Spectrogram reading as a tool to teach acoustic phonetics

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ABSTRACT
Any course in phonetics must cover acoustic phonetics. This paper presents an approach to the teaching of acoustic phonetics using spectrogram reading that has been used successfully for over a decade in an introductory university course. The method is easy to implement, allows students to learn quickly, and builds knowledge and skills that extend to other domains in phonetics and linguistics. Moreover, students tend to enjoy doing the exercises, which makes for an enjoyable classroom experience for everyone involved.

This paper outlines the educational context of our phonetics course and the position of the spectrogram reading module, how the materials are developed, how assessment is done, and which learning outcomes are achieved.

Keywords: spectrograms, acoustic phonetics, student engagement, material design, assessment

1. INTRODUCTION
Part of the introductory course in phonetics at the University of Amsterdam is learning to read spectrograms, which is used as a tool to teach acoustic phonetics. By studying spectrograms with the objective of ‘reading’ them, students are presented with visual cues to the acoustic properties of vowels and consonants in a structured way that allows them to learn many new things fast. Doing spectrogram reading means students apply their general knowledge of acoustics in a specific instance, and it allows students to get a sense of accomplishment very quickly, which is helpful in keeping students motivated and interested in the topic. Students generally find spectrogram reading exercises fun to do and feel they are learning a skill, rather than simply memorising properties.

Materials for spectrogram reading exercises are easy to create for an instructor, whether the material is meant to illustrate basic phenomena or to serve as test material. We feel many instructors of phonetics could benefit from integrating spectrogram reading exercises in their courses, and offer this paper as an example of how to develop a spectrogram reading module as part of a phonetics course.

2. EDUCATIONAL CONTEXT
The introductory course in phonetics for first-year linguists at the University of Amsterdam aims to provide students with basic knowledge of speech perception, production and acoustics, and knowledge of Dutch phonetics, and aims to teach basic skills in speech recording and acoustic analysis, phonetic transcription, and articulation. The initial part of the course covers four main topics: acoustics, transcription of Dutch, perception, and articulation. The second part covers a bit more typological ground, considering the sounds of the world’s languages and historical sound changes.

Dutch is the language of instruction and also the main language of study. Languages that are commonly taught in secondary education in the Netherlands (English, French and German) are also used often to illustrate phonetic phenomena. The instruction and assessment materials presented in this paper pertain mostly to Dutch phonetics, but the approach would be easily transferable to other languages.

The central concept of the whole course is the interaction between speakers and listeners, and acoustics is presented as the channel through which the interaction takes place. All material is taught using a learning-by-doing approach where students have to reproduce the phenomena discussed in their English textbook [2] for Dutch or another language they know well. In the first session students learn to record and inspect their own speech using the program Praat [1], which is used throughout the course.

Before the spectrogram reading module starts, the course covers measuring formant values from waveforms and spectrograms of vowels in single syllables, so students are familiar with the parameters of the spectrogram. The articulatory definitions of (pre)voicing and aspiration have also been introduced. The spectrogram reading module is coupled with the study of the Dutch sound inventory, including regional and social variation and correct use of IPA symbols, and the main goal of the module is to endow students with basic knowledge of acoustic concepts and the ability to apply their knowledge independently to perform phonetic analyses.
3. INSTRUCTION MATERIALS

3.1 General setting

Before every class, students complete assigned reading on the topic of the class, e.g. ‘plosives’ or ‘nasals’. Students are required to record their own speech and study the spectrograms to identify visual cues and compare these to the English examples in the textbook. They are also encouraged to seek out and study speech material of varieties of Dutch different from their own, using databases like the ‘Speaking Map’ of Dutch dialects [3], or YouTube [4].

Classes start with discussing homework, to explore which cues students discovered by themselves and which cues will require more elaboration from the instructor. When discussing homework and classroom exercises, spectrograms are both projected on screen and distributed on paper. The paper handout allows students to scribble notes and mark salient properties for their own reference, and the projection enables students to come up to the front of the class and literally point to the cues they identified. This tends to be more effective than letting students verbally note or describe what they are seeing in a spectrogram.

When the homework has been discussed, the relevant cues to the phenomenon under investigation are identified in spectrograms of a limited set of items with minimal variation that can be real words or pseudowords. A similar set can then be used for the first spectrogram reading exercise. Figure 1 shows an example of a demonstration or practice set for place of articulation cues.

Figure 1: A very limited spectrogram set to highlight cues to Place of Articulation. Syllables to be matched are [bap], [dat], [gak].

When students are just starting out with spectrogram reading, practice sets should always be labelled, i.e. there should be a list of words or syllables to be matched with the spectrograms. Such matching exercises allow students to use their knowledge of acoustic phonetics in both bottom-up and top-down directions. They can start with the spectrograms themselves to determine properties like number of syllables, presence of plosives, and presence of corner vowels, but they can also start with the labels and determine which properties they need to find at specific positions in the spectrograms to make a match. Unlabelled exercise material only allows for bottom-up analysis, which is great practice once the basics have been covered, but we suggest waiting a few sessions before introducing unlabelled practice sets, which are discussed further in section 3.6.

3.2 Vowels and variation

Vowels are presented initially in single-syllable words like [beːk] and [bit] and the spectrogram of the vowel is only inspected from 25% to 75% of the vowel duration, so transitions from or into the consonants are not given attention at this stage. Formants of monophthongal vowels are easy to identify visually, allowing students to learn which formant patterns are typically associated with the corners of the vowel space. We use the terms ‘bottom heavy’ ([u]-like), ‘top heavy’ ([i]-like) and ‘spread out’ spectrograms ([a]-like) for these patterns.

Diphthongal vowels provide a more diverse learning opportunity. Dutch has both true diphthongs and diphthongised tense vowels, and their realisations are a source of regional variation. Students have to determine whether their own high-mid tense vowels are diphthongised or not. Enforcing awareness of diphthongisation in vowels that are traditionally considered monophthongs in Dutch prepares for the transcription part later on in the course, and helps students improve their pronunciation of foreign languages; all students speak English, where diphthongisation is stronger than in Dutch, and many speak German and/or French, where diphthongisation is minimal.

A practice set for spectrogram reading that can be successfully completed based only on vowels requires careful selection of items. For English, the numbers one to ten would make a nice set.

3.3 Plosives: voice and place of articulation

Plosives are exceptionally easy to identify in a spectrogram, which is why they are the next sound class to be studied in our spectrogram reading module. First, students are instructed to look for ‘gaps’ in the spectrogram signalling the closure of the vocal tract, and they learn to identify prevoicing and aspiration. At this point in the course the different voicing contrasts in Dutch, German and English are also discussed.
Identifying place of articulation in plosives is less straightforward because of the different types of cues that are involved. Formant transitions are most clearly illustrated in conjunction with different vowels, so a practice set like in Figure 1 but with several different vowels should be used. Burst properties are best covered in conjunction with fricatives (section 3.4).

### 3.4 Fricatives and recording settings

Recording and analysing fricatives for the first time is a good opportunity for students to explore the frequency range of the spectrogram. Standard settings in Praat [1] show the spectrogram only up to 5000 Hz, which is generally enough to identify vowels but cuts off a large part of most fricatives, particularly sibilants. Students have to identify the frequency range that is covered in the spectrograms of their own fricatives. At this point in the course, we also include an exercise to demonstrate the relationship between sample rate and the frequency range that is available for acoustic analysis. Students who have tried and failed to distinguish sibilants in 8 kHz recordings, both by ear and by spectrogram, are less likely to make the mistake of using low sample rates in field assignments in later stages of their studies.

Since fricatives and stop bursts share cues to place of articulation, spectrogram reading exercises should ideally include both. Once these properties are covered, students should be able to ‘read’ most matching exercises with ease.

### 3.5 Sonorants

Sonorants are the sound class with the trickiest cues to distinguish in a spectrogram, but their functional load in matching exercises can be fairly low once students are successfully recognising most vowels and obstruents. Place of articulation in sonorants can be compared to obstruents in carefully constructed sets. Because the cues to distinguish nasals and liquids from one another in a spectrogram are fairly subtle, it is advisable to make several practice sets with minimal pairs, ideally from different speakers.

In Dutch, liquids have a strong tendency to colour preceding vowels whereas nasals do so less, so students can learn to inspect the transition of a vowel into a sonorant to distinguish nasals from liquids. Nasals often undergo place assimilation, and studying the spectrograms helps make students aware of this automatic process, which will help them in the transcription part of the course.

### 3.6 Larger-scale matching and reading exercises

At the end of a class, students are given a spectrogram reading exercise that is a list of related words rather than carefully selected minimal pairs. Because students need to take into account several cues at once, this is more engaging than cue-specific exercises, and it offers a true ‘reading’ experience. Students often report a great sense of accomplishment from these exercises. The degree of difficulty of this exercise is determined first by whether labels are provided or not (see section 3.1), with labels allowing for more targeted inspection of the item. For unlabelled sets, the difficulty is mostly determined by the size of the semantic domain, e.g. ‘numbers under 10’ would be easier than ‘numbers’, and ‘weekdays’ would be easier than ‘European cities’. Figure 2 shows an example of a set of semantically related spectrograms.

**Figure 2:** A small set of related trisyllabic words from the semantic domain ‘sweet bakery items’. The easy version of the exercise would include the labels ‘speculaas’, ‘taai-taaiipop’, ‘boterkoek’.

Beyond operationalising the knowledge and skills the students are acquiring throughout the spectrogram reading module, larger-scale matching or reading exercises are useful to familiarise the student with regularities in the pronunciation and connected speech phenomena of the language under study, provided items are longer words or whole phrases. Vowel reduction and place assimilation have visible traces in a spectrogram, and a student who has had to recover this from a spectrogram is less likely to overlook these phenomena in transcription exercises at a later point in the course.

### 4. ASSESSMENT

Spectrogram reading exercises make up a substantial part of the written exam on acoustics, which is the first of four written exams in this course. Three types of questions are used, testing different aspects of students’ knowledge and understanding, particularly recognition and synthesis.

#### 4.1 Assessing recognition

The simplest exam question to assess knowledge at the recognition level involves a single sound or sound class, where the student needs to identify a single property. Examples include: which of three
spectrograms shows a diphthongised vowel, or which of three spectrograms shows an approximant /r/. This exercise tests recognition of individual properties in a very constrained context.

A larger labelled matching exercise of 10-12 related words is used to assess to what extent a student is able to recognise multiple acoustic properties in a moderately constrained context, combining bottom-up and top-down analysis. This exercise usually includes items that are obviously different from other items as well as very similar pairs (e.g. [fiaːlem] – [ʔaːnɛm], a pair that was often confused in an exam question involving Dutch cities). Students can rely on multiple cues to solve this exercise, which means getting a good score on this exercise does not require exhaustive knowledge, but a single mistake easily leads to multiple points lost because at least two items will be involved in a label matching switch.

4.2 Assessing synthesis

A very different type of exercise is to make students describe (and/or sketch) the expected spectrogram of a given syllable. This requires active knowledge of the acoustic properties of the sounds in the target syllable and uses only top-down reasoning. This type of exercise prepares students for thinking about de novo speech synthesis, which is addressed later on in the course, and allows differentiation between students who are explicitly aware of cues from students who just know enough to succeed at a matching exercise when there are bottom-up cues present. In effect, this exercise will show whether students have reached comprehension at the level of application or at the level of synthesis.

5. LEARNING OUTCOMES

The educational goals of our phonetics course as a whole were described in section 2. We use spectrogram reading primarily to create and reinforce knowledge and skills in the domain of acoustic phonetics, but as described in section 3, engaging with the material allows for plenty of opportunities to extend to other domains.

The basic body of knowledge and skills students acquire through spectrogram reading is called upon later in this course in more integrative assignments like designing a simple experiment. The awareness of spectral detail that develops through spectrogram reading allows students to formulate specific experimental manipulations. Particularly further study of language variation and perception invite the operationalisation of acoustic phonetic knowledge and skills.

The learning outcomes of the spectrogram reading module also benefit students beyond their further studies in linguistics. Because students gain hands-on experience with Praat software, the learning curve in subsequent courses where the program is used is leveled, and because students learn to record and analyse their own speech and study specific phonetic details, they can work independently to improve their pronunciation in foreign languages as they have also been made aware which properties are particular to Dutch.

In sum, using spectrogram reading as a tool to teach acoustic phonetics is an engaging and effective way to cover a lot of ground on basic acoustic concepts while also building practical research skills. It is easy to develop instruction and assessment materials for, and it provides a range of learning outcomes that can be built upon in further studies of phonetics, linguistics and language learning. We highly recommend making it a part of any introductory phonetics course.

6. ACKNOWLEDGEMENTS

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7. REFERENCES