An Acoustic Analysis of Fricative Variation in Three Accents of English

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Abstract

This study reports on an analysis of accent and gender differences in the realisation of the fricative /s/ within three accents of English: London, Cambridge, Belfast. There were 30 speakers in the study. Using multilevel modelling, significant differences between accents in the dynamic acoustics of the alveolar fricative /s/ are evident. Significant gender differences in the fricative energy measure trajectories are also found, within each accent. We further discuss the implications of these differences to our understanding of the role of gender and accent in the realisation of spectra movements in English fricatives, highlighting the necessity of a dynamic approach to sociophonetic acoustic variation.

Index Terms: Fricatives, accent, gender, spectral movements, skewness, kurtosis, centre of gravity, peak frequency

1. Introduction

1.1 Accents

The English spoken in the British Isles is characterised by extensive variation, illustrated in the pioneering work of Wells [1]. A dialect can be distinguished by grammatical and lexical variation, as well as at the (morpho)syntactic level [2]. The focus of this study is on dynamic segmental realisational variability in three accents of English, for the alveolar fricative /s/. The study analysed peak frequency and spectral moment measures in order to investigate the extent to which sociophonetic information is encoded in the dynamics of fricative acoustics.

1.2 Fricative production

Extensive research has gone into characterising the source and filter mechanisms of fricatives [3, 4, 5, 6]. Fricative consonants are produced with a narrow constriction in the oral tract, articulated with a central groove and lateral bracing of the tongue on the hard palate or teeth [7]. The main source of fricative noise in speech is generated as a turbulent jet of air passed through this constriction impinges on the teeth [4, 6, 8].

The source spectrum of fricative noise therefore depends on the shape of the constriction, the cavity anterior to the constriction, and the flow velocity through the constriction [6, 9, 10]. The resonant properties of the vocal tract amplify certain frequencies and dampen those frequencies that occur around the resonant frequencies, creating a characteristic spectral envelope dependent on the geometry of the resonating chamber. The spectral envelope of fricatives is mainly defined by the resonances of the anterior cavity downstream from the lingual constriction [6, 11, 12]. Both source and filter mechanisms for the alveolar fricative /s/ are highly dependent on the articulatory configuration adopted, and very small changes in articulation can lead to abrupt spectral changes.

It has been well-documented that the articulation of fricatives in speech is not static, or even characterisable by any static articulatory posture [13, 14, 15]. This articulatory temporal variability translates to acoustic temporal variability [9, 15, 16, 17, 18]. Measuring the spectral mean, Iskarous *et al.* [15] found no stationary stretch across the nine measurement points in the alveolar fricative. Rather, the measurements followed a roughly quadratic convex trajectory, rising to a peak at around 80% of the fricative duration, attributable to the action of the jaw raising the lower incisors into the path of the airstream [8, 11, 19, 20].

The trajectories of fricative energy measurements have been shown to be language-specific, suggesting that not only the static articulation but also the temporal coordination of the articulators vary from one language to the next [17]. Reidy [17] fitted growth curve models to acoustic trajectories of fricatives in English and Japanese, using a psychoacoustic analogue of peak amplitude frequency. It was found that there was a significant interaction of linear time with language and quadratic time with language. This indicates that both the overall linear trajectory of the peak measurement as well as the curvedness of the trajectory are language specific. Crucially, static measures were found to elide language-specific information. This study investigates whether similar results may be found within accents of the same language.

1.3 Spectral measures

Several spectral measures were employed to investigate differences in fricative acoustic trajectories. All are supported in the literature as valuable acoustic measures [15, 16, 18, 21, 22, 23, 24, 25]. Peak amplitude frequency denotes the frequency in the spectrum at which there is the greatest excitation of energy. In addition, three spectral moments were extracted for analysis [26].

Although spectral moments have been used to successfully distinguish place of articulation [18], their use has been questioned due to their lack of interpretability and inconsistency across studies [21, 27]. However, the advantage of using spectral moments is that they collapse the complexities of fricative spectra to single values that describe the energy distribution.

The first moment (M1) describes the spectral mean and is related to the front cavity resonance. The range of articulatory dimensions which may potentially contribute to changes in the spectral mean are extensive. The third spectral moment (M3), or skewness, refers to the degree of symmetry of a distribution about the mean. Skewness and spectral mean can be strongly correlated, and therefore the same ambiguities as to the articulatory-acoustics link apply. The fourth spectral moment is kurtosis (M4), which measures how peaked the distribution is compared with a normal distribution. A longer anterior cavity corresponds with a more defined, i.e., peaked, spectrum [8].

The measures above have been shown to significantly vary between genders [18, 28]. Female speakers typically have a concentration of energy at higher frequencies compared with male speakers [18, 28, 29, *inter alia*]. However, the work of Stuart-Smith *et al.* [29] indicates that gender effects are not uniform across different accents and are dependent on socio-cultural factors. They posit that anatomical sex provides the range of variation through which gender, as a sociocultural identity, is expressed. Empirical evidence for this comes from their study of the effects of class, age, and sex on the acoustics of the alveolar fricative /s/ in Glaswegian English. They found that the working-class girls patterned more closely with working-class men than the equivalent female age group in the middle-class, suggesting that the sociocultural identity of 'gender' was more closely tied to class, as opposed to anatomical sex. The effect of gender will therefore be closely examined across all three accents.

1.4.   Aims and hypotheses

The literature above strongly supports a dynamic analysis of fricatives, as opposed to one that utilises static measures. In fact, Reidy [17] found that static measures showed no language-specificity, and differences between languages were to be found in the trajectories of the measures over time. Therefore, a dynamic analysis of fricative acoustics will be adopted.

The necessity of dynamic acoustic analysis in understanding the extent of sociophonetic variation is increasingly being recognised [30, 31, 32, 33]. However, with the exception of vowel monophthongs [31, 33], sociophonetic variation in the dynamic acoustics of traditionally static sounds, such as fricatives, is yet to be fully understood. This study aims to explore the nature of sociophonetic dynamic acoustic variation in three accents of English (London, Cambridge and Belfast). While dynamic acoustic differences in /s/ between accents are expected, given dynamic language-specific acoustics [17], how the sociocultural expression of gender is phonetically expressed within each accent is less easy to predict [29].

2.   Materials and Method

2.1.   The IViE corpus

We used the Intonational Variation in English (IViE) corpus, a collection of audio recordings of speakers of nine different accents of English, with a sampling frequency of 16 kHz [34]. The subjects were young adults from urban secondary schools. The data used in this study were from the Retold section of the IViE corpus, which is semi-spontaneous and therefore partially controlled for its content [34, 35].

2.2.   Annotation

The manual annotation of fricative boundaries was done by the first author, who is a trained phonetician, guided by the work of Skarnitzl & Macha [36]. The second author checked a portion of the annotations for consistency and differences were resolved through discussion among authors. The different number of tokens per recording led to an unbalanced set of speakers per accent and gender. This was because speakers with an insufficient number of tokens were discarded at the end of the annotation process. As a result, there were 11 speakers for the London accent, 10 speakers for the Cambridge accent, and 9 speakers for the Belfast accent. For the London accent, there

were 6 female speakers and 5 male speakers. For the Cambridge accent, there were 5 female speakers and 5 male speakers. For Belfast, there were 4 female speakers and 5 male speakers. The decision was made to prioritise the amount of data available to analyse, as opposed to having a balanced dataset. The effect of excluding speakers to achieve a balanced dataset of 4 speakers per gender, and 8 per accent, resulted in no change in significance levels across all tests.

2.3. Acoustic parameter extraction

Acoustic parameters were extracted using a Praat script [37], using FFT and the Hamming window function. Following Iskarous *et al.* [17] and Reidy [20], the fricative duration was divided by twelve, and at each point a 10 ms frame was extracted. The two rightmost and leftmost frames were discarded such that the middle of the outermost frames corresponded with the annotated left and right fricative boundaries, yielding ten frames per segment. Values were extracted from frames 3 to 8. In order to isolate the peak amplitude frequency, a high-pass filter of 2 kHz was applied. The other three spectral moments were computed with a high pass filter of 500 Hz, to minimise ambient noise [23] yielding a total of five parameters – peak amplitude frequency (PF), spectral mean (M1), skewness (M3), and kurtosis (M4).

From casual inspection of the data, errant data points were evident across all parameters. However, the processes of rapid speech, ambient noise, and the inherent randomness of fricative noise all likely contributed to the errors in measures of the spectral slices [38]. A total of 1,381 tokens were collected across the accents, and 13,810 frames were extracted for each parameter. Subsequently, each frame for each token for every speaker was averaged, reducing the data to ten frames per speaker, and minimising the effect of errant measurements, shown in Figure 1.
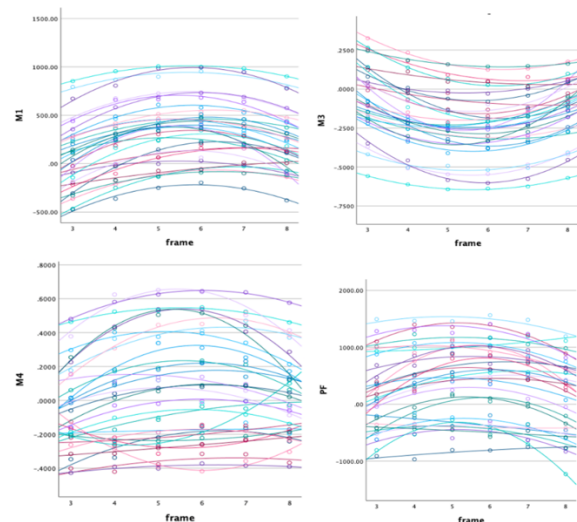

Figure 1. *Frame averages for all speakers, across all four parameters*

2.4. Analysis

Growth curve analysis was used to analyse the dynamic aspects of the acoustic measures, using SPSS 28.0.1.1 and Python 3 packages. It is a kind of multilevel modelling, where explanatory variables enter at the first level and higher-level

explanatory variables enter at the second level. For all tests, a *p* value of ≤0.05 was considered significant. Models were evaluated using the Akaike Information Criterion (AIC). If adding or discarding a parameter lowered the AIC by more than two, the model with the lower AIC was chosen.

For both gender and accent models, the growth curve was estimated from the third to the eighth frame. This is to minimise potentially accent-specific coarticulatory effects, found at the edges of fricatives, but nonetheless within the boundaries of fricative noise [39, 40]. Each value was normalised by mean-centring, by subtracting the mean across all speakers for the relevant measure. This yielded a range of negative and positive values which then entered the statistical analysis.

3. Results

3.2. Growth curve analysis

3.2.1. Gender

To investigate possible effects of gender in the middle portion of the fricative, a model was estimated for each accent, for every parameter. For the most complex model, fixed effects for gender, time, quadratic time, time by gender, and quadratic time by gender, were estimated. Random effects were set for the intercept, time, and quadratic time.

For the London speakers, four measures yielded significant effects: peak amplitude frequency (PF), spectral mean (M1), skewness (M3) and kurtosis (M4). The fixed effect of gender was significant for the peak amplitude measure, estimated at 643.114 ($F(1, 10.104) = 7.255$, $p = .022$). The M1 interaction of gender and quadratic time was significant, estimated at 12.105 ($F(1, 41.508) = 6.560$, $p = .014$). The M3 interaction of gender and linear time was significant, estimated at .010 ($F(1, 50.003) = 6.709$, $p = .013$). The M4 interaction of gender and linear time was significant, estimated at 0.017 ($F(1, 41.387) = 21.225$, $p = .012$), as well as the M4 interaction of gender and quadratic time, estimated at -0.082 ($F(1, 50.749) = 7.856$, $p = .007$).

For the Cambridge speakers, M4 yielded significant effects. The kurtosis measure yielded significant effects for the interaction of gender and linear time, estimated at -0.101 ($F(1, 37.976) = 10.115$), and the interaction of gender and quadratic time, estimated at 0.022 ($F(1, 45.674) = 11.459$, $p = .001$).

For the Belfast speakers, one measure yielded significant effects, peak amplitude frequency. The peak amplitude significant effects were the fixed effect of gender, estimated at 966.150 ($F(1, 6.864) = 24.659$, $p = .002$), the cross-level interactions of gender and linear time, estimated 2151.275 ($F(1, 25.786) = 11.094$, $p = .003$), and gender and quadratic time, estimated = -37.247, $F(1, 18.424) = 9.131$, $p = .007$).

For London, the average effect for gender in the average across frames for peak amplitude frequency, i.e., changing from male to female speakers, is 643.114 Hz. ($F(1, 10.104) = 7.255$, $p = .022$). The M1 significant positive linear interaction term indicates that the female speakers have a more positively sloped spectral mean trajectory. The positive quadratic term indicates that the female speakers have a significantly flatter trajectory. The positive linear interaction term for M3 indicates that the female skewness trajectories are significantly more positively sloped. The M4 interactions indicate that the female speakers have a more positive slope for kurtosis, and a more peaked curvature.

or the Cambridge speakers, the interactions in the kurtosis measure indicate the female group has a significantly more

negatively sloped trajectory and a more concave curvature than the male group. For the kurtosis measure, the female group has a more negatively sloped trajectory, and a more concave curvature than the male group.

For Belfast, the significant effect of gender indicates that the female speakers have a significantly greater mean across the frames, by 966.150 Hz. The interactions indicate that the female group has a significantly more positively sloped trajectory, and a significantly more peaked trajectory. The overall results by gender (0 - male; 1 - female) across measure are shown in Figure 2.
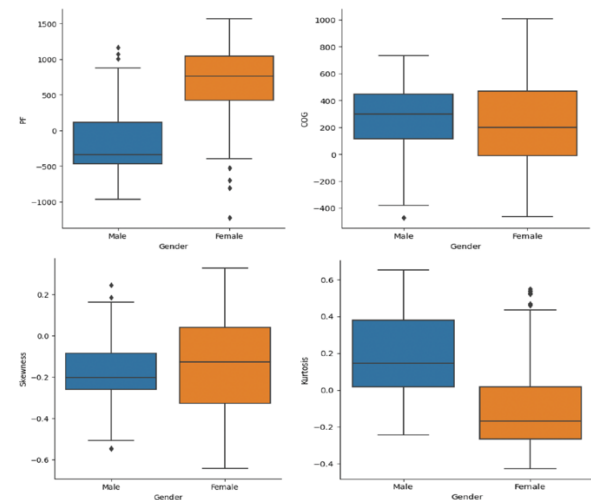

Figure 2: *The overall production by gender across 4 spectral movements (PF – peak frequency; COG – centre of gravity)*

3.2.2. Accent

For the investigation of accent effects, a growth curve model was estimated, with interactions of time and quadratic time with accent. Gender was included as a fixed effect when it lowered the AIC by more than two. The random effects structure of the model was dictated by whichever configuration lowered the AIC the most. For simplicity, results are presented in pairs of accents.

For the London-Cambridge pair, only one measure yielded significant differences between the accents, namely skewness. The skewness linear interaction was significant, estimated at -0.030 ($F(1, 82.322) = 6.528$, $p = .007$), as well as the quadratic interaction, estimated at -0.006 ($F(1, 87.125) = 5.086$, $p = .027$).

For the Cambridge and Belfast pairing, two measures yielded significant effects: spectral mean and kurtosis. The quadratic M1 interaction was significant, estimated -9.019 ($F(1, 52.102)$, $p = .028$). For kurtosis, the linear interaction was significant, estimated at 0.052 ($F(1, 75.786) = 4.769$, $p = .032$), as well as the quadratic interaction, estimated at -0.013 ($F(1, 95.147) = 7.787$, $p = .006$).

For the London and Belfast comparison, two measures yielded significant effects: skewness and kurtosis. The linear interaction of accent and time for skewness was significant, estimated 0.038 ($F(1, 74.960) = 8.593$, $p = .004$), as well as the quadratic interaction, estimated at 0.008 ($F(1, 77.494) = 6.710$, $p = .011$). For kurtosis, the linear interaction was significant, estimated 0.032 ($F(1, 77.876) = 7.789$, $p = .007$) as well as the quadratic interaction, estimated 0.006 ($F(1, 95.147) = 7.787$, $p = .006$). The estimates for the significant results are shown in table IV.

The M1 trajectory for Belfast is significantly more peaked than the Cambridge trajectory (-9.019). The negative significant quadratic interaction (-.006) for the London and Cambridge pair for skewness (M3) indicates that the Cambridge trajectory is flatter (recall that the trajectory of skewness is concave, as opposed to convex). The Cambridge trajectory is also more negatively sloped. The Belfast accent trajectory is significantly more peaked than the London accent (.008) and is significantly more positively sloped (.038).

The kurtosis (M4) trajectory for Belfast is significantly more peaked than the Cambridge trajectory (-.013), and is significantly more positively sloped (.052), The Belfast trajectory is significantly flatter (.006), and more positively sloped (.032) than the London trajectory.

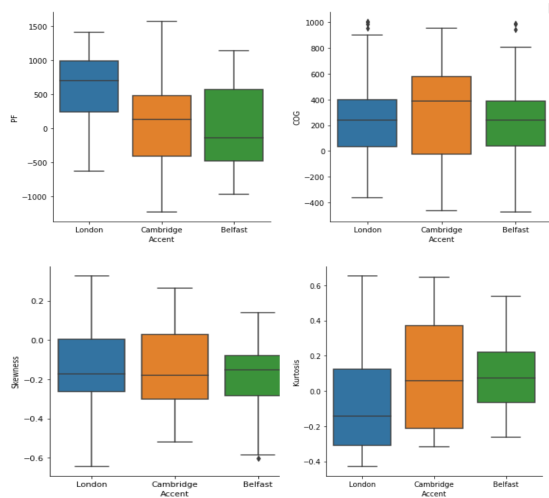The overall results by spectral measure and accents are shown in Figure 3.

Figure 3: *The overall production by accent across 4 spectral movements*

4.   Discussion

The growth-curve analysis indicates significant gender and accent differences during the selected duration. Significant differences between accents were found in the trajectories of various acoustic measures. The spectral mean (M1) for the alveolar fricative /s/ is more peaked for the London accent compared with the Cambridge accent, and the Belfast accent is significantly more peaked than the Cambridge accent. Given the complex articulatory acoustic mapping outlined in section 1, there can be several possible articulatory differences that underlie these effects: the Belfast and London accents may articulate /s/ with more raising or fronting of the jaw or articulate /s/ with a higher flow velocity through the constriction, among several other possibilities. The greater peakedness means there is a steeper decline in the centre of gravity measurements – this may indicate an earlier constriction release for the Belfast and London accents, compared with the Cambridge accent. However, in the absence of articulatory data, no firm conclusions may be drawn.

The kurtosis trajectories for Belfast were significantly more peaked than for Cambridge – does this indicate that the Belfast speakers lengthen the anterior cavity in some way more than the Cambridge speakers? The fact that the Belfast M1 trajectory was significantly more peaked than for Cambridge seems to conflict with this hypothesis, as the lengthening of the anterior cavity would be expected to lead to lower, and

therefore flatter, M1 values. Some sort of counter-acting raising or fronting of the jaw could take place, thus raising the M1 values, but without articulatory data no firm conclusions may be drawn.

The significant effects of gender on the trajectories of the fricative measures suggest different articulatory patterns for the male and female groups, within accents. These differences may be explained by normative anatomical differences between sexes or as reflexes of the speakers' gender identities as a socialized and learned behaviour. Only the latter explanation is tenable, due to the nature of the source and filter mechanisms of /s/ production.

The source and filter mechanisms of fricative production are predominantly determined by the space in front of the lingual constriction. This means that sexual differentiation is not relevant for /s/ production [41, 42], limited to the proportion of the teeth, the morphology of the palate and the relative position of the jaw, which is itself voluntarily controllable.

The pattern of results obtained from this study across the acoustic parameters may in fact indicate that the strategy of gender expression varies across the accents. For example, while the curvature of peak frequency differs significantly for the genders within the Belfast group, it does not for either the London or Cambridge speakers. Similarly, the curvature and slope of the kurtosis measure significantly vary across genders, only for the London and Cambridge speakers, but not for Belfast. This may therefore indicate a situation where different accents employ different gender distinction strategies, reflected by the different set of significant parameters for each accent. This finding would be consistent with Heffernan [43] who found that /s/ acoustics differentiate gender more for speakers of Canadian English, than for speakers of Japanese. It has also been noted that similar strategies for gender differentiation in /s/ are adopted across a wide range of languages [43, 44, 45] namely that female groups are distinguished by a concentration of energy at higher frequencies. This study adds to this the dynamic aspect of peakedness, indicating that female groups are also distinguished by a generally more peaked, more extreme trajectory of the acoustic measurements. However, although there are similarities between the accents in the way gender is differentiated, it seems that there may be differences in the articulatory strategies adopted by different accents, in linking the shared cross-linguistic association of higher frequency energy concentration with femininity, indicated by the differing significance of the spectral measures across accents.

The results obtained from this study indicate that the strategy of gender expression varies across accents, and that the male-female differentiation in the alveolar fricative follows similar patterns within each parameter, across accents.
Similar strategies for gender differentiation in /s/ are adopted across a wide range of languages, and the dynamic aspect of peakedness is also used.

5.   Conclusion

The key findings of this study are that the accents of London, Cambridge and Belfast significantly differ across measures taken over the middle portion of the fricative. Furthermore, it has been shown that there are gender differences in the acoustics of /s/ according to the slope and curvature of various spectral measurements. This study highlights how inherently dynamic acoustic information encodes sociophonetic information for the fricative /s/.

6. References

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