Lecture 2-5: Formant Transitions

Overview

1. **Stationary and Dynamic sounds**: so far we have been concerned with sounds such as monophthongs and fricatives for which the quality does not rely on a moving vocal tract. We have explained such stationary or continuant sounds by looking only at a spectral cross-section and considering the source spectrum and the vocal tract frequency response. However many speech sounds require movements of the vocal tract; these can be called dynamic or non-continuant sounds. The acoustics of such sounds need to be studied using a spectrogram.
2. **Diphthongs**: the simplest dynamic sounds are diphthongs, which can be thought of as arising from a tongue gesture which starts and stops at different vowel articulations. Acoustically, we hear the change in articulation as a movement in the formant frequencies caused by the changing frequency response of the vocal tract tube. Since the articulators move in a smooth manner, we also see a smooth movement in formant frequency.
3. **Approximants:** the **semi-vowels** [w] and [j] have articulations that are similar to vowel articulations. The formant frequencies for [w] are similar to those for [u], while the formant frequencies for [j] are similar to those for [i]. The **liquids** [l] and [r] have articulations distinct from vowels and hence have their own distinct formant pattern. The quality of [l] is strongly affected by the position of the back of the tongue, which leads to a range of formant frequencies and to sounds which vary in 'darkness' or palatalisation. Formant frequencies for [r] are strongly affected by any **retroflexion** of the tongue, which can lead to a dramatic lowering of the third formant F3. In general, approximants differ from diphthongs by the speed of the gestures and the subsequent formant transitions that arise.
4. **Acoustic consequences of obstructions:** sounds such as fricatives and stops involve obstructions being made in the vocal tract. Although the gestures that make these obstructions are quite rapid, we can see evidence of the closing movement in the formant pattern going into an obstruction, and evidence of the opening movement coming out. If we study the formant frequency movements that occur as an obstruction is made we see a lowering of F1 for all places of articulation, and changes in F2 and F3 which vary according to the place of articulation. These **formant transitions** are perceptually important clues (or **cues**) to the manner (F1) and the place (F2 & F3) of the consonant. It is important to understand that the exact shape of the formant transitions will vary according to the neighbouring vowel: they must start at the formant frequencies for the preceding vowel or they must end at the formant frequencies for the following vowel. However the frequency to which each transition is directed seems to be fairly consistent for a given consonant across different vowel contexts. These frequencies are called the consonant's **locus frequencies**, see figure 2-5.1.
5. **Manner series:** many common elements of the formant transition pattern can be observed for a single place of articulation as the manner varies from vowel to approximant to fricative to stop, see figure 2-5.2.

Reading

At least one from:

- Kent & Read, The Acoustic Analysis of Speech (1st edition), Chapter 6:The acoustic characteristics of consonants, pp 116-120. *Discussion of transitions & loci.*
- Hewlett & Beck, An introduction to the science of phonetics. Chapter 12: Spectrograms, pp165-178. *Introduction to speech dynamics as seen on spectrograms. Do have a go with the exercises!.*

Learning Activities

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

1. Use a program like WASP (http://www.phon.ucl.ac.uk/resource/sfs/wasp.htm) to record yourself saying [idi], [ede], [ædæ], [ɑdɑ], [ɔdɔ]. Study the spectrographic pattern to see if the F2 transitions demonstrate evidence of a common locus.
2. Much discussion about how phonetic information is embedded in speech signals seems to be concerned with stationary spectral quality. Make a list of examples where dynamic changes in the signal are also important for conveying phonetic information.
3. Look up some of the original scientific articles on formant locus frequencies – you should be able to understand these now. For example: Delattre, Liberman & Cooper, JASA 27 (1955) 769-773.

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

Frequently Asked Questions

What is "Locus Frequency"?

Formant transitions from vowels into obstruents, or from obstruents into vowels vary in shape depending on the formant frequencies characteristic of the vowel and on the place and manner of the consonant. Human listeners appear to be able to use these formant transitions to identify the place and manner of the consonant, even when other aspects of the spectrographic pattern of the consonant are missing or ambiguous. But since the transitions are different in shape before different vowels (the formant trajectory must have one end rooted at the vowel formant frequencies), what is it about the transition that informs the listener about the consonant? The hypothesis is that it is the frequency that each formant transition is heading towards as a obstruction is made, or the frequency from which the transition comes as the obstruction is released that is important. This frequency seems to be characteristic of the consonantal place and manner, and appears to be roughly the same in different vowel contexts. Thus each formant for each consonant has a 'target' frequency which the listener can use to help identification of the consonant and which is the 'locus' of all formant transitions.

Reflections

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

1. Put consonant phonemes into two groups depending on whether their main acoustic properties are stationary or dynamic.
2. Discuss the statement: "all speech sounds have some dynamic aspect"?
3. What causes a formant transition? Why can we hear them?
4. Why are /w/ and /j/ sometimes called "semi-vowels"?
5. What causes the acoustic difference between clear-/l/ and dark-/l/?
6. If the F1 locus frequency for [d] is 0Hz, and F2 locus frequency for [d] is 1800Hz, sketch the spectrographic pattern for /ɑːd/ and /iːd/.
7. How can you use a statistical test to check whether there are systematic differences in the production of two speech sounds?
8. How can you check whether a listener makes use of a systematic acoustic difference between two speech sounds?

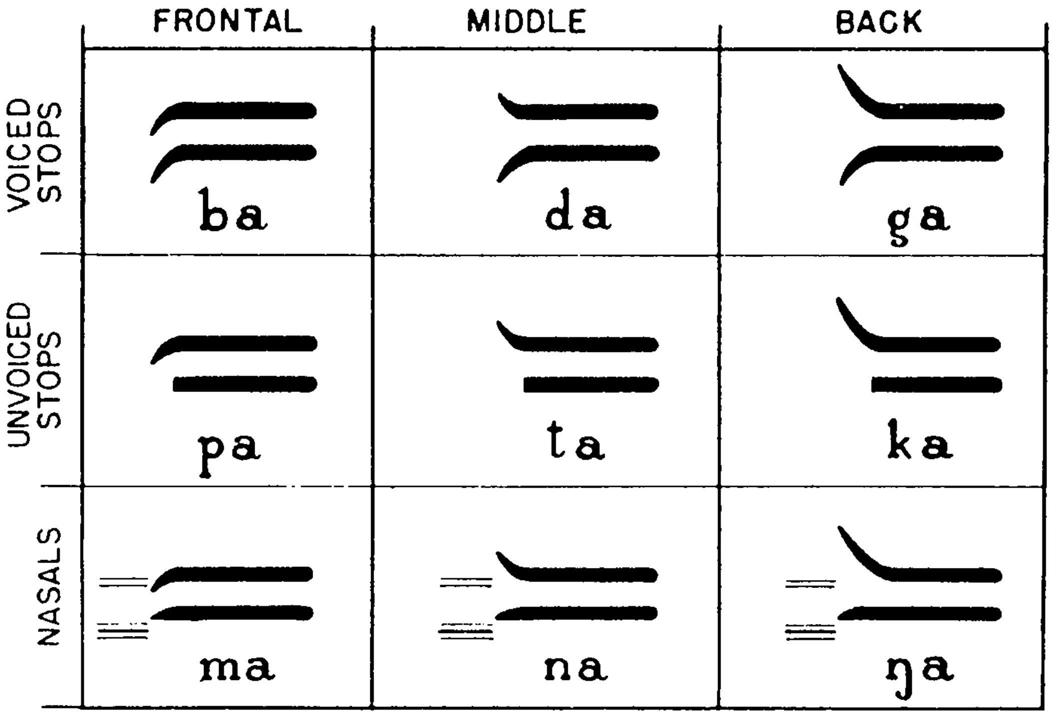
Examination Questions

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

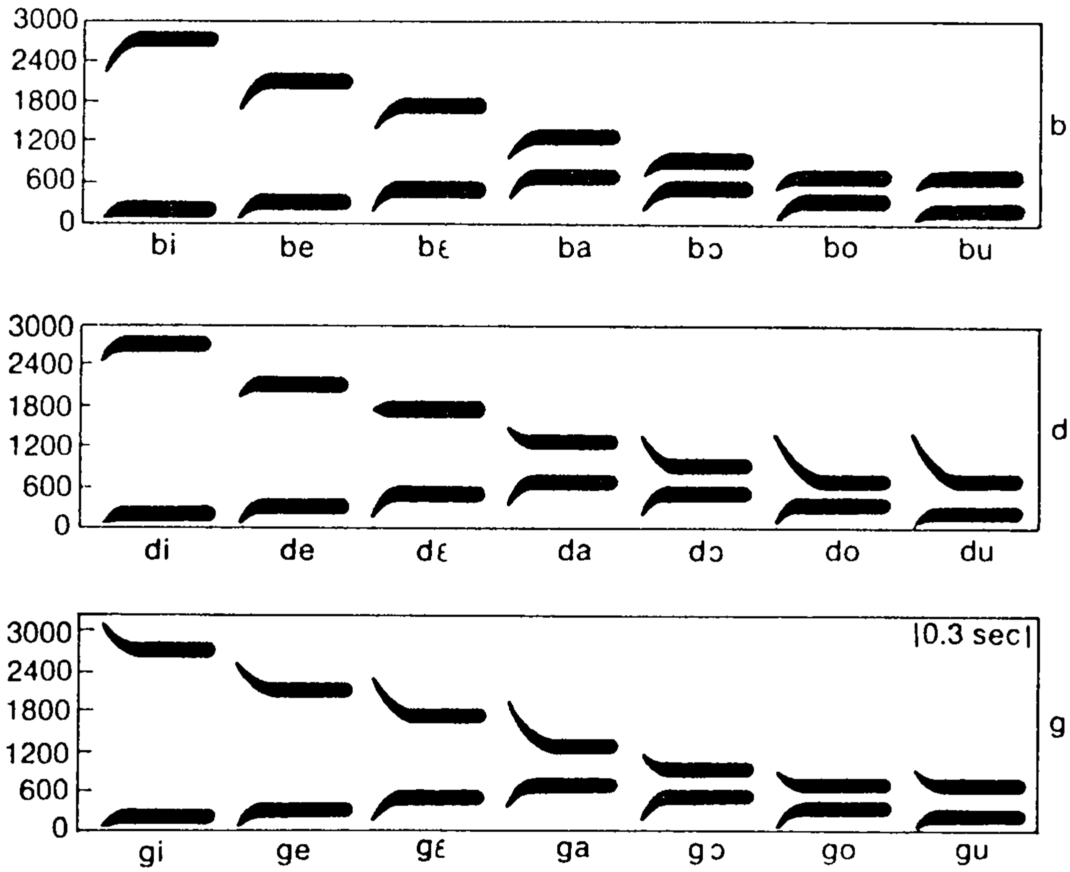
1. Use stylised spectrograms to show how realisations of /d/ vary depending on the vowel context. Use your sketches to justify the concept of "locus frequency". How can locus frequencies be used to help listeners differentiate the place of plosives in English? [2004/5]
2. Use stylised spectrograms to describe how formant transitions in a consonant-vowel syllable can sometimes provide cues to the voice, place and manner of the consonant. Explain how these cues can be independent of the target formant frequencies for the vowel. [2008/9]
3. Explain why the formant pattern for a vowel-plosive-vowel sequence varies across different choices of vowel for the same consonant. Use stylised spectrograms to explain how such variation in the formant patterns can then be used by listeners to help identify the place of the consonant independently from the vowel. [2009/10]

2-5.1 Patterns in Formant Transitions

1. Schematic formant transition patterns varying in place and manner

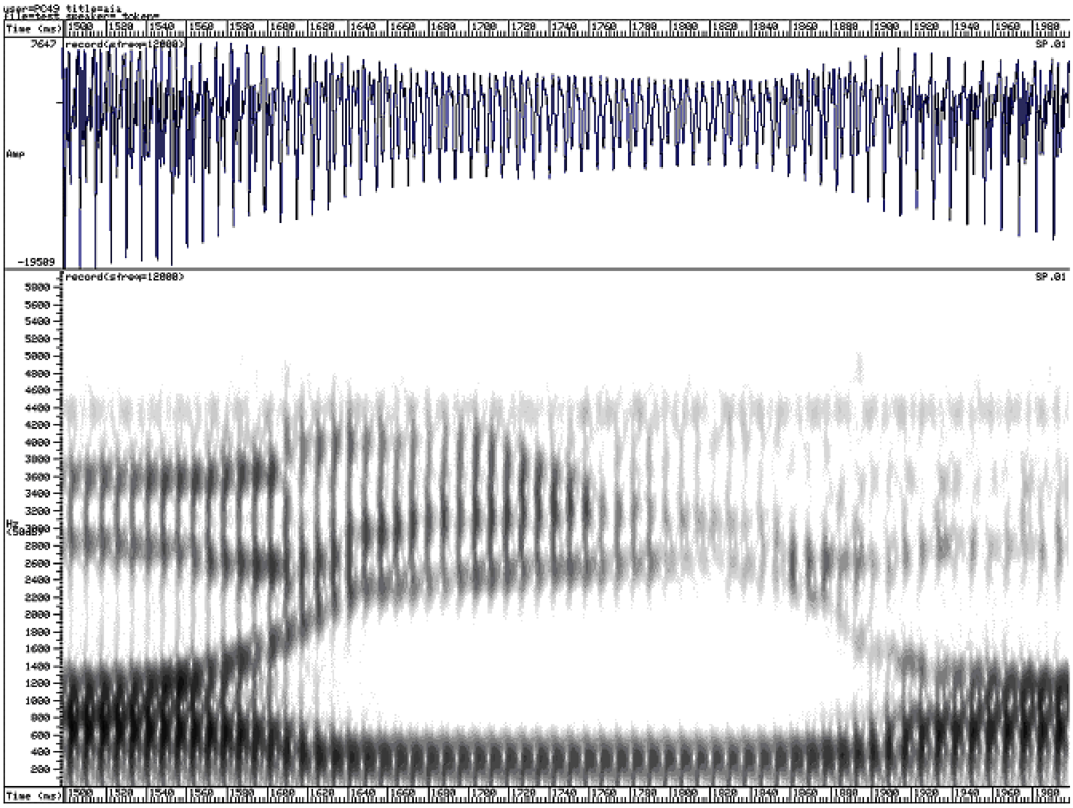


2. Schematic formant transition patterns for voiced stop-vowel syllables

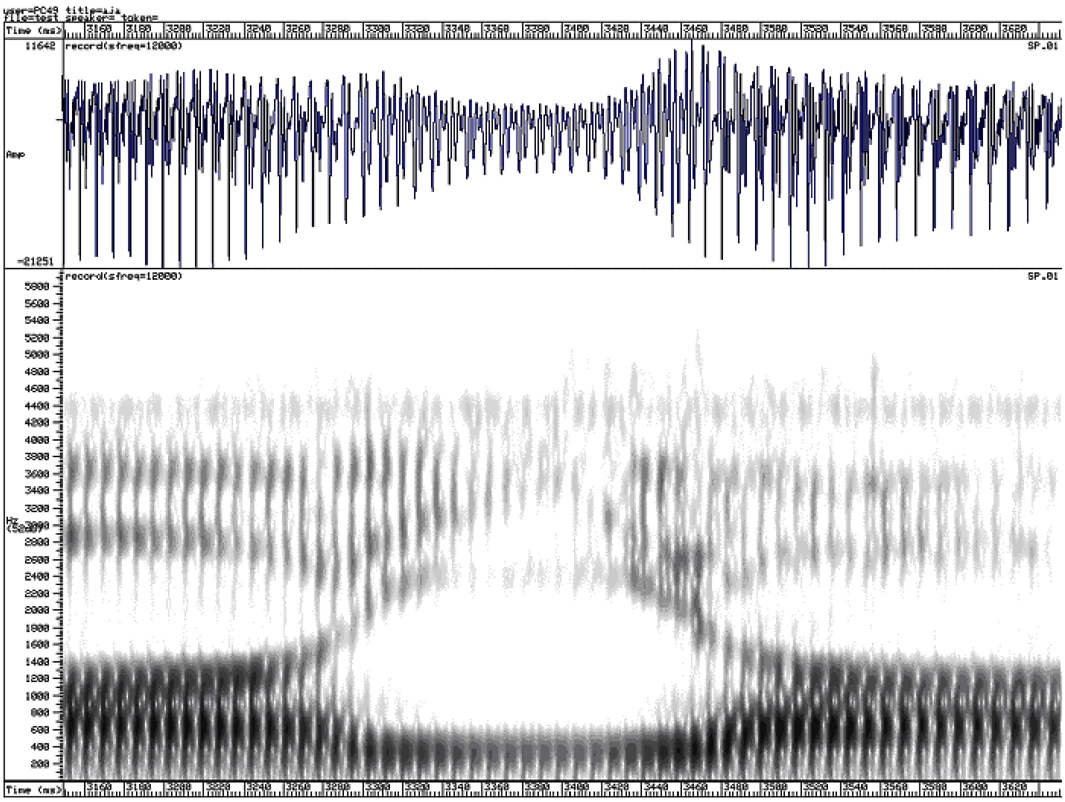


2-5.2 Spectrograms of Changing Manner

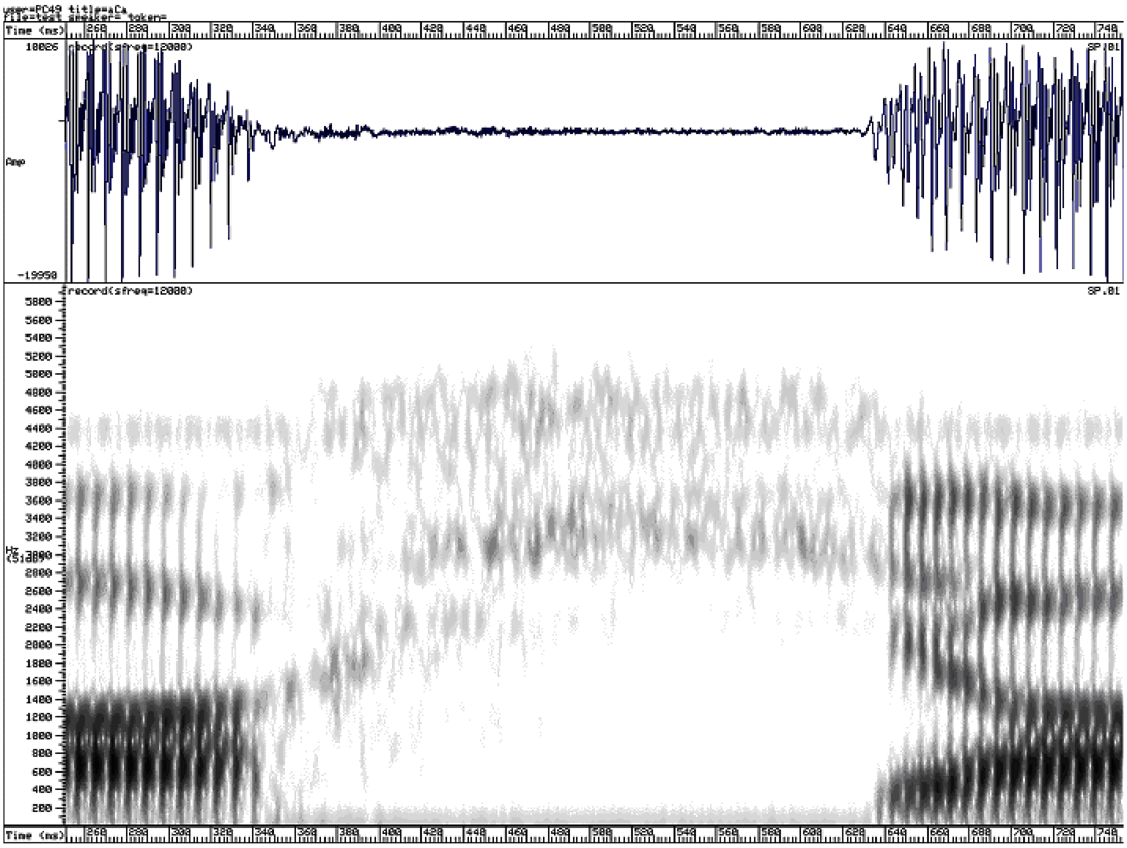
1. Vowel sequence [ɑiːɑ]



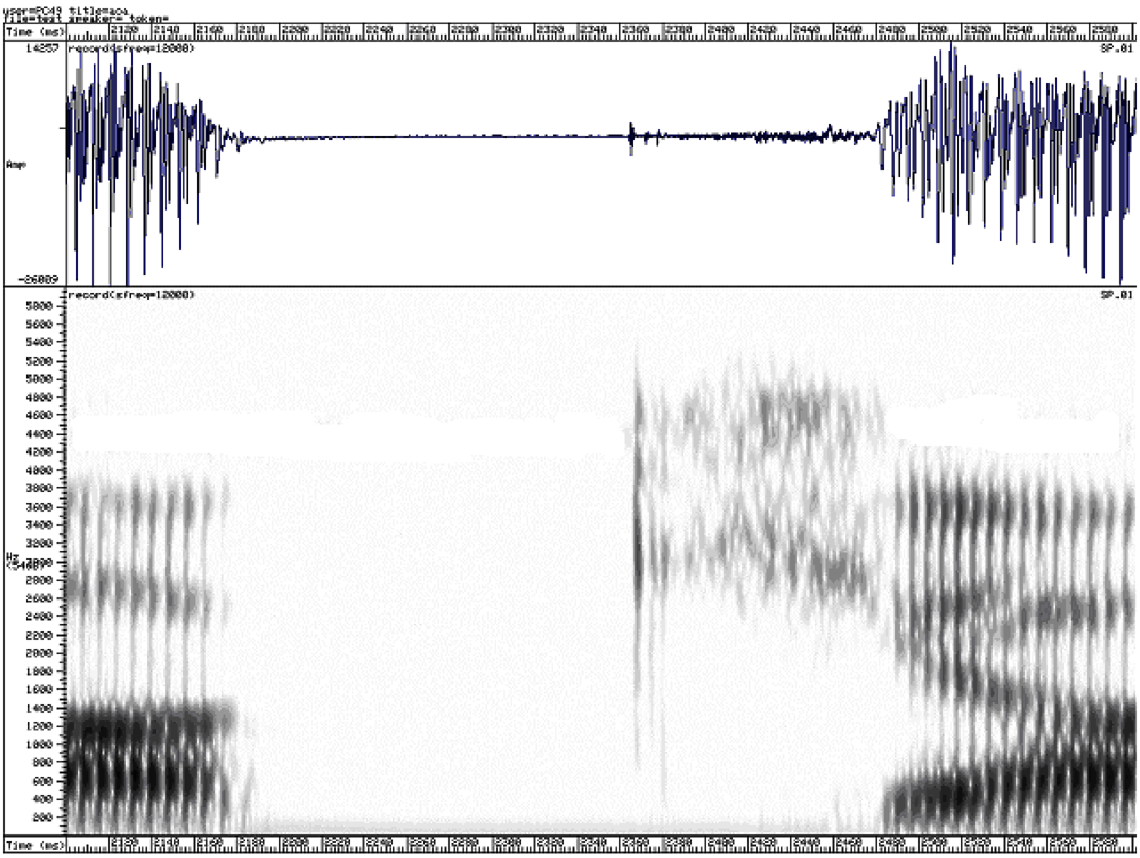
2. Approximant [ɑjɑ]



3. Fricative [αçα]



4. Plosive [αcα]



Lab 2-5: Spectrographic Analysis of Consonant Manner

Introduction

The articulation of consonants may be conveniently catalogued under the headings of voice, place and manner. Manner refers to the nature of the obstructing articulation, including its speed and degree. The degree of obstruction can be complete (a 'stop') or sufficient to cause turbulence (a 'fricative') or only give rise to a narrowing (an 'approximant'). The movement of the articulators to make obstructions changes the resonant properties of the vocal tract and these changes appear as formant transitions out-of and into surrounding vowels. This acoustic patterning combined with other acoustic and aerodynamic effects of the articulation form the pieces of evidence that allow a listener to identify the consonant manner.

In this experiment you shall look at the acoustic patterning in your productions of [ʊ], [w], [m], [v], [f], [b] and [p] in a V_V context.

Scientific Objectives

- to create a dichotomous key for the identification of intervocalic consonants from their spectrograms.

Learning Objectives

- to understand what is meant by formant transitions and why they are important in speech perception.
- to be able to relate articulatory phonetic knowledge about consonant manner to acoustic-phonetic knowledge.
- to learn how to draw stylised spectrograms.
- to gain more experience in looking at spectrograms of natural speech.

Method

You should work in groups of three or four. Only analyse the speech of one of the speakers in your group.

On the recording of the speaker, locate and load into the computer the productions of:

/ɜ'bɜ/	/ɜ'wɜ/	/ɜ'mɜ/
/ɜ'vɜ/	/ɜ'pɜ/	/ɜ'fɜ/
/'əʊə/		

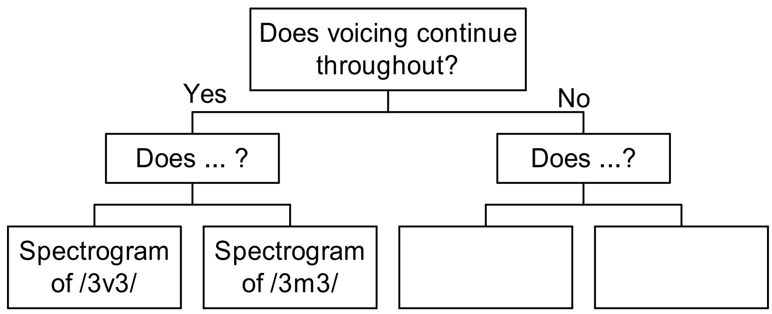
Using the Esection program (http://www.phon.ucl.ac.uk/resource/sfs/), print out wide-band spectrograms for each of these. Try to ensure that the display is zoomed to approximately the same timescale so that the printouts can be easily compared.

Observations

1. Sketch a stylised spectrogram of each of the seven productions. The sketches should be small enough that all fit on a single side of A4 and contain only a cartoon outline of the formant transitions, bursts, frication, etc. In each case include enough of the surrounding vowel context to make the formant transitions out-of and into the vowel clear. Try to make your sketches to scale so that they may be compared in frequency and in time.

2. Taking into account the complete spectrographic pattern for each production identify a number of characteristics that differentiate these segments. Make sure that these differences are clear on your stylised spectrograms too.

3. Cut out the spectrographic patterns of the seven productions and label them. Now devise a tree of YES/NO questions based on characteristics you have found which would form a key to identify the segments. Paste the spectrograms onto the large sheet provided, and write in your questions. The result should look something like this:



Concluding Remarks

1. What aspects of the spectrographic pattern do all these segments have in common? Why is this?

2. What advantages to listeners come from the fact that there is more than one way to build this key?