AN ACOUSTIC STUDY OF NORTH WELSH VOICELESS FRICATIVES

Mark J. Jones and Francis J. Nolan

Department of Linguistics, University of Cambridge, UK
mjj13@cam.ac.uk, fjn1@cam.ac.uk

ABSTRACT

Welsh, a Celtic language spoken in Wales, is unusual amongst the languages of the world in having a minimum of 8 fricative contrasts at (at least) 6 places of articulation, a relatively large number. Most research on fricatives has been conducted on languages with a relatively small (but cross-linguistically common) number of fricative place contrasts. Welsh fricatives have not previously been the subject of a detailed acoustic study across speakers. This study begins to fill that gap, and also provides some phonetic information on how one language organises a large system of fricative place contrasts.

Keywords: Speech acoustics, universals and typology.

1. INTRODUCTION

The production of fricatives involves the generation of audible turbulence (frication) in the vocal tract, either within a narrow constriction, or when the jet of air created by a constriction impinges on some downstream obstacle, or both [1, 2]. The IPA Alphabet provides a large set of symbols for fricatives, yet most languages have far fewer 'place' contrasts. According to the UPSID survey of the phonological systems of 317 languages [3], 296 languages (93.4% of the sample) have at least one fricative, but the modal pattern within the UPSID sample is for a language to contrast only two fricatives (19.6% of cases, 62 languages). The mean number of fricatives is just over 4, including voiced-voiceless pairs. Most languages under-utilise the range of available contrasts, but it is unclear why this is the case. Production variability across speakers and perceptual limitations may motivate use of a small number of fricative contrasts cross-linguistically, but until more languages with more fricatives are investigated, the reasons behind this tendency will remain unclear.

Welsh, a Celtic language spoken natively by around 700,000 people in Wales, is relatively unusual in having voiceless fricatives at 6 places of articulation: /f, θ, s, ʃ, ɬ, χ/. Voiced fricatives also occur at the most anterior places of articulation: /v/ and /ð/, as well as /z/ in English loanwords for some speakers. The place of articulation of /χ/ is regarded as uvular in the north (hence the transcription here), and velar in the south [4]. Standard Welsh and Northern Welsh, but not some southern Welsh dialects, have /h/, a labialised velar/uvular fricative /χʷ/ (usually treated phonologically as a cluster), and a voiceless trill, /r̥/, which may also be realised as a fricative and could be regarded phonologically as a cluster of /r/ and /h/ [4, 5].

This study investigates the acoustic characteristics of the 6 voiceless fricative place contrasts /f, θ, s, ʃ, ɬ, χ/ produced by native speakers of northern Welsh dialects. The realisation of /h/ did not form part of the data set. The realisations of /χʷ/ and /r̥/ were investigated, but are not reported here. The results will contribute to a small but growing body of knowledge on the acoustic characteristics of fricatives cross-linguistically, including some rare fricative types.

2. METHOD

Subjects were 5 native speakers of North Welsh living in north-west Wales who were Welsh-dominant by self-report. Results presented here come from 2 males and 3 females, aged 15-60.

Subjects controlled their own progress through a PowerPoint slide show. Each slide showed the carrier phrase *Dyweda X hefyd* 'Say X also', where X was the test word or one of a range of filler words. All test words contained a voiceless fricative in word-initial position followed by a low vowel. All fricatives were elicited in monosyllabic words except /ʃ/ and /θ/ which were elicited in disyllabic words.

The fricatives /θ/ and /χ/ are present in native vocabulary in non-initial position, e.g. final /θ/ and /χ/ in *llath* 'yard', and *braich* 'arm', but their occurrence in initial position is generally limited to where the fricative is the 'aspirate mutated' counterpart of a plosive [6, 7]. In order to elicit the initial /θ/ and /χ/, subjects were asked to read sentences in which the initial fricative had been morphosyntactically ‘mutated’ from the corresponding plosive after *ei* ‘her’. The ‘aspirate mutation’ is rare in vernacular speech, though it is common after *ei* ‘her’ [6, 7]. The word *ei* was written in brackets to indicate it should not be read aloud, so all fricatives occurred after spoken /a/ of *Dyweda*. Results are based on five repetitions of each test word.

Word-initial realisations of these fricatives are normal in aspirate mutation contexts where these occur, as in the standard language, so the forms produced by subjects, though morphophonologically complex, are no less natural than the elicitation of English /a/ would be in the word ‘ran’ (past tense of ‘run’). Not all fricatives occur word-medially or finally, so using aspirate mutated forms was necessary to investigate the full range.

Recordings were made in the field in a quiet room using a Sennheiser ME64 directional condenser microphone (cardioid, frequency response 40-20,000 Hz, ±2.5 dB) with a Demion pre-amplifier and recorded at a sampling rate of 22,050 Hz as WAV files onto a Creative Nomad Jukebox 3. The WAV files were then transferred to a Toshiba notebook computer for processing and analysis. All files were bandpass filtered (50-10,000 Hz, 100 Hz smoothing). Filtering and analysis was carried out using Praat.

The analysis involved measurements of total duration of frication, as well as both amplitude and spectral characteristics based on a 100 ms DFT spectrum made at the fricative midpoint. Total duration of frication was based on the onset and offset of aperiodic noise in the waveform and spectrogram, and was normalised to the average syllable duration of the elicitation phrase. The amplitude of the 100 ms window at the fricative midpoint was normalised to the amplitude of a 100 ms window of modal voicing in the following vowel. Where frication or modally voiced vowel was less than 100 ms in duration, the entire duration of frication or of modally voiced vowel was used for the analysis.

A range of measures employed in recent studies on fricatives (e.g. [8, 9]) was applied to the data, but only the results for amplitude, duration, and centre of gravity (COG) of the spectrum are reported here. Amplitude and COG were measured using pre-set commands in Praat. Statistical analysis in SPSS used one factor (consonant) repeated measures ANOVAs pooled across group means and Bonferroni pairwise comparisons.

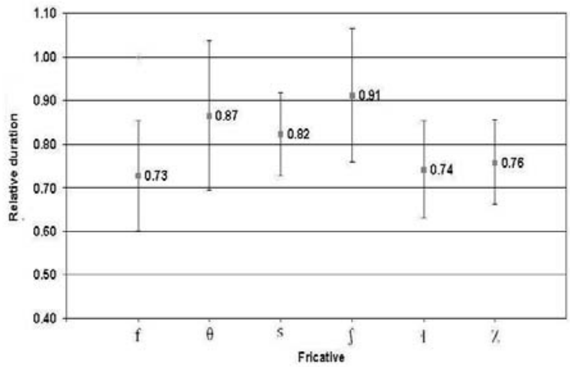
3. RESULTS

3.1. Relative duration

Average results for relative duration show that /ʃ/ is the longest and /f/ the shortest, with the intervening rank order /θ/ > /s/ > /χ/ > /ɬ/. The one factor repeated measures ANOVA (consonant) pooled across subjects indicated that relative duration differed significantly between fricatives: $F(5, 20) = 7.535$; $p = .000$. Bonferroni pairwise analysis indicated that only the difference between /s/ and /χ/ reached significance ($p = .031$).

If the results for individual subjects are ranked, /ʃ/ and /θ/ tend to be ranked as the longest fricatives, and /ɬ/ and /f/ as the shortest, in line with the ranking of the group average. Although the fact that only the words containing /ʃ/ and /θ/ were disyllables not monosyllables could have had an effect on the relative duration of the fricatives, for one female subject /θ/ was only the fourth longest fricative on average, with /s/ and /χ/ longer, though /ʃ/ was again longest for this subject. The relative length of /ʃ/ and /θ/ was therefore not necessarily due to the disyllabic context, but more research is clearly needed on this point. The results are presented with that caveat in mind.

Figure 1: Average relative duration normalised to average syllable duration by fricative. Error bars show ± 1 standard deviation.



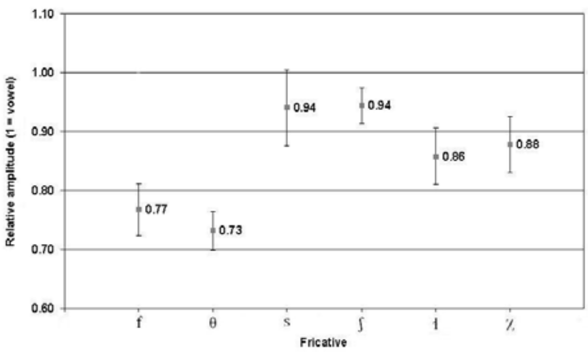
3.2. Relative amplitude

The average results for relative amplitude show a tripartite division into a high amplitude pair (/s/ and /ʃ/, average 0.94), a medium amplitude pair (/ɬ/ and /χ/, average 0.87), and a low amplitude pair (/θ/ and /f/, average 0.75). This division is maintained at the level of individual subjects in all cases but one: the youngest female subject has a relative amplitude for /χ/ which at 0.85 is greater than her relative amplitude for /s/ at 0.84, reflecting the low absolute amplitude values for /s/ for this subject on individual tokens.

Relative amplitude differed significantly across fricatives according to a one factor repeated measures ANOVA implemented using group means: $F(5, 20) = 31.540$; $p = .000$. Bonferroni pairwise comparisons showed that differences in relative amplitude reached significance for four pairs of fricatives: /f/ and /s/ ($p = .021$), /f/ and /ʃ/ ($p = .007$), and /θ/ and /s/ ($p = .044$) and /θ/ and /ʃ/ ($p = .004$).

Individual ranks revealed that for most subjects, the fricative with the highest average relative amplitude is /s/, and the fricative with the lowest relative amplitude ranking is /θ/ or /f/. Deviation from this pattern is seen for one male subjects who has /ʃ/ with the highest average relative amplitude. The female subjects present a more consistent pattern.

Figure 2: Average relative amplitude by fricative, normalised to amplitude of following vowel. Error bars show ± 1 standard deviation.

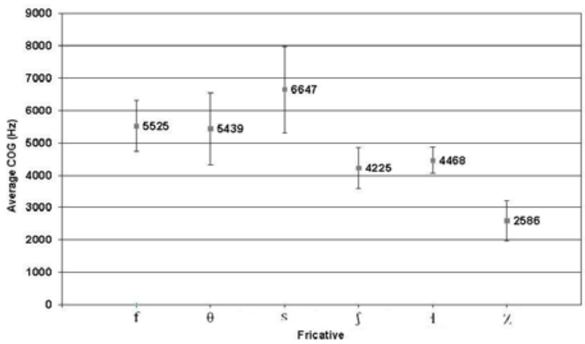


3.3. Centre of Gravity

The average COG across subjects decreases from 6647 Hz for /s/ to 2586 Hz for /χ/. A one factor repeated measures ANOVA shows that the group means for COG differ significantly: $F(5, 20) = 16.303$; $p = .000$. However, a Bonferroni pairwise analysis of COG means showed that only /f/ and /χ/ ($p = .028$), and /s/ and /χ/ ($p = .025$) differ significantly. The lack of pairwise significance is undoubtedly due to interspeaker variation in COG.

The rank order for average COG is /s/ > /f/ > /θ/ > /ɬ/ > /ʃ/ > /χ/. The female subjects show a consistent ranking of average COGs, with /s/ highest, /θ/ or /f/ as second or third highest, and the other fricative COGs appearing in descending order as /ɬ/ > /ʃ/ > /χ/. The two male subjects vary in their rankings, though /χ/ is again lowest for both. One has the rank order /f/ > /θ/ > /ʃ/ > /s/ > /ɬ/ > /χ/, with the relative ordering of /s/ and /ʃ/ a particular surprise. The other male subject has the ranking /s/ > /f/ > /ɬ/ > /θ/ > /ʃ/ > /χ/. The majority of subjects (4/5) have a higher COG for /ɬ/ than for /ʃ/. The COG for /f/ is ranked no lower than third in all cases. The female subjects do not necessarily have higher COGs for a given fricative than males: this is only true in all cases for /s/, /ɬ/, and /θ/.

Figure 3: Average COG (Hz) by fricative. Error bars show ± 1 standard deviation.



4. DISCUSSION

The acoustic analysis carried out on the relatively large fricative system of Welsh shows that statistically significant differences in COG, relative duration, and relative amplitude do occur at the group level, though post-hoc pairwise comparisons reveal a more complicated picture in which interspeaker variation in individual average values for some fricatives may play a considerable role. However, patterns do emerge, and relative ranking of individuals' results shows some similarities. The COG of the anterior fricatives /s/, /θ/ and /f/ generally outranks all others, with /ɬ/ usually ranking higher than /ʃ/, and /χ/ always ranked last.

Previous studies have attributed lower COG values to more posterior articulations [8], and this pattern is reflected here. However, the occasionally higher COG for /s/ than for /θ/ or /f/ is at odds with the predictions, and indicates that a simple relationship between anteriority and COG is unfounded. In many ways this is expected, as COG is substantially determined by anterior cavity size, rather than place of articulation per se. This distinction between place and cavity size is worth maintaining, particularly as /ʃ/ probably has a more anterior source of turbulence than /ɬ/, despite the higher COG seen for the lateral fricative in this study, but lip-rounding contributes to reducing COG.

The COG is, as one reviewer remarks, a "coarse" measure, but it has been widely used as a simple, if partial, descriptor for fricative spectra [8, 9]. Measures for other spectral moments (dispersion, skewness, kurtosis) will be presented in a more complete analysis of the full data set, including data on /χʷ/ (usually treated phonologically as a cluster), and the voiceless trill, /r̥/.

The duration effects show the greatest interspeaker variation in terms of ranking, perhaps in line with the observation that duration differences between fricatives rarely reach significance [8]. Amplitude ranks indicated a tripartite division between the /s/ and /ʃ/, /ɬ/ and /χ/, and /θ/ and /f/. The high amplitude pair /s/ and /ʃ/ are usually regarded as 'sibilants', and the low amplitude pair /θ/ and /f/ are usually regarded as 'non-sibilants' in studies of comparable English fricatives [9, 10]. The status of /ɬ/ and /χ/ with regard to sibilance and stridency is less clear. The tripartite division in Welsh suggests that a simple sibilant vs. non-sibilant dichotomy may be unwarranted in larger fricative systems.

The female Welsh subjects showed great interspeaker consistency, whereas more deviation from the norm was seen for the male subjects. These observations may be language-specific and therefore learnt, but raise a question about possible biological constraints on fricative production. Studies based solely on male speech may give the impression of greater interspeaker variability in fricative production than is actually present in a language, and conversely, all-female data may obscure the degree of interspeaker variability which must be dealt with perceptually. More research is needed to clarify whether there is a robust sex difference in production variability of fricatives cross-linguistically.

The apparent limitation of the number of fricative contrasts in most languages is likely to have multiple causes: articulatory, perceptual, and diachronic. Interspeaker variation may limit the extent to which the auditory space can be populated to a greater extent than is the case with vowels. The detailed study of fricative production and perception in a large system of contrasts like that of Welsh can reveal much about the limitations on fricative contrasts generally.

5. REFERENCES

[1] Shadle, C.H. 1997. The aerodynamics of speech. In: Hardcastle, W., Laver, J. (eds), *The Handbook of Phonetic Science*. Oxford: Blackwell, 33-64.

[2] Stevens, K.N. 2000. *Acoustic phonetics*. Cambridge, MA: The MIT Press.

[3] Maddieson, I.M. 1984. *Patterns of Sounds*. Cambridge: Cambridge University Press.

[4] Ball, M.J., Williams, B. 2001. *Welsh phonetics*. Llanbedr/Lampeter, The Edwin Mellen Press.

[5] Jones, G.E. 1984. The distinctive vowels and consonants in Welsh. In: Ball, M.J., Jones, G.E. (eds), *Welsh Phonology*. Cardiff: University of Wales Press, 40-64.

[6] King, G. 1996. *Modern Welsh: A Comprehensive Grammar*. London: Routledge.

[7] Ball, M.J., Müller, N. 1992. *Mutation in Welsh*. London: Routledge.

[8] Gordon, M., Barthmaier, P., Sands, K. 2002. A cross-linguistic acoustic study of voiceless fricatives. *Journal of the IPA* 32, 141-174.

[9] Jongman, A., Wayland, R., Wong, S. 2000. Acoustic characteristics of English fricatives. *J. Acoust. Soc. Am.* 108, 1252-1263.

[10] Behrens, S.J., Blumstein S.E. 1988. Acoustic characteristics of English voiceless fricatives: a descriptive analysis. *Journal of Phonetics* 16, 295-298.

ACKNOWLEDGEMENTS

This research was made possible by a Small Research Grant (SG-39674) from the British Academy. The first author gratefully acknowledges the support of a British Academy Post-doctoral Fellowship.