INTRODUCTION TO ACOUSTIC PHONETICS 3

Hilary Term, week 7
01 March 2006

1. Acoustic properties of fricatives

Fricative consonants are aperiodic sounds but we can still use source-filter theory to account for their production. Their turbulent noise source is generated as the result of the airflow travelling through a narrow constriction. Then this aperiodic continuous source is filtered by the vocal tract.

1.1. Sound source in fricatives

In production of fricatives the source is **turbulent noise** which occurs when air flows rapidly through a constriction. The turbulent noise is a result of irregular particle movement, which happens when particles leave a relatively narrow channel and hit inert outside air. The physical factors determining turbulence are the *size of the channel* and *volume velocity* of the airflow (volume of air going past a fixed point per unit of time).

A turbulent noise can be produced at any point along the vocal tract where a constriction can be formed, including the glottis. Noise produced at a glottal constriction is known as **aspiration noise**. [h] and whispered speech have aspiration noise source. **Frication noise** is produced through a supraglottal constriction that can occur at many different points along the vocal tract.

Frication/aspiration noise source can be combined with glottal periodic source as in production of voiced fricatives. Voiced fricatives are not very common cross-linguistically because they are relatively harder to produce. Turbulent noise requires a high velocity of airflow but during voicing, airflow from the lungs is slowed by the constant closing (and opening) of the glottis. As a result voiced fricatives sometimes lose frication and become glides.

There are two major mechanisms for generating turbulence noise at a given constriction and these two mechanisms produce noise sources that are quite different in amplitude/intensity.

(1) **Channel turbulence** - air stream is directed in such a way that it does not impinge on any surface; flow of air from the constriction forms a jet which is distributed over the area in front of the constriction. Resulting noise is of low intensity. This source is involved in production of [ɸ], [β] and [h].

(2) **Obstacle turbulence** - air stream at a constriction is directed against a surface or obstruction (Fig. 1). The presence of the obstacle increases the intensity.

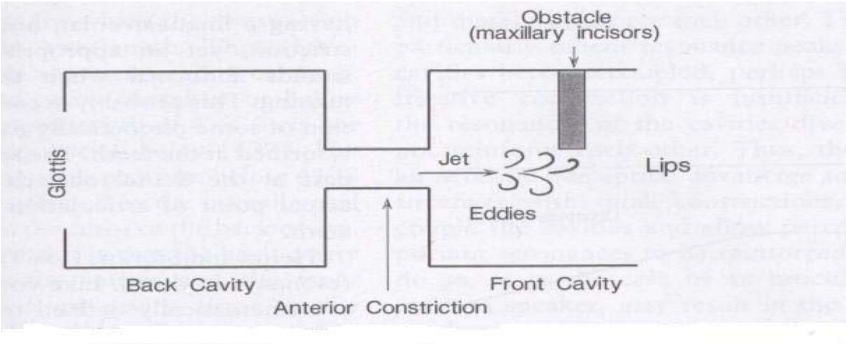

Fig. 1. Tube model of the vocal tract for obstacle fricatives. From Lass (1996)

Aperiodic turbulent noise is idealised as having a straight line spectrum, i.e. consisting of all frequencies at equal amplitude. However, in speech fricative source spectra vary in shape depending on how the fricative is produced. Shadle (1990) demonstrated that there are at least two types of fricative sources that have distinctive spectra.

a) *Wall* or *surface source* results when the airflow impinges on the surface that is nearly parallel to its direction, as in the production of the sounds [x] and [χ]. Spectrum of a wall source has a broad peak around 4-9 kHz and is relatively low in amplitude (Fig. 2).

b) *Obstacle source* occurs when the airflow is directed against an obstacle which is roughly at a right angle to its direction. For example, the tongue may be grooved to direct the air stream against upper or lower teeth. This source is involved in production of *strident* fricatives, e.g. [s], [ʃ], [z] and [ʒ]. Spectrum of an obstacle source is gradually falling in higher frequency region but overall source amplitude is relatively high (Fig. 2).

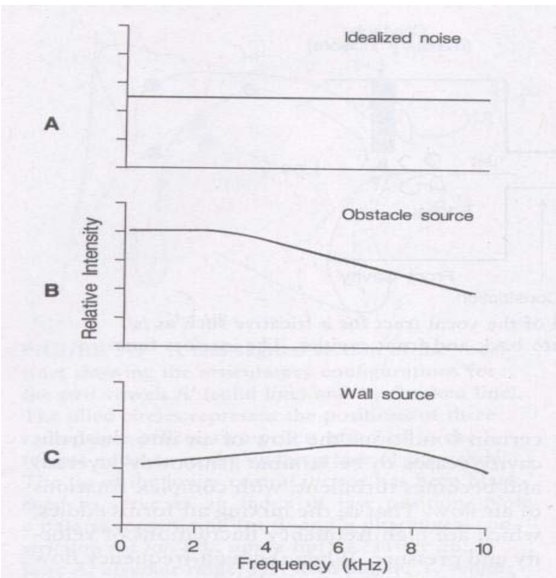

Fig. 2. Examples of spectra for fricatives sounds. From Lass (1996)

1.2. Filtering effects in fricatives

Main difference between filter function of vowels and fricatives is the presence of **antiformants**, or zeros. Zeros are frequencies that are not transmitted by the vocal tract but are instead ‘trapped’ in the back cavity. They arise because in production of fricatives vocal tract is radically constricted,

The front cavity behaves like a half-open tube and acts as a main filter. Thus filtering function and poles of high energy are determined by the size and length of this cavity. Longer front cavity gives rise to lower resonant frequencies Conversely, constrictions occurring more forward in the mouth result in shorter front cavity that has high resonances.

Thus *alveolars* have an energy peak at around 7500 Hz although there may also be a minor peak at 4500 Hz. *Post-alveolars* have a peak at around 3500-4000 Hz. The further back in the vocal tract the constriction occurs, the lower the peak of spectral energy is (Fig. 3). Therefore *pharyngeal* fricatives have peaks at a lower frequency then *velar* ones, velars have peaks at a lower frequency than *palatals* etc. Production of *glottal* fricative does not involve the constriction in the vocal tract, therefore the filtering function is very similar to vowel resonant structure.

Sounds which are produced with constriction in the very front of the mouth, such as dentals, labiodentals and bilabials have flatter spectra because there is almost no vocal tract in front of the constriction to filter the sound. Generally, *labiodentals and dentals* both exhibit a slight emphasis in high frequency energy while *bilabials* have relatively more energy in lower parts of spectrum.

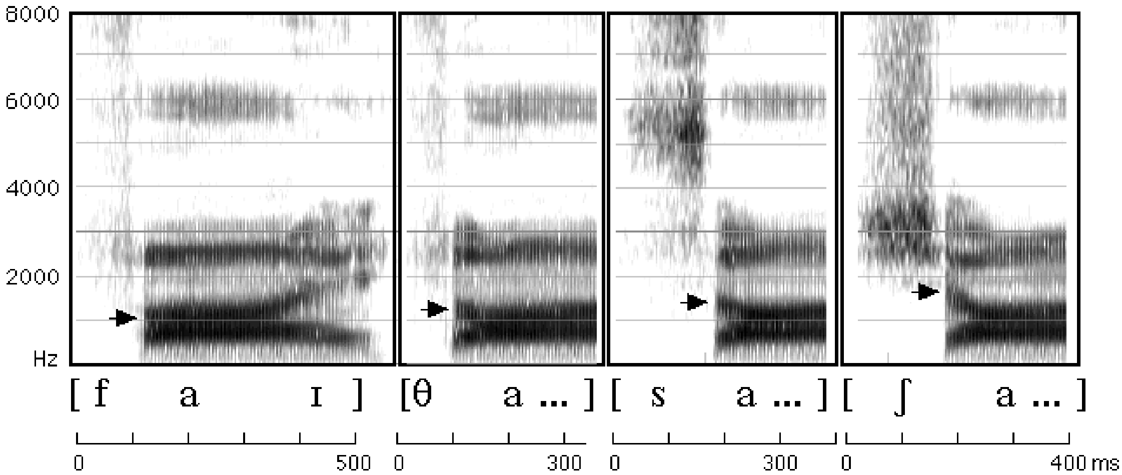

Fig. 3. Spectrograms of 4 fricatives in [C+ai] context. From Ladefoged (2001)

2. Acoustic properties of stops and affricates

The production of stop consonants involves a sequence of articulatory and acoustic events; therefore they have more complicated acoustic properties. When talking about production of stops it is useful to distinguish several stages/phases. Note that these stages are not always discrete, they often overlap temporally and not every stage is necessary for production of a given stop in a given context.

i) if the stop is preceded by a vowel, a closing phase, or transition between the vowel and the stop;
ii) an interval of complete closure;
iii) release of the closure;

iv) in some stops, an interval of aspiration;
v) an interval of transitions from the stop into the following vowel.

As their production requires a complete closure, all stops have a period of silence; except for fully voiced (e.g. some intervocalic voiced stops in English) that have a low level of periodic energy during the closure.

2.1. Sound sources in stop consonants

Because of the complex nature of stop production there are several sound sources involved.

i) during the closing phase the most common source is *voicing* but in pre-aspirated stops there may also be *aspiration noise*;
ii) usually no source during closure, except for voiced stops when *periodic glottal* source is possible;
iii) release produces aperiodic *transient noise* known as **release burst**;
iv) following release *continuous aperiodic noise* is generated; it can be *aspiration* (aspirated stops) or *frication* (affricates);
v) during transition *voicing* starts.

The release burst is very brief transient noise which has a flat spectrum. Irrespective of other variations, bursts tend to show a strength hierarchy: voiceless aspirated > voiceless unaspirated > voiced. i.e. burst spectrum of voiceless stops has more energy than that of voiced stops. The source spectra for aspiration and frication are nearly the same as for fricatives.

2.2. Vocal tract filter function in stops

Again production of stops is determined by several different types of filtering effects.

i) part of the vocal tract in front of the constriction influences the spectral properties of the release burst, re-shaping its flat spectrum;
ii) complete closure of the upper vocal tract introduces antiformants into filtering function; it also decreases F_1 to a value close to zero.
iii) before and after release front and back cavities are coupled, therefore the filter can be presented as a two-tube model. As the articulators move from the position of the stop to the position of the vowel, the formants move rapidly. These are the **formant transitions**, which are seen in the adjacent vowel. Formant transitions are important cues for the place of articulation.

3. Acoustic properties of nasals, liquids and glides

Nasals and liquids share periodic glottal source with vowels. But their filtering effects are more complicated. Vocal tract filtering effects for vowels were modelled as resonances of coupled tubes, each of which was open at one end. Nasals and laterals are characterized by the presence of a side branch, i.e. a closed tube.

During the production of nasal consonants, the velum is lowered so that the pathway from the pharynx to the nasal passages is open and air flows from the lungs out through the nostrils. In nasal stops, the mouth cavity is closed off by a complete constriction in the vocal tract. (Fig. 4).

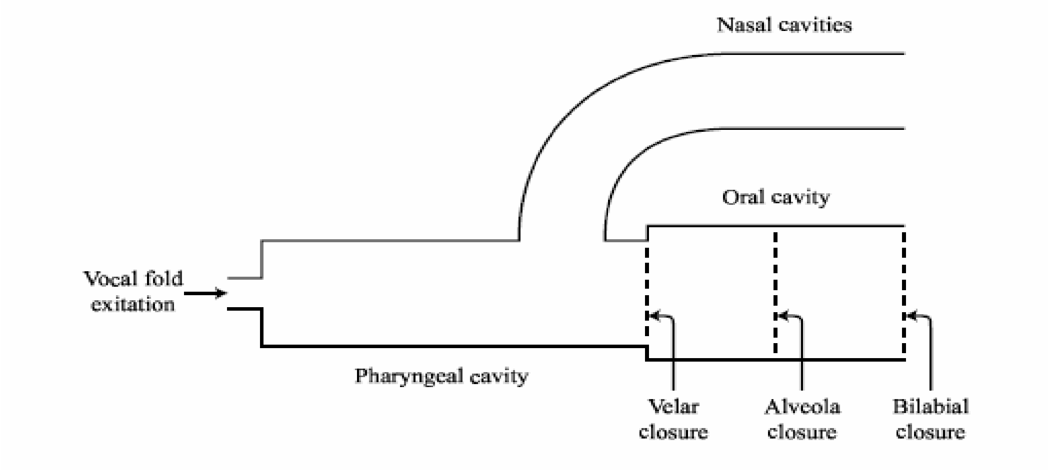

Fig. 4. Tube model for the production of nasal consonants

This means that nasal consonants that are made with an oral constriction add a side cavity onto the long pharyngeal-nasal tube. The side cavity is a tube closed at one end, thus resonating frequency components of the side branch are not transmitted out of the vocal tract but are "absorbed" by the side cavity. This gives rise to antiformants. Nasals have several antiformants which are determined by the size of side cavity. As [m] has the longest side resonator its antiformants are low and narrowly spaced (first antiformant A_1 around 800-1000 Hz). Antiformants of [n] are higher and wider spaced (A_1 around 2000 Hz) and short oral branch produces the highest and widest antiformants for [ŋ] (A_1 around 3000 Hz).

Other characteristic properties of nasals include:

(i) low F_1 (sometimes called N_1 or *nasal murmur*), typical figures 250-300 Hz, as a result of increase in overall length of the filtering tract;
(ii) formants are much weaker than in vowel sounds, i.e. the peaks are lower in amplitude due to the fact that soft mucous membranes of nasal cavity absorb sound.

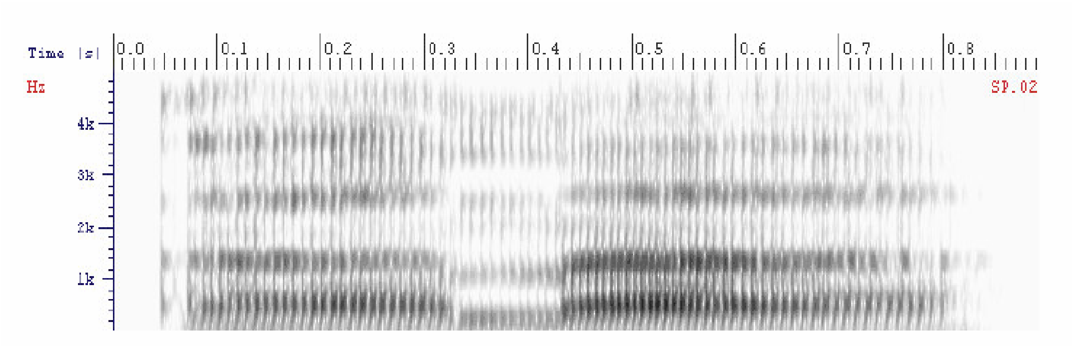

Fig. 5. Spectrogram of [əmə] sequence

Liquids demonstrate similar features to those of nasals. They typically have a clear formant structure, though with less energy than vowels. F_1 is much lower than in vowels and formant transitions are usually very sharp, although less so in trills.

Laterals also have antiformants, due to the presence of a side cavity – a pocket of air on top of the tongue. However their antiformants are usually less strong than those in nasals.

Trills and [ɹ] approximant are distinguished by low F_3 but otherwise their spectral structure can vary considerably.

Filter characteristics of the glides [j] and [w] are very similar to those of the vowels [i] and [u]. The main difference between glides and vowels is that the former do not have a steady-state positions, i.e they cannot be characterized in terms of stable formant values, ultimately they are formant transitions.

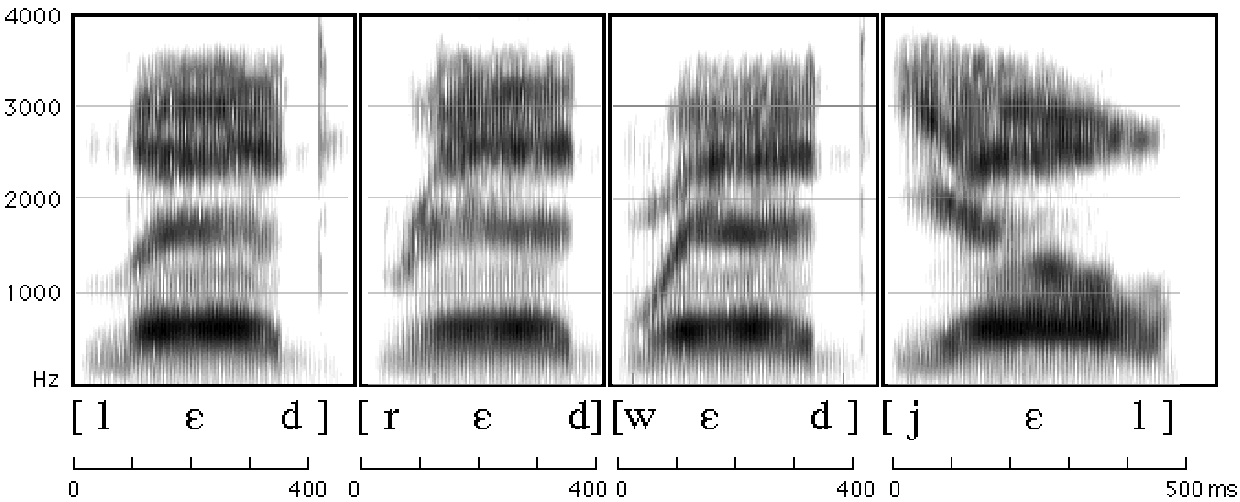

Fig. 6. Spectrograms illustrating distinctive properties of liquids and glides in English. From Ladefoged (2001)

Reading:

Fry, D.B. (1979) *The Physics of Speech*. Cambridge: Cambridge University Press (chapter 10-11).

Johnson, K. (2003) *Acoustic and Auditory Phonetics*. 2nd edition. Oxford: Blackwell (chapters 6-9).

Kent, R. D., Dembowski, J., and Lass, N. J. (1996) The Acoustic Characteristics of American English. In N. J. Lass (ed.), *Principles of Experimental Phonetics*, pp. 185-225.

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Shadle, C.H. (1990) Articulatory-Acoustic Relationships in Fricative Consonants. In W.J. Hardcastle and A. Marchal (eds.), *Speech Production and Speech Modelling*, pp. 187-209.

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