Residuals	298	5440101	16913			0.8360

The effect of voice on zero-crossing values was significant, and this was seen for fricatives in the VCV position. The voiced fricatives/z/ and /ʒ/ had lower zero-crossing points than /ʃ/ and /ʒ/ respectively (Cf. Figure 15).

Airstream had a significant effect on zero-crossing points: /s'/ had higher zero-crossing points than /s/.

a.

b.

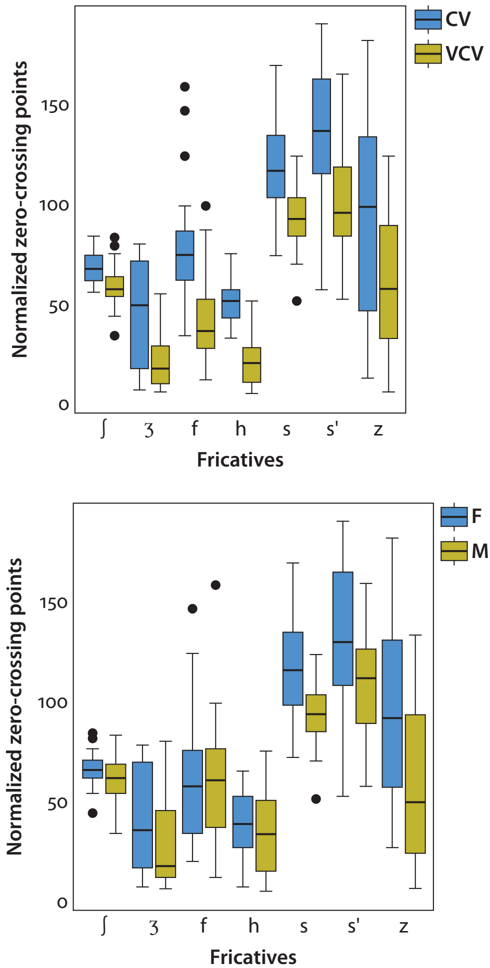


Figure 18. Box plot of normalised zero-crossing (a) by position within a word and (b) by gender

Normalised zero-crossing values were significantly different among the places of articulation. Bonferroni post hoc test showed that differences between the alveolars and the rest of the three places were significant at $p < 0.001$, and the glottal versus the labiodental fricative at $p < 0.001$. Because the postalveolars did not have significant differences with the non-sibilants, there was no significant differences in zero-crossing points of sibilants and non-sibilants.

Gender had a significant effect on normalised zero-crossing values. For all the fricatives, female values were higher than male values.

As presented in Figure 18, position had a significant effect on the normalised zero-crossing values: fricatives in CV position had higher values than fricatives in VCV position, which was statistically significant.

Table 13.

a. Results of a three-way analysis of variance of the effects of gender, place and position within a word on normalised zero-crossing points

	Sum Sq	Df	F value	Pr(>F)	Part. eta sq
Gender	21530	1	29.3800	0.0000001025 ***	0.0299
Place	296427	3	134.8366	< 2.2e-16 ***	0.4116
Position	84375	1	115.1397	< 2.2e-16 ***	0.1172
Gender:Place	14224	3	6.4702	0.0002757 ***	0.0198
Gender:Position	700	1	0.9551	0.3290093	0.0010
Place:Position	5860	3	2.6655	0.0475176 *	0.0081
Gender:Place:Position	1023	3	0.4653	0.7066907	0.0014
Residuals	296053	404			0.4111

b. Results of a univariate analysis of variance of the effects of airstream and gender on normalised zero-crossing points

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	Part. eta sq
Airstream	1	5925	5925	6.988	0.00932 **	0.0559
Residuals	118	100044	848			0.9441
Voice	1	121608	8121608	86.8	<2e-16 ***	0.2256
Residuals	298	417511	1401			0.7714

The effect of airstream on normalised zero-crossing values was also significant: /s'/ had higher normalised zero-crossing points than /s/.

The effect of voice on normalised zero-crossing values was also significant: voiceless fricatives had higher normalised zero-crossing points than voiced fricatives did, and this was clearly seen for the fricatives in the VCV position.

5.6 Voice measurements

The differences in voice quality between the vowels following /s/ and /s'/ were measured in terms of four voice measurements: H1-H2, H1-A1, H1-A2, H1-A3. Box plot of values of these voice measurements are presented in Figure 19. All the voice measurements showed significant differences due to airstream.

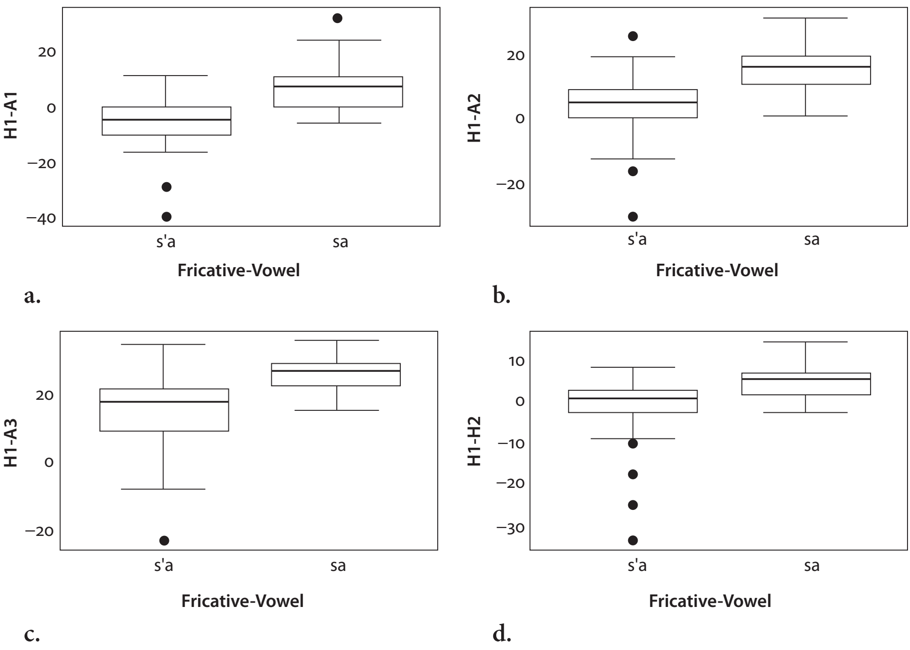


Figure 19. Box plot of voice measurements of Amharic fricatives: H1-A1 (a), H1-A2 (b), H1-A3 (c), H1-H2 (d)

Airstream had a significant effect on the voice quality of the following vowel (Cf. Table 14). The ejective /s'/ was followed by vowels that had lower values on the voice measurements, showing creaky phonation at the beginning of the vowel. The creaky phonation in the vowels following the ejective fricative can be clearly seen in the spectrographic displays, as can be seen in the middle of Figure 20.

Table 14. Results of a two-way analysis of variance of effects of position and airstream on voice results: (a) H1-A1, (b) H1-A2, (c) H1-A3, and (d) H1-H2

a. H1-A1

	Sum Sq	Df	F value	Pr(>F)	Part. eta sq
Airstream	3763	1	68.037	2.837e-13 ***	0.3443
Position	418	1	7.556	0.006936 **	0.0382
Position:Airstream	332.6	1	6.012	0.015695 *	0.0304
Residuals	6416.9	116			0.5870

b. H1-A2

	Sum Sq	Df	F value	Pr(>F)	part. eta sq
Airstream	3411.2	1	58.751	0.001085 **	0.3083
Position	652.2	1	11.233	0.001085**	0.0590
Position:Airstream	264.3	1	4.552	0.034972 *	0.0239
Residuals	6735.1	116			0.6088

c. H1-A3

	Sum Sq	Df	F value	Pr(>F)	Part. eta sq
Airstream	3227.8	1	51.985	6.142e-11 ***	0.2992
Position	84.7	1	1.363	0.24526	0.0079
Position:Airstream	273.0	1	4.392	0.03819 *	0.0253
Residuals	7202.4	116			0.6676

d. H1-H2

	Sum Sq	Df	F value	Pr(>F)	Part. eta sq
Airstream	950.7	1	33.767	0.00004580981 ***	0.1937
Position	505.2	1	17.945	0.00000005557 ***	0.1030
Position:Airstream	185.4	1	6.584	0.01156 *	0.0378
Residuals	3265.9	116			0.6655

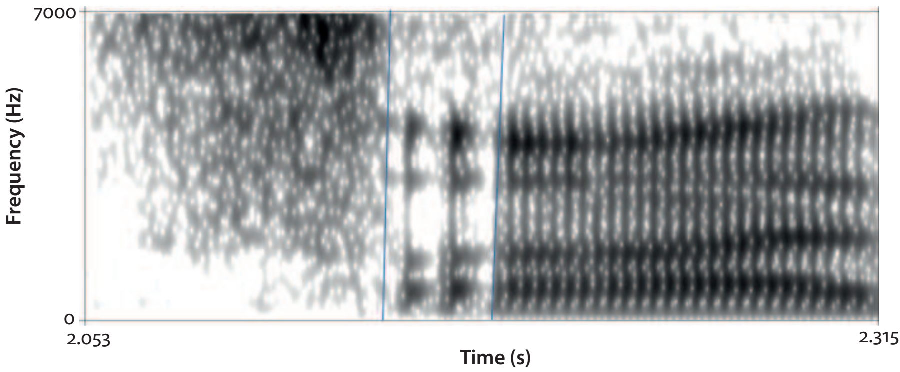


Figure 20. Creaky voice at the beginning of the vowel following the ejective fricative /s'/

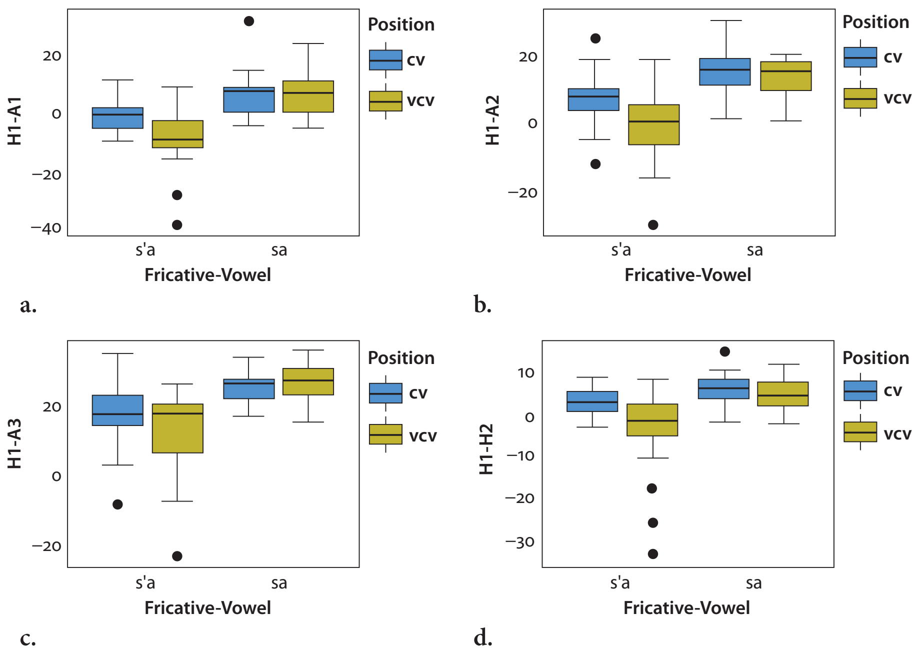


Figure 21. Mean voice measurement values for the vowel following Amharic fricatives by position within a word: H1-A1(a), H1-A2(b), H1-A3(c) and H1-H2(d)

Position had no significant effect on three of the four voice measurements (except H1-A3). Both fricatives were followed by vowels that had higher values in H1-A1, H1-A2 and H1-H2 values in the cv context than in the vcv context.

6. Discussion

The results on durational measurements showed that only gender, position within a word and voice had effects on some of the durational measurements. Gender had effects on the frication duration and the duration of the vowel following the fricatives, position had effects on vowel duration and voice had effects on frication duration and normalised duration. Place of articulation and airstream had no effects on any of the durational measurements, though sibilants were longer than non-sibilant voiceless fricatives. These results do not agree with that of Jongman, Wayland & Wong (2000) on English fricatives, or with that of Dejene (2019), who reported significant differences of fricative noise duration and normalised duration between sibilants and non-sibilants. The duration of the vowel following the fricatives was not affected by place of articulation or airstream, a finding that contradicts that of Dejene (2019). The effect of voice on the duration of the fricatives and normalised duration was in agreement with previous studies on Arabic (Al-Khairy 2005), Argentine Spanish (de Manrique & Massone 1981) and English (Cole & Cooper 1975).

Spectral peak location values were significantly affected by place of articulation. Sibilant fricatives had higher values than non-sibilant values, and the differences were also statistically significant. These results agree with previous studies on English (Jongman, Wayland & Wong 2000; Fox & Nissen 2005), Arabic (Al-Khairy 2005) and Oromo (Dejene, 2019). Nevertheless, the results of this study did not show a decreasing spectral peak location from the front to the back of the oral cavity (labiodental > alveolar > postalveolar > glottal), as reported for English (Jongman, Wayland & Wong, 2000), Arabic (Al-Khairy, 2005) and Oromo (Dejene 2019). The spectral peak location for Amharic had the pattern alveolar > postalveolar > labiodental > glottal. The effect of gender of the speaker partially confirmed to that of Fox & Nissen (2005), as the sibilants (but not the non-sibilants) had higher values for females than for males. The spectral peak location was also an important acoustic correlate of airstream: the ejective fricative /s'/ had the highest value of all the fricatives.

Results of all intensity measurements – namely maximum intensity, mean intensity and relative intensity – showed that they were important acoustic correlates of place of articulation. The findings were similar to the findings in English (Jongman, Wayland & Wong 2000) who reported a significant effect of place of articulation on mean amplitude and normalised amplitude. The differences in intensity values between the sibilants and between the non-sibilants were not as significant as reported for English, but the differences between sibilants and non-sibilants were highly significant, in agreement with results reported for English and Oromo (Jongman, Wayland & Wong 2000; Dejene 2019). The effect of voice on intensity values also agrees with the results reported for Argentine Spanish (de

Manrique & Massone 1981), English (Jongman, Wayland & Wong 2000). There was also a significant difference in maximum, mean and normalised intensity values between /s/ and /s'/ demonstrating that intensity is an important acoustic correlate of airstream in Amharic.

Spectral COG, the first spectral moment, results were able to distinguish between three of the four places of articulation: the differences between the postalveolars and the labiodental fricative were not significant. As a result, there were not significant differences between sibilants and non-sibilants in spectral COG values, a finding that confirms results reported by Fox & Nissen (2005). These results do not agree with previous studies on English (Jongman, Wayland & Wong 2000; Dejene 2019). The highest spectral COG values of alveolar fricatives confirms earlier results (Nissen 2003; Jongman, Wayland & Wong 2000; Al-Khairy 2005; Dejene 2019). The effect of window was attributed to the fourth window only, which agrees with results in previous studies (Jongman, Wayland & Wong 2000; Dejene 2019). Gender had a significant effect on spectral COG values, specifically for sibilants. Spectral COG values for females were higher than values for males, which confirms the study on the effects of gender on spectral properties for English (Fox & Nissen 2005) and the study on Arabic fricatives (Al-Khairy 2005). The ejective fricative /s'/ had the highest value, which was significantly different at $p < 0.0001$ with all the rest of the fricatives, making it an important acoustic correlate of airstream. This is in agreement with the results on Mehri ejective fricative (Ridouane, Gendrot & Khatiwada 2015).

The second spectral moment, spectral SD results showed that the effect of place of articulation was significant, but the differences were between the postalveolar plus the glottal fricatives in one group and the labiodental and alveolar fricatives in another group, which is a front-back distinction. The labiodental and alveolar fricatives had higher spectral SD values than the postalveolar and glottal fricatives. The sibilant-non-sibilant differences in spectral SD values were not attested for Amharic, unlike the results for English (Jongman, Wayland & Wong 2000), and Oromo (Dejene 2019).

The third spectral moment, spectral skewness, and the fourth spectral moment, spectral kurtosis, separated alveolars from the rest of the fricatives, as reported in earlier studies (Jongman, Wayland & Wong 2000; Al-Khairy 2005). The effect of window location was significant mainly due to the transition window (the fourth window) having significantly lower values on the third and the fourth spectral moments (Jongman, Wayland & Wong 2000; Al-Khairy 2005; Dejene 2019). No differences were seen between sibilant and non-sibilant fricatives, nor were voice effects on these moments significant. These results do not agree with results in previous studies (Jongman, Wayland & Wong 2000; Fox & Nissen 2005), and Oromo (Dejene 2019).

The results on zero-crossing points and normalised zero-crossing points showed that they distinguish alveolars from the rest of the fricatives. Position and voice had significant effects on both zero-crossing points and normalised zero-crossing points: Fricatives in CV position had higher values than those in VCV position, and voiceless fricatives had higher values than voiced ones, all effects being significant at $p < 0.001$. Airstream had a slightly significant effect on both zero-crossing points and normalised zero-crossing points at $p < 0.05$. Gender has a consistent and significant effect on normalised zero-crossing points only. So far zero-crossing measurements were considered as acoustic correlate of periodicity, to differentiate voiceless from voiced consonants (Gurlekian, Franco & Santagada 1989; Santagada & Gurlekian 1989; Weigelt, Sadoff & Miller 1990; Fernández 2010). In this study, however, zero-crossing points and normalised zero-crossing points were investigated for fricatives and were found to be important acoustic correlates of position within a word, gender, airstream and voicing.

The voice measurements showed consistent and significant values, showing their being robust correlates for airstream differences. All the four voice measures showed the effect of the ejective on the voice quality of the vowel following them. This study confirms earlier results by Vicenik (2010), and Derib (2011) who reported creaky phonation following ejective stops.

The effect of gender was seen in durational and spectral measurements. Females generally had higher values than males. The COG values for Amharic fricatives is no exception, given females produce consonants with higher COG values (Schwartz 1968; Pépiot 2012), which can be attributed to anatomical differences between males and females.

7. Conclusions

This study aimed at investigating the acoustic correlates of place or articulation and airstream for Amharic fricatives, and the effects of position within a word, voice, window location and gender on durational, spectral, zero-crossing and voice measurements. Durational, spectral, zero-crossing and voice measurements were conducted on a total of 420 tokens, which were recorded from five male and five female native speakers of Amharic. The results showed that spectral peak location, intensity (mean, maximum and relative intensity) and spectral COG were robust acoustic correlates of place of articulation for Amharic fricatives. Airstream was found to have significant effects on spectral peak location, intensity and spectral COG values. Voice measurements also proved to be very important correlates for airstream. The differences in gender were significant on spectral peak location, mean intensity, spectral COG and normalised zero-crossing points. The effect of window on spectral measures was not important within the fricative duration. This study showed the role of zero-crossing points and normalised zero-crossing points to distinguish fricatives based on voice, gender and airstream.

Acknowledgements

The data for this research were collected with the financial support of the individual research grant from the Office of the Vice President for Research and Technology Transfer, Addis Ababa University. An earlier version of the article was presented at the 46th Edition of the North Atlantic Afro-Asiatic Conference held at California State University Long Beach from 1–3 June 2018 with the financial support of the project *Linguistic Capacity Building: tools for the inclusive development of Ethiopia*. I am grateful to Addis Ababa University and the LCB project for their support. I thank Wendy Elvara-Garcia of the University of Barcelona, who sent me the Praat script for the analysis. I am grateful to two anonymous reviewers who gave me valuable comments and who suggested ways to improve the presentation of data.

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Appendix 1. Mean and SD values of intensity measurements and spectral peak location for Amharic fricatives by gender and position

Fricatives	Gender	Position	Maximum intensity		Mean intensity		Relative intensity		Spectral Peak Location (Hz)	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD
f	F	CV	51.33	5.98	46.00	4.78	22.33	5.07	2900.27	1238.74
		VCV	58.40	4.67	51.60	4.12	14.07	3.10	1410.53	768.76
	M	CV	52.73	4.59	47.47	3.98	25.47	5.30	2620.80	1686.03
		VCV	61.67	3.54	54.80	3.00	14.80	3.10	2126.87	1212.87
h	F	CV	49.60	3.52	45.73	2.91	23.40	4.56	1840.27	1010.02
		VCV	64.93	2.87	60.80	4.02	7.67	3.42	1175.00	127.45
	M	CV	53.53	4.90	49.07	4.33	23.67	5.27	2221.00	1301.76
		VCV	69.53	4.73	66.60	5.88	6.40	3.42	2081.93	1230.14
s	F	CV	59.00	4.64	54.27	4.33	12.73	4.65	7609.40	1464.29
		VCV	62.47	3.27	57.67	3.29	7.60	3.27	7478.07	1363.37
	M	CV	62.73	2.74	57.73	2.69	12.93	3.58	5505.80	465.59
		VCV	65.27	2.91	61.40	2.90	9.47	3.52	5094.00	670.42
s’	F	CV	66.20	4.87	59.73	5.01	5.47	4.82	9333.60	1258.86
		VCV	67.00	3.78	60.13	3.93	6.20	4.84	9093.20	2313.53
	M	CV	67.13	3.16	61.20	2.73	9.53	4.41	6950.13	2166.71
		VCV	65.07	3.10	59.40	2.64	11.40	3.79	6659.93	1461.19
ʃ	F	CV	65.67	3.35	59.87	3.20	7.33	4.40	3320.73	361.24
		VCV	67.07	3.47	61.93	3.73	3.67	5.09	3409.60	485.35
	M	CV	62.40	3.40	57.47	3.14	14.13	3.46	2809.60	377.60
		VCV	66.20	2.81	62.27	2.87	8.73	2.91	2920.53	483.81
z	F	CV	61.07	4.17	56.40	3.46	13.80	4.30	7108.53	1352.73
		VCV	63.67	2.55	58.73	2.74	9.73	2.31	5865.73	3490.45
	M	CV	63.73	5.40	58.00	4.02	15.27	4.50	5602.53	1142.84
		VCV	69.33	3.90	66.13	3.94	7.40	2.75	5259.73	1812.05
ʒ	F	CV	62.87	5.67	58.07	5.43	12.07	5.73	3461.53	477.43
		VCV	69.33	3.92	66.13	3.78	4.07	2.69	2883.13	647.67
	M	CV	66.47	8.33	60.27	8.05	11.40	6.78	2965.20	614.67
		VCV	71.60	3.00	68.20	2.96	4.53	2.47	2592.13	679.98

Appendix 2. Mean and SD values of Spectral moments and zero-crossing points for Amharic fricatives

Fricatives	Gender	Position	Spectral centre of gravity (Hz)		Spectral standard deviation (Hz)		Spectral skewness		Spectral kurtosis		Zero-crossing points		Normalised zero-crossing points	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
f	Female	CV	3272.11	1043.71	1665.37	454.24	1.89	1.78	10.36	22.70	225.27	118.70	79.37	26.69
		VCV	2382.58	769.56	1507.45	489.42	2.84	2.29	21.50	35.86	79.67	24.83	38.18	14.11
	Male	CV	3395.39	1133.58	1933.00	613.02	1.52	1.63	7.03	20.68	267.60	95.25	75.52	28.25
		VCV	2993.29	912.72	1915.55	527.09	1.86	1.67	7.56	18.48	87.07	46.43	43.51	26.05
h	Female	CV	2202.06	516.74	1271.61	326.60	2.44	2.03	16.52	35.13	152.33	34.72	50.69	7.79
		VCV	2003.68	412.90	1186.18	281.93	2.42	1.84	15.14	30.58	53.47	20.64	24.08	9.75
	Male	CV	2520.56	805.92	1405.79	414.80	2.19	1.57	10.37	14.19	147.67	37.39	51.95	14.69
		VCV	2451.19	704.58	1381.65	243.98	1.97	1.42	8.43	11.86	49.67	29.79	17.13	11.97
s	Female	CV	6278.73	1849.21	1894.76	402.52	−.08	.97	1.09	2.53	350.07	109.35	134.56	21.18
		VCV	5345.87	2453.89	1811.15	514.02	.65	2.38	8.52	21.57	296.20	58.40	100.31	14.47
	Male	CV	5158.96	1040.83	1447.60	320.09	.89	1.10	4.25	9.10	284.07	68.11	102.46	13.81
		VCV	4864.00	1299.19	1599.12	298.34	.90	1.06	3.44	5.85	234.13	42.36	84.81	12.42
s’	Female	CV	6782.23	2603.39	1637.31	545.52	−.22	2.11	6.52	13.22	487.07	138.29	150.46	28.85
		VCV	6171.98	3054.63	1883.75	720.98	.07	2.39	7.43	16.17	247.47	146.21	112.81	32.83
	Male	CV	6156.69	1696.10	1708.45	422.45	.47	.99	1.66	3.36	399.47	93.25	123.05	24.45
		VCV	5802.70	1598.40	1797.91	514.08	.24	1.27	2.47	4.84	240.40	63.16	92.03	18.34
ʃ	Female	CV	3408.69	459.99	1045.29	196.09	2.04	.79	10.17	8.78	204.73	26.20	71.07	6.87
		VCV	3136.87	762.15	1057.26	230.53	2.00	1.11	11.87	11.71	159.13	46.40	59.65	6.01
	Male	CV	3148.82	465.43	1266.13	297.40	1.87	.89	7.72	9.58	195.73	19.70	65.46	7.22
		VCV	3197.74	651.29	1246.32	198.93	1.81	1.10	7.48	10.30	149.13	36.93	58.71	12.40

Fricatives	Gender	Position	Spectral centre of gravity (Hz)		Spectral standard deviation (Hz)		Spectral skewness		Spectral kurtosis		Zero-crossing points		Normalised zero-crossing points	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
z	Female	CV	6524.16	1550.40	1932.55	552.19	−.03	.83	.72	2.15	299.00	220.88	109.23	54.26
		VCV	5966.87	1968.25	2355.33	713.17	−.08	1.32	1.65	4.18	149.00	90.95	77.37	27.67
	Male	CV	5461.84	1248.10	1681.22	492.90	.62	.97	2.88	4.00	262.27	154.15	80.35	42.13
		VCV	4982.79	1339.53	1728.69	400.58	.23	.93	2.29	3.29	97.33	50.75	37.87	23.80
ʒ	Female	CV	3629.10	402.83	1051.67	262.97	1.84	.82	10.28	8.62	175.07	80.98	57.31	23.24
		VCV	3074.38	507.21	1152.72	245.52	2.13	.87	12.65	10.57	49.07	28.27	23.79	15.48
	Male	CV	3346.56	573.23	1325.01	314.59	1.92	.76	7.74	7.26	150.33	84.25	35.59	23.07
		VCV	3035.29	622.30	1234.74	239.22	2.17	1.40	11.98	14.11	45.47	26.65	19.98	14.93