



Lecture 2-4: Acoustics of Fricatives

Overview

1. **Turbulence:** all phonetic fricatives involve **turbulence** as a source of excitation in the vocal tract. Turbulence arises when fluid is forced to flow at a high speed through a constriction or when fast moving fluid mixes with stationary fluid, see Figure 2-4.1. While at low speeds the fluid flow is smooth and predictable, at high speeds eddies and counter currents arise which create a disturbed flow of an unpredictable nature. This turbulent flow in air gives rise to random pressure variations that we hear as an aperiodic or noise waveform.
2. **Fricative excitation in the vocal tract:** turbulence in the vocal tract arises from two main causes: (i) when air flow becomes turbulent as it passes through a constriction, e.g. at the glottis or at the lips; (ii) when a constriction creates a high-velocity jet of air which hits a stationary sharp-edged obstacle, e.g. in /s/, where the alveolar constriction directs a jet at the upper teeth. Shadle's fricative model (see figure 2-4.2) is able to recreate most aspects of fricatives. Little is known in detail about the form of the spectrum of turbulent excitation in the vocal tract. We assume it is relatively flat in the speech frequencies from 1k to 10kHz.
3. **Source-filter model for fricatives:** the noise excitation is generated close to the point of constriction and relatively little energy passes back through the constriction from the posterior cavity to the anterior cavity. This means that most of the spectral shaping of the excitation is caused by the response of the cavity anterior to the constriction.
4. **Specific fricative production:** English fricatives show variation in place of constriction, forward cavity size and intensity, see figure 2-4.3. Fill in this table yourself.

Symbol	Source of friction	Spectrum shaping	Special character
h			
ʃ			
s			
θ			
f			

5. **Voiced fricatives:** in a sound like [z], vocal fold vibration occurs in the larynx while simultaneous turbulence is generated close to the alveolar ridge. Sound from the periodic source must pass through the constriction (or through the flesh of the neck) and so is quiet and predominantly low-frequency. Sound from the aperiodic source is modulated by the changing air-flow pattern caused by the periodic interruptions in flow caused by the vibrating vocal folds. This '**pulsed turbulence**' can be clearly seen in wide-band spectrograms, see figure 2-4.4.
6. **Bursts and Aspiration:** the spectra of bursts are similar to the spectra of fricatives made at the same place: this is because the anterior cavity is similar for both. The spectrum of aspiration is much like the spectra of [h], and is variable depending on the following vowel articulation, see figure 2-4.4.

Readings

At least one of:

- Johnson, *Acoustic & Auditory Phonetics* (1st edition), Chapter 6: Fricatives. *Comprehensive and clear description.*
- Kent & Read, *The Acoustic Analysis of Speech* (1st edition), Chapter 6: The acoustic characteristics of consonants, pp 121-130. *Essential information.*

Learning Activities

You can help yourself understand and remember this week's teaching by doing the following activities before next week:

1. Search the web for an easy-to-understand definition of turbulence.
2. Apply the Shadle model to English voiceless fricatives, identifying in each case the place of constriction, back cavity, front cavity and any obstacle.
3. Sketch a frequency domain explanation for the spectral quality of voiceless fricatives using the source-filter model. How would your diagrams change for voiced fricatives?
4. Glottal frication is found in [h], aspiration, whispering and breathy voice. Write a discussion of the similarities and differences between these.

If you are unsure about any of these, make sure you ask questions in the lab or in tutorial.

Reflections

You can improve your learning by reflecting on your understanding. Here are some suggestions for questions related to this week's teaching.

1. Think of some other situations when turbulence generates an audible noise.
2. What is the source of excitation in whistling? In playing a flute?
3. Why does the spectrum of turbulence have energy at every frequency?
4. Why are the sibilant fricatives so much louder than the others?
5. Think of two ways in which losing your two front teeth will affect fricative production.
6. How and why does lip-rounding affect fricative quality?
7. Do you think whispered speech has intonation?
8. What is meant by "coarticulation"? Think of some other examples.

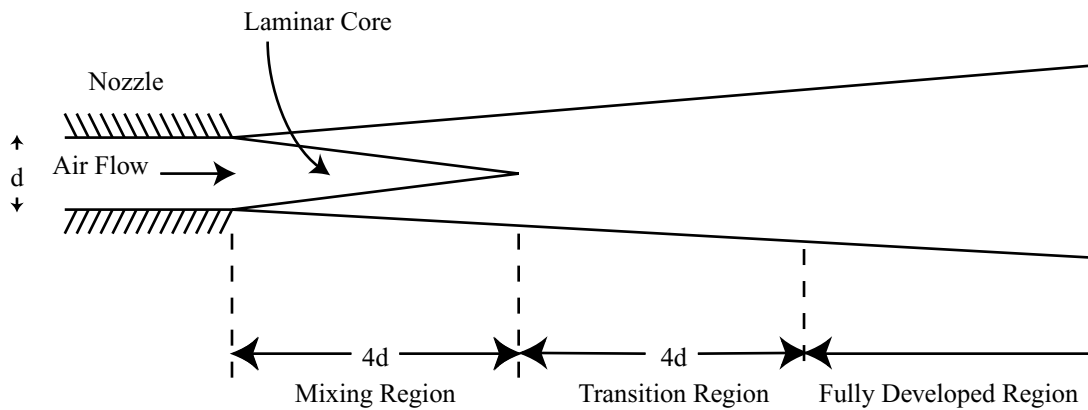
Examination Questions

These are questions from past exam papers. You may like to write outline answers to these, or to discuss them in tutorial.

1. Relate the acoustic properties of fricatives to their production. Discuss sources of variability in the acoustic form of the fricative in the word 'think'. [2003/4]
2. Describe the acoustics of English voiceless fricatives in terms of the source-filter model. Explain how and where the source signal is generated and how the filter can be affected by the articulation of preceding and following segments. [2006/7]
3. Show how the articulations of the English voiceless fricatives (/h,ʃ,s,θ,f/) have aerodynamic and acoustic consequences which broadly explain their spectral properties. How does simultaneous phonation in voiced fricatives affect this? [2007/8]

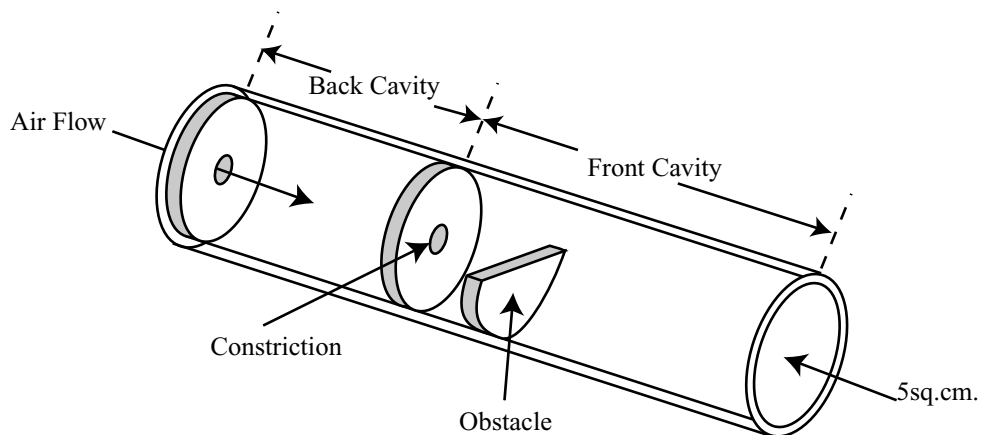
Figure 2-4.1 Acoustics of Fricatives

Turbulence in jet of air emerging from a nozzle



As a jet of air emerges from a nozzle, it hits the stationary air and mixes with it. Turbulence arises if the air is moving fast enough.

Figure 2-4.2 Physical Model of Fricative Production (after Shadle)



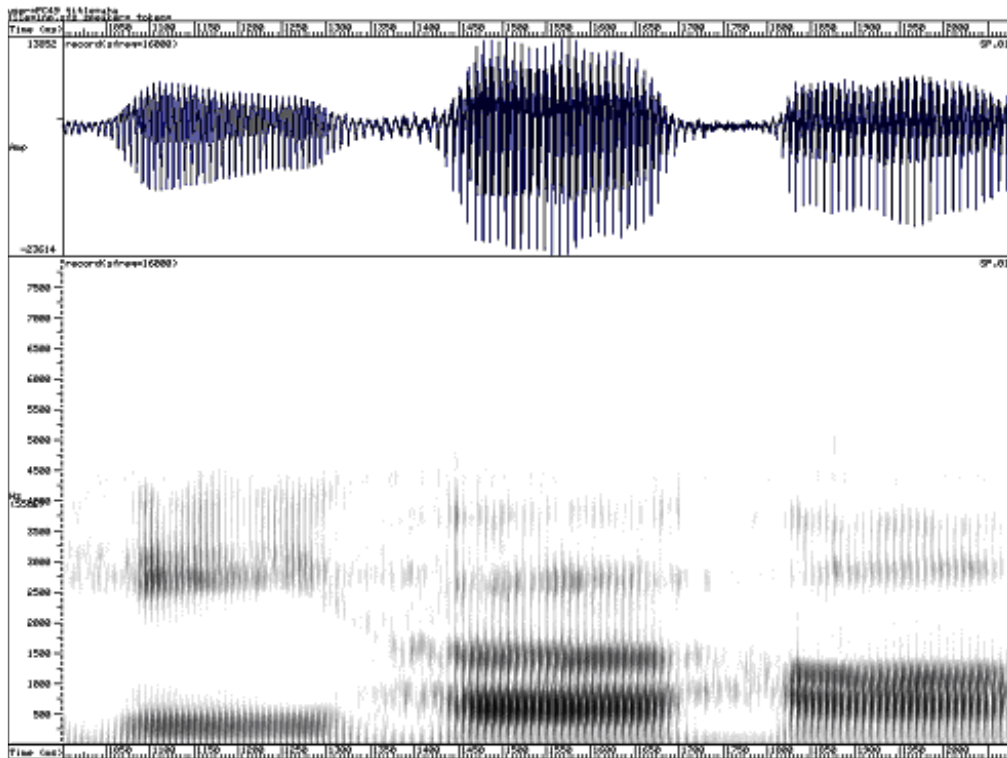
Shadle's model is a general model of fricative production, whereby air flow becomes turbulent both in a constriction and at an obstacle. The spectral shaping of the turbulence is mostly performed by the front cavity, although there are minor effects caused by the back cavity. The presence of the obstacle in the front cavity also affects its resonant characteristics.

Figure 2-4.3 Fricative Summary

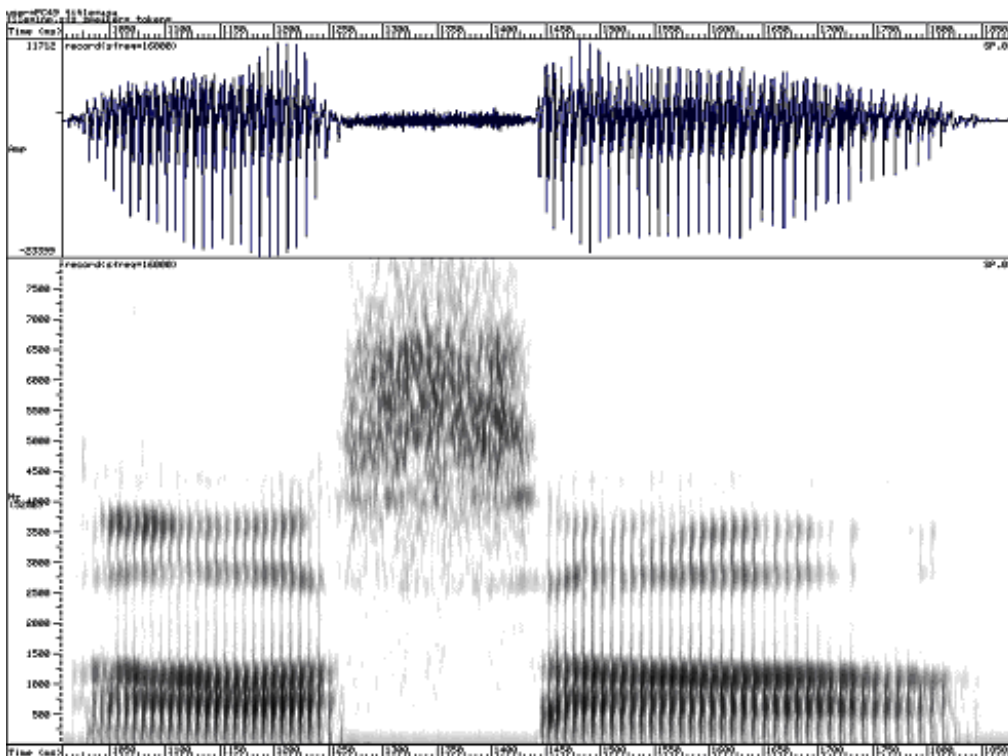
Fricative	h	x	ʃ	s	θ	f
Constriction	glottis	velum	palato-alveolar	alveolar	dental	labial
Obstacle	wall?	wall	lower teeth	upper teeth	none?	upper lip?
Front Cavity	vowel response	1-3kHz	2-4kHz	>4kHz	little effect?	little effect?

Figure 2-4.4 Fricative Spectrograms

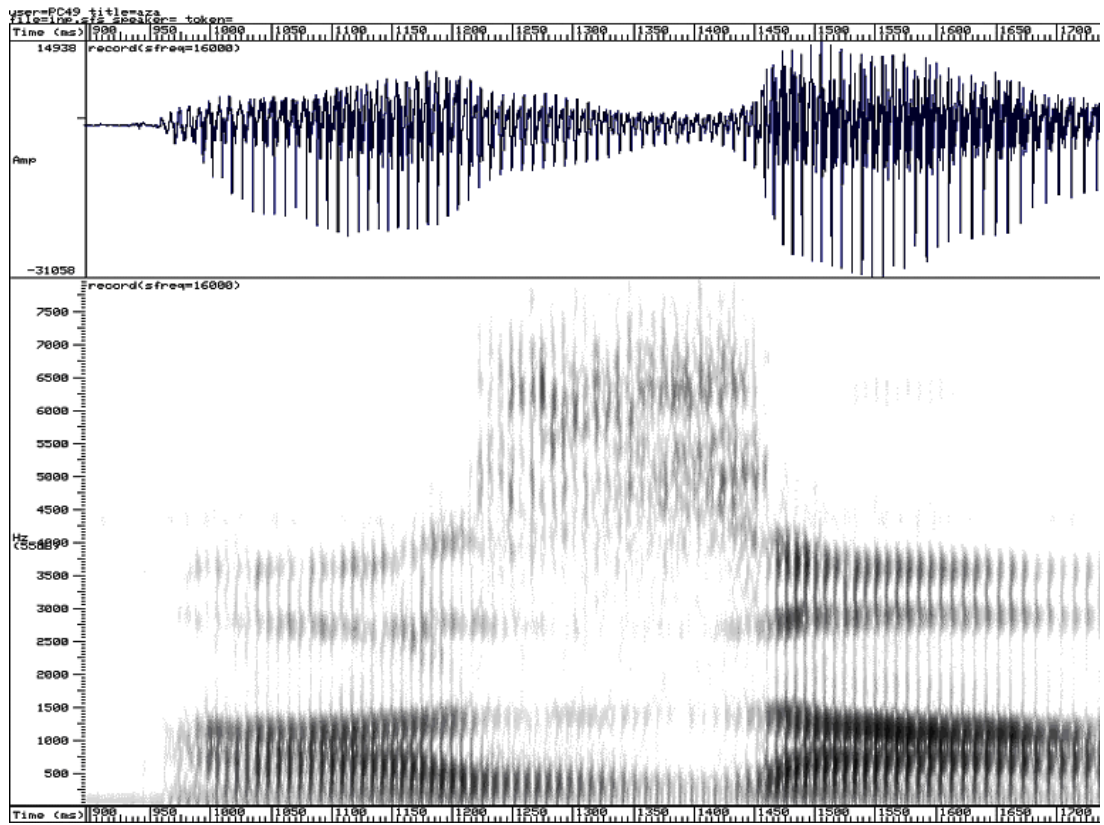
1. Coarticulation of /h/ with following vowel: [hihəhə]



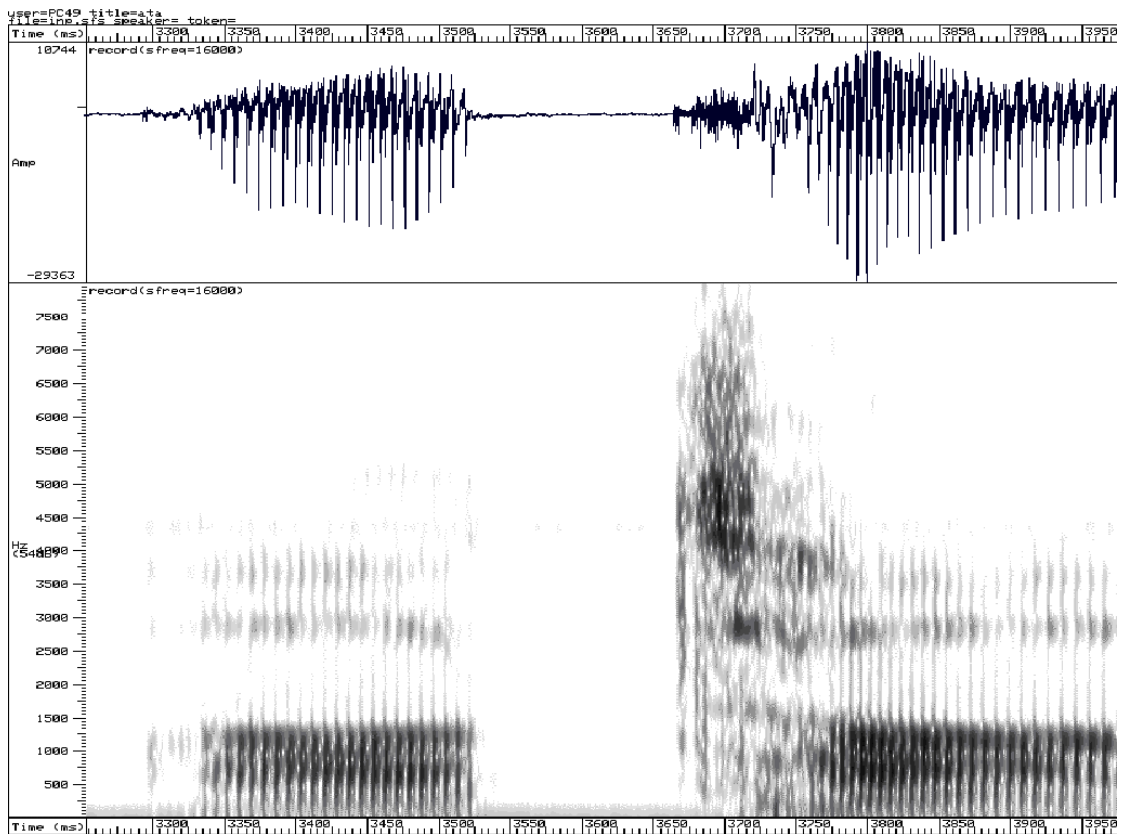
2. [asa]



3. [aza]



4. [at^ha]



Lab 2-4: Spectrographic Analysis of Fricatives

Introduction

Fricatives are produced by articulations that direct air flow through constrictions and/or onto obstacles causing turbulence. Turbulence provides a random, noise-like signal with a fairly flat spectrum in the normal range of speech frequencies. This noise is then shaped by cavity resonances adjoining the point of constriction; most significantly by any anterior cavity. In general, the further forward in the mouth the constriction occurs, the smaller the anterior cavity and the higher the frequency of the main spectral peak for the fricative. However the most front articulations also have the most heavily damped resonant cavities.

In this lab we shall look at the spectral and spectrographic properties of some common fricatives.

Scientific Objectives

- to investigate the main spectral properties of fricatives and relate these to their articulation.

Learning Objectives

- to become familiar with the visual form of fricatives on a spectrogram.
- to understand the relationship between a spectrographic picture and a spectral cross-section, and the advantages and disadvantages of each.
- to compare normal fricative production with one disordered production.
- to become more familiar with the dynamic characteristics of the spectrographic patterning of speech.

Method

You will be given a ready-prepared print containing both wide-band and narrow-band spectrogram of your production of the sentence:

'The thin fish swims in heaving seas'

You can use the Esection program on the laboratory computers to print spectral cross-sections through the different fricatives (<http://www.phon.ucl.ac.uk/resource/sfs/>). You should ensure the recording has been captured at a high sampling rate to display frequencies up to 16000Hz. Under the Menu "Signal|Configure Analysis", set "Analysis Window Size" to 0.002s, and "Number of Predictor Coefficients" to 10.

Observations

1. Annotate your spectrogram using a *broad phonetic* transcription with an appropriate level of allophonic detail. Pay particular attention to voicing.
2. Your utterance has been acquired onto the laboratory PCs. Print out spectral cross-sections for [h, ʃ, s, θ, f]. Make sure you properly title each print. Try and find evidence to confirm the main predictions that the main spectral peak becomes higher in frequency and greater in bandwidth as the articulation becomes more fronted.
3. Compare [f] in "fish" with [v] in "heaving". What similarities and differences can you observe in the spectrogram.
4. Compare [z] in "swims" with [z] in "seas". How do you explain the differences in the spectrogram?
5. Compare [s] in "swims" with [s] in "seas". How do you explain the differences in the spectrogram?

6. Record /ɑ:sɑ: α:zɑ:/ and look for pulsed turbulence. What causes this?
7. Display a wide-band spectrogram for the "Sean's snowman" sentence by Tim. Compare the fricatives in the spectrogram and in the spectral cross-sections with your own. What differences can you observe? What does this tell us about Tim's articulation?

Concluding Remarks

1. What other aspects of the spectrographic pattern can be seen that might allow a listener to differentiate between fricatives? (Hint: look at the edges of adjacent vowels)
2. Discuss the statement: "If /h/ is just a vowel with turbulent noise excitation, then varieties of [h] should be as distinct as varieties of vowels".

