PSYCH-UH 3516EQ: Lab in Psychology of Language
Lab 1: Acoustic Phonetics
Basic Acoustic Measurements

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1 Overview

This is the first lab of the semester. It is divided in three parts. In the first part, you will be measuring the values of the first two formants (F1 and F2) for English vowels. In the second part, you will be trying to find acoustic correlates of stop consonants in English. In the third and final part, you will be measuring acoustic information responsible for making the difference between voiced and unvoiced stop consonants like, for instance, between [b] and [p].

In order to perform these acoustic measurements, you'll be using Praat on a set of files that are provided together with this document. Praat is a free, cross–platform, open–source phonetic analysis package that can be downloaded from http://www.praat.org, and is straightforward to install. However, in case you have any difficulty installing Praat, please do not hesitate to reach out to me.

1.1 Deadlines and deliverables

Part A: Is due by *Monday, February 19th, by midnight*, via the NYUClasses web interface. You should create a zip file containing your write up and the `csv` file you created with your acoustic measurements.

Important: There will *no penalties* for handing in Part A of the lab after the deadline, as it was *my fault* that you received this assignment late. Therefore, for this part of the lab, even if you hand it in late, you will have it back as soon as possible. However, please try to return the assignment by its due date, so you do not create a backlog of work for yourself, and it allows the class to follow a steady pace.

Parts B and C: Are due by *Monday, February 26th, by midnight*, via the NYU-Classes web interface. You should create a zip file containing your write up and the spreadsheet file you created with your acoustic measurements.

2 Part 1A: Vowel Formant Analysis

2.1 Overview

In this part, you will analyze recordings of speakers of American English uttering the following words:

1. heed – [h iː d]
2. hid – [h ɪ d]
3. head – [h ɛ d]
4. had – [h æ d]

5. hod – [h ɑː d]
6. hawed – [h ɔː d]
7. hood – [h ʊ d]
8. who'd – [h uː d]

Your task will be to measure the values of the first two formants (i.e., resonant frequencies of the human voice), F1 and F2, for the sounds produced by one speaker, and create a scatter plot of their F1 and F2 values, with F2 in the x–axis and F1 in the y–axis.

In addition, you will replot the same data in the context of an older database of F1 and F2 values collected by Peterson and Barney (1952) to compare the values observed in a single individual with those of a larger group of people.

2.2 What you will need

In order to complete this part of the lab, you will need:

1. the sound files
2. the software Praat, for the formant analysis and data plotting
3. a spreadsheet program — Googlesheeets, Microsoft™ Excel, or LibreOffice are fine options — to store the values you measure.

2.2.1 The sound files

The sound files are available in the compressed folder for this lab, and come from a large study of American English vowels by Hillenbrand, Getty, Clark, and Wheeler (1995). The folders *men* and *women* contain the recordings done by Hillenbrand et al. (1995) for 50 men and 50 women. Each uttered one of the 12 American English vowels in a h_V_d context. In this lab, we will only analyze the eight vowels enumerated in the previous section.

Each sound file is coded in the following manner:

- the first letter indicates whether the speaker is male (*m*) of female (*w*)
- the numbers after the first letter indicate the participant's code (1–50)
- the next two letters indicate the vowel that is pronounced in the sound file, which are:
  - ae="had";[æ]
  - ah="hod"; [ɑ]
  - aw="hawed"; [ɔ]
  - eh="head"; [ɛ]

- er="heard"; [ɚ]
- ei="haid"; [e]
- ih="hid"; [ɪ]
- iy="heed"; [i]
- oa=/o/ as in "boat"; [o]
- oo="hood"; [ʊ]
- uh="hud"; [ʌ]
- uw="who'd"; [u]

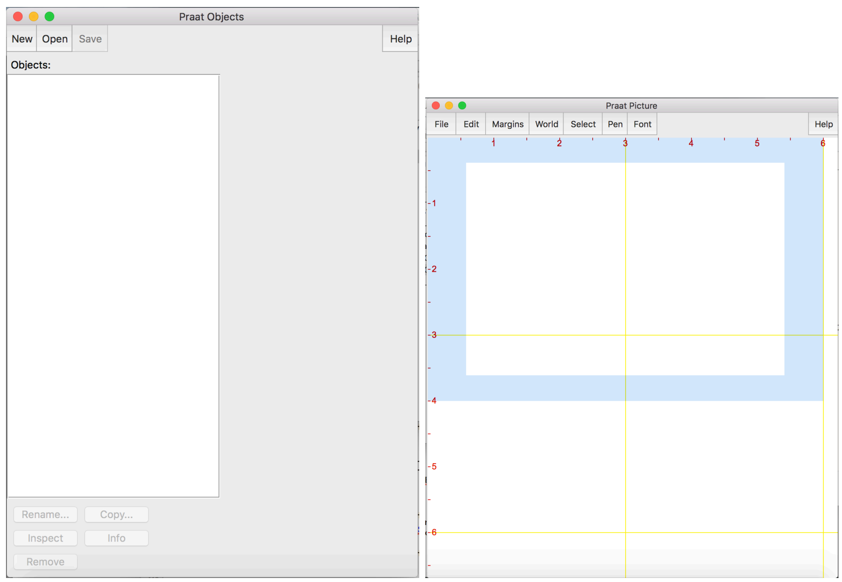
Your goal will be to select one participant at random and measure the formants F1 and F2 values for a subset of the vowels above, repeated below with the coding used in the file names:

1. heed – [h iː d] – iy
2. hid – [h ɪ d] – ih
3. head – [h ɛ d] – eh
4. had – [h æ d] – ae
5. hod – [h ɑː d] – ah
6. hawed – [h ɔː d] – aw
7. hood – [h ʊ d] – uh
8. who'd – [h uː d] – uw

How to select the sound files to analyze? First, you will need to pick a random number between 1–50. You will also pick a male speaker if you are male and a female speaker if you are female. For instance, if you are female, and you picked the number 33, you would analyze the following files in the *women* folder:

1. `w33iy.wav`
2. `w33ih.wav`
3. `w33eh.wav`
4. `w33ae.wav`
5. `w33ah.wav`
6. `w33aw.wav`
7. `w33uh.wav`
8. `w33uw.wav`

Figure 1: Praat – Main Windows



2.2.2 Using Praat to measure the formant values

Opening Praat. The first thing you need to do is open Praat. You should see two separate windows, called `Praat Objects` and `Praat Picture`, as shown in figure 1:

Loading a file. In the `Objects` window, click on `Open` > `Read from file`, as shown in figure 2:

Once you select the file you want to open and click on it, its name should appear in the `Objects` window, as shown in figure 3.

Notice how the button `View & Edit` has automatically highlighted for you.

Looking at the spectrogram. Once you have read the appropriate file into Praat, you should be able to see it on your object list (figure 3), and the button `View & Edit` has automatically been highlighted for you. If you click on it, it should open the sound editor window, as shown in figure 4.

The sound editor window displays the waveform (oscillogram) of the sound on the top part of the display and its spectrogram (figure 4) immediately below it. You can play the sound by pressing the `Total Duration` button at the bottom of the window. If you select a subpart of the sound by clicking and dragging the cursor over a portion of the waveform/spectrogram, a small pane

Figure 2: Praat – Reading from a file

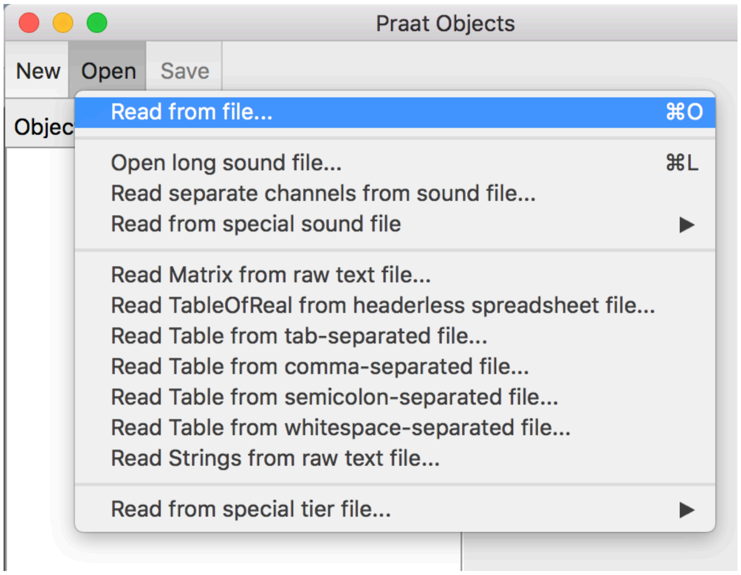


Figure 3: Praat – Object in List

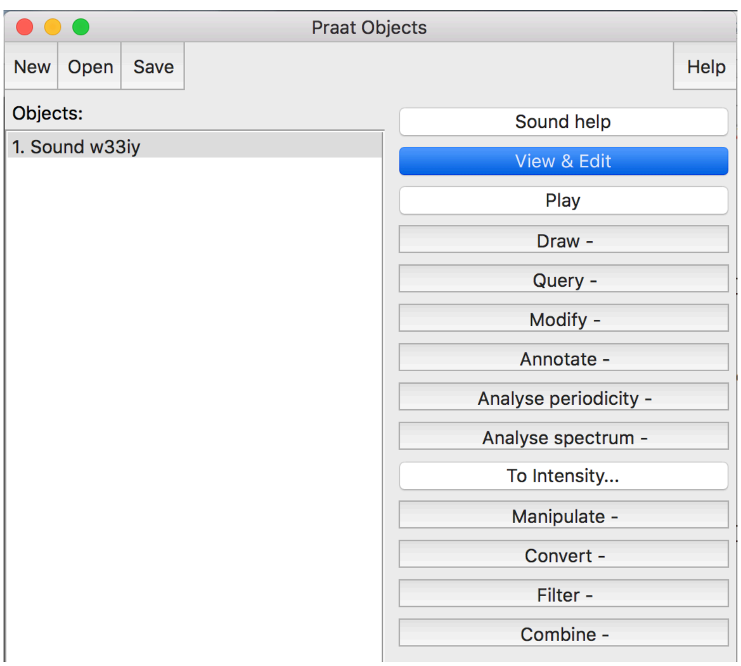


Figure 4: Praat – View and Edit Window

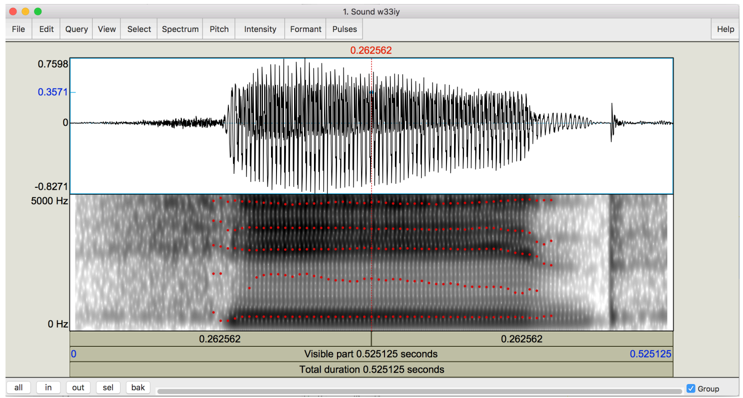
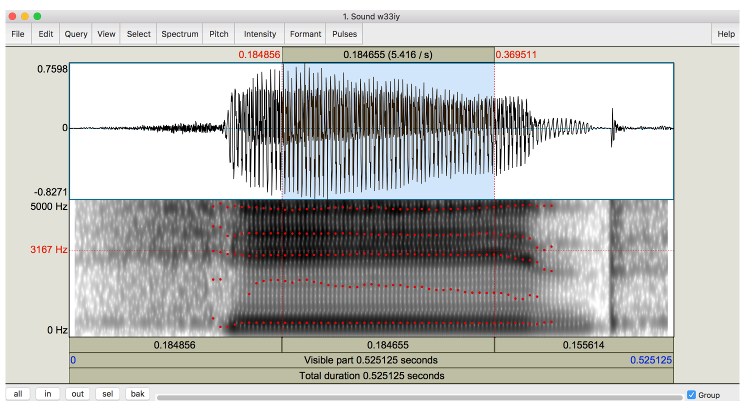


Figure 5: Praat – View and Edit Window: Selection of part of the waveform for inspection



with the duration of the selection will appear at both the top and bottom of the display; pressing either will play just the selected part of the sound, as shown in figure 5.

Making the measurements. Once you have your spectrogram in front of you, Praat defaults to showing a series of red dots overlaid over the spectrogram. This is Praat's automatic formant tracking algorithm doing the best it can to display where the formants are for you. In case you don't see the red dots right away (or in case you inadvertently deselect the option of displaying them), you can turn it back on by going to `Formant` > `Show Formants`. As

Figure 6: Praat – Getting the Formants automatically – Selecting the *steady state* of the vowel

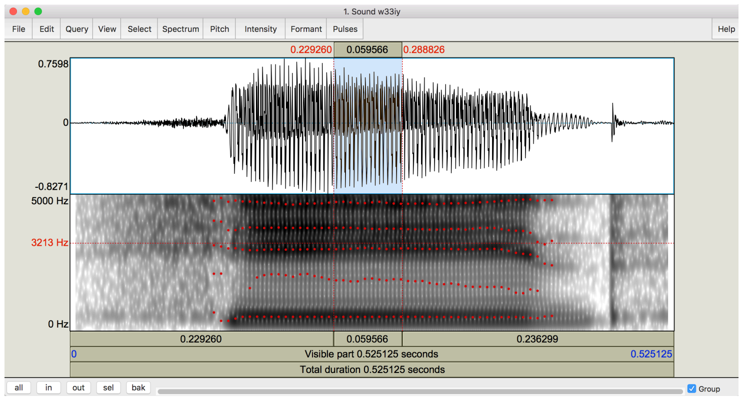
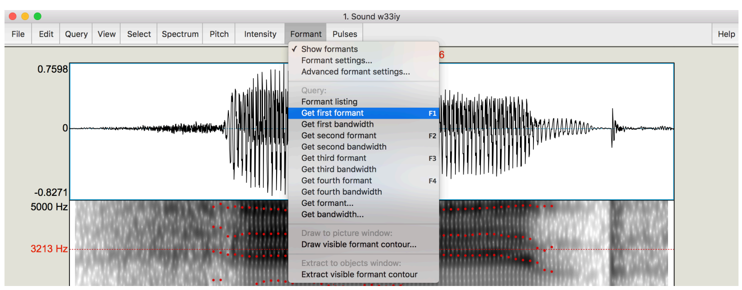


Figure 7: Praat – Getting the Formants automatically – Automatically calculate F1



you can see, Praat's formant tracking algorithm is pretty neat, but it is not flawless so make sure that the dots make sense given the underlying spectrogram.

If Praat gave you reasonable formant tracks, then you can select a window over the center of the vowel – its *steady state* – as shown in figure 6, and go to `Formant` > `Get first formant` (figure 7). This should give you a window with a value, as shown in figure 8. Pay close attention to what that value represents (its unit of measurement, and whether it is a single or average measurement).

If Praat gave you formant tracks that don't seem to capture the formants you see adequately, then you can try to pin a couple of points in the formants (if you can easily see them on the spectrogram, which you should), get their values, average them and record that value in the spreadsheet. To get the value of any particular point, you can just click on it and Praat will give you its value on the left side of the spectrogram in red. You can then jot down the numbers

Figure 8: Praat – Getting the Formants automatically – Getting the mean F1 value over the vowel's *steady state*

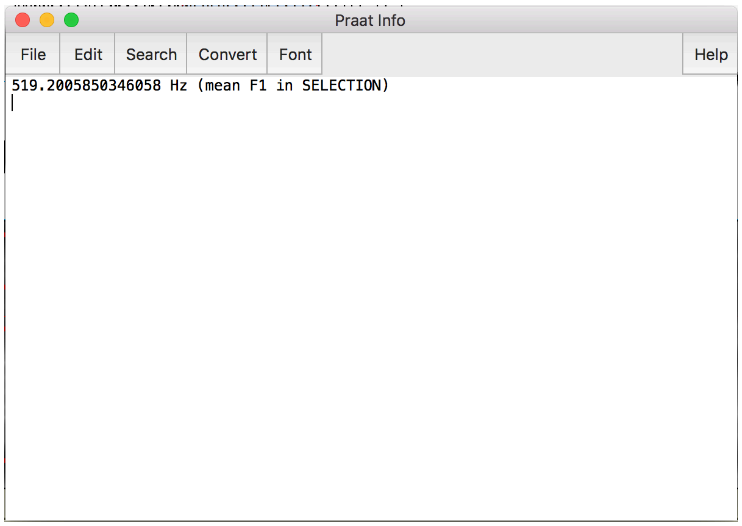


Figure 9: Microsoft™ Excel – Saving the Formant values of each recording

	A	B	C	D	E
1	file	vowel	IPA	F1	F2
2	w33iy	iy	i	519	
3					
4					
5					

somewhere. If you want numbers that you can copy and paste, just click on the point, and then go to `Spectrum` > `Get frequency at cursor`.

If you decide to do that, then you should be consistent across measurements. Choose the same number of points and be explicit about why you decided to take them. Finally, remember to follow the same procedures you used when measuring F1 when you measure F2.

Saving Formant values to a spreadsheet. Once you get your formant values, you should start saving them into a spreadsheet. Remember to label the values appropriately, as shown in figure 9.

Once you finish copying the values to the spreadsheet, you should export them to a *comma separated value* file or `csv` file, so that you can then import the values to Praat for plotting. Every spreadsheet program should have an `export` or `save as` option that allows you to save the contents in a worksheet to a `csv` file.

CSV. The *comma separated file* is a pure text format used to represent tabular data, the kind that is normally inspected and manipulated by spreadsheet programs. However, unlike the binary formats used by these programs, `csv` files can be opened by any text editor and is a useful format for transferring data across different pieces of software.

IPA symbols for the vowels. In order to plot the values you measured from a particular individual, you need to save not only the vowel codes used by Hillenbrand et al. (1995), but the actual IPA symbols will look better in a graph. Here's how you should input the IPA symbols in your spreadsheet in order to plot them appropriately in Praat:

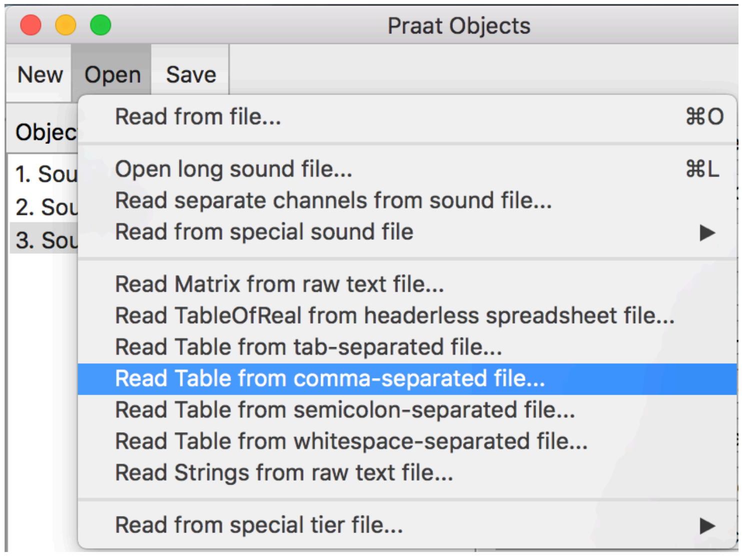
1. `w33iy.wav`: i = i
2. `w33ih.wav`: ɪ = \ic
3. `w33eh.wav`: ɛ = \ef
4. `w33ae.wav`: æ = \ae
5. `w33ah.wav`: ɑ= \as
6. `w33aw.wav`: ɔ= \ct
7. `w33uh.wav`: ʊ = \hs
8. `w33uw.wav`: u = u

Example `csv` file. I created a small example of what the `csv` should look like. It is named *american-vowels-example.csv*. This file is distributed with the rest of the lab resources, and it contains the measurements of F1 and F2 for just three vowels ([i], [ɑ] and [u]) for the *w33* participant.

2.2.3 Plotting the Formant values

Using the plot functions of Praat. There are many ways in which you could plot your measurements. Any decent spreadsheet program would allow you to create a simple scatterplot. Unfortunately, how you can accomplish this task will vary not only across programs, but also within different versions of the same program (an older version of this lab from 2013 became largely obsolete because of software changes in Microsoft™ Excel, for instance). Ideally, one should use a real programming language with good plotting capabilities, like R or Python. The downside is that the learning curve can be a little steep in

Figure 10: Praat – Read your data from *comma separated value* file



case you never did any programming. Since the goal of this lab is to get you to interpret phonetic data graphically without getting too bogged down in general implementation details, I eventually settled on using Praat to plot the data. It's a bit of an *ad-hoc* solution — I would not recommend that you use Praat as your plotting solution for other kinds of data — but it works quite well for the kind of data we have at hand, and it produces publication–ready figures with minimal fuss.

Inspecting your data. Once you have the the average formant values, you are ready to plot your data. The first step is to read your measurements into Praat. In the `Praat Objects` window, click on `Open` and then on `Read Table from comma separated file`, as shown in figure 10.

The command `Read Table from comma separated file` takes a `csv` file and produces a *Table* object in Praat, as shown in figure 11. A *Table* object in Praat can organize tabular data, much like a spreadsheet. You can inspect its contents by pressing the button `View & Edit` after you select (click on) the object in the `Praat Objects` window, as shown in figure 12. However, unlike in a real spreadsheet program, a Praat *Table* object cannot be directly modified by clicking and typing, it can only be modified via cumbersome menu options. Thus, if you notice something wrong with the `csv` file you just imported when you inspect it in Praat, I strongly suggest that you open it on a spreadsheet program and edit there, and then try to read it in again into Praat.

Figure 11: Praat – Newly created *Table* object in the `Objects` window

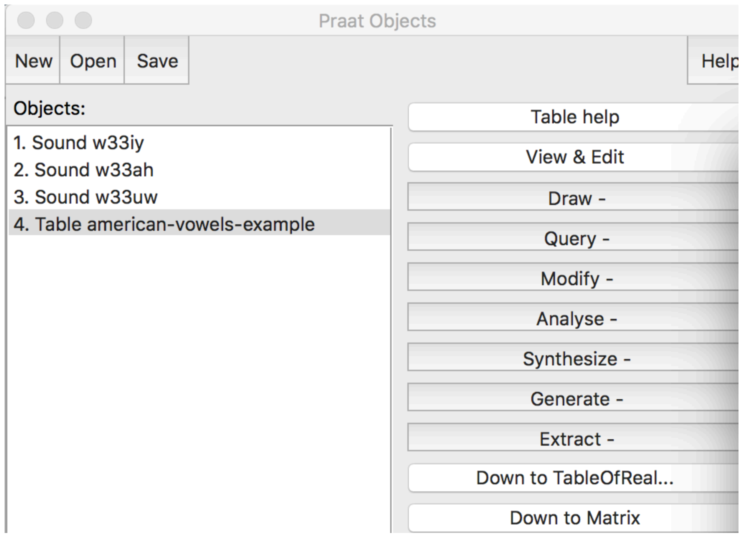


Figure 12: Praat – Visually inspecting Table object

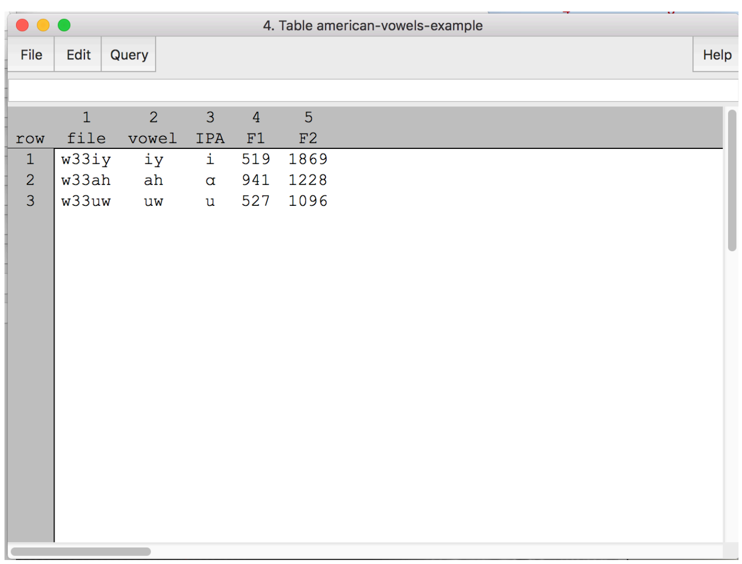
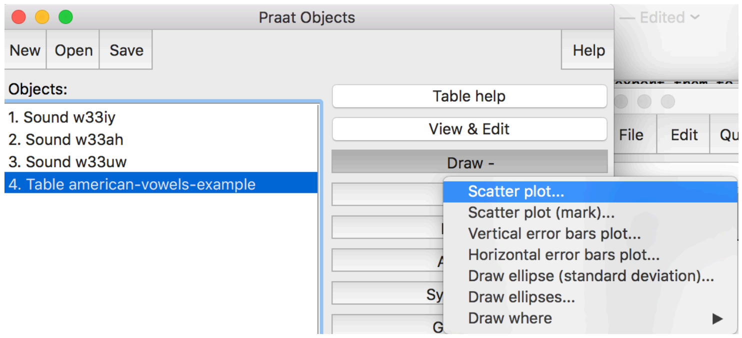


Figure 13: Praat – Visually inspecting Table object



Plotting your data. Once you are satisfied that your data has been collected appropriately and read into Praat correctly, you can create a scatterplot for the F1 and F2 values that you measured. Click on `Draw` > `Scatter plot`, as shown in figure 13. This will bring up a dialog window asking you which variable (i.e., column) of your table object should be plotted on the horizontal (i.e, x–axis) and the vertical (i.e., y–axis), as well as the range of each axis. It also asks which variable (i.e., column) contains the symbols that are going to be used for plotting in the `Column with marks` textbox, the font size to use, and finally whether you want to plot all the axes information and a box around the plot (the `Garnish` checkbox option).

You should fill out this dialog box such that F2 is displayed on your x–axis, F1 in your y–axis, and that the column containing the IPA symbols for the vowels you measured (I suggest you use the name IPA for that column, for obvious reasons) is used in the `Column with marks` textbox. Finally, the default fontsize 12 is ok, and you should plot all the axis information, so make sure that the `Garnish` checkbox is checked.

A note on the range of the axes. Even though Praat offers you to set the ranges of your axes automatically, here you should avoid that, because we will want to produce overlaid plots (i.e., plots on top of other plots). Therefore, you should you use a preset set of values for the range of your axes such that your plot will be able to accommodate as many plausible vowel values as possible. I suggest that you use the values below.

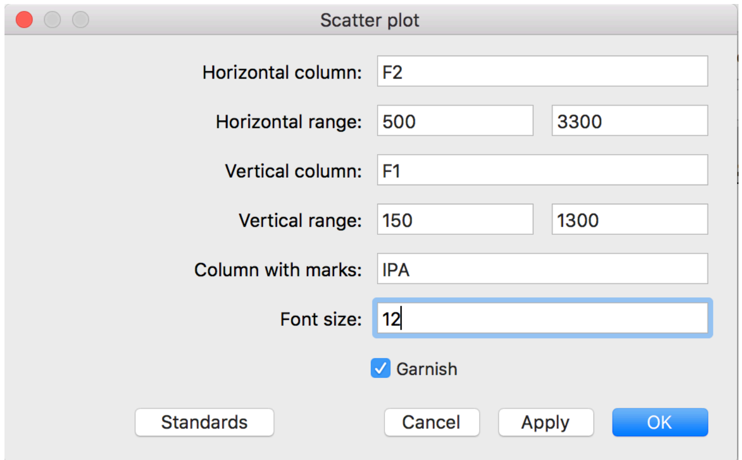
minimum value for F1 150

maximum value for F1 1300

minimum value for F2 500

maximum value for F2 3300

Figure 14: Praat – Scatterplot dialog box

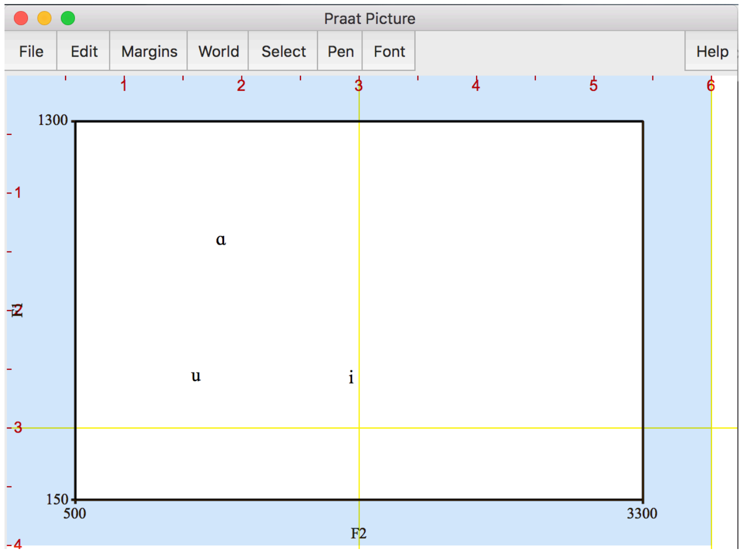


Another important piece of information is that each axis has two boxes where you can establish its range. For the x–axis, the left box indicates the limit on the left side of the plot and the right box the limit on the right side of the plot. Likewise, on the y–axis, the left box indicates the limit on the bottom side of the plot and the right box the limit on the top side of the plot. Thus, if you want your plot to have increasing values from left-to-right and bottom-to-top, you should input the lower bound of each axis on the left boxes and the upper bounds on the right boxes. If you wanted to plot axes that presented information in the opposite pattern, all you would need to do is invert the values you use for the left and right bounds. Figure 14 indicates how you should initially fill the dialog box for the plot, and figure 15 shows the result for the example data I've provided (only for three vowels, you should have more vowels in your plot).

Saving your graph. You can save your graph by clicking on `File` on the `Praat Picture` window and selecting the most appropriate format. I strongly suggest either `.pdf` or `.png`, as they are easy to embed in most modern text processing applications.

Interpreting the graph. Plotting a graph is not just about being able to see data, but rather being able to see data *in the most informative way* possible. So you should ask yourself certain questions like *Do I need a legend if the points are labeled?*, *Does the range of the scale on the axes make sense?*, and so on. Creating a good graph necessitates thinking in some detail about what relevant features of your data you want to convey. This will turn out to be important in the future, so keep that in mind.

Figure 15: Praat – Scatterplot result



In this case, the basic plot parameters were given by me, but in the future when you start producing your own graphs, you will need to really think about how to best convey the information you want to convey in a graph. For instance, take a look at the graph of the F1 and F2 values you just created. Does it suggest any pattern to you? (hint: think back to your IPA chart). If so, is the way the graph is currently set up the best way to see this pattern? If not, how should you modify your plot in order to make the relevant pattern more immediately accessible to the reader/viewer? Try to produce this plot and see if the pattern becomes clearer. You can always erase a particular graph from your current `Praat picture` window by clicking on `Edit` > `Erase All`, as shown in figure 16.

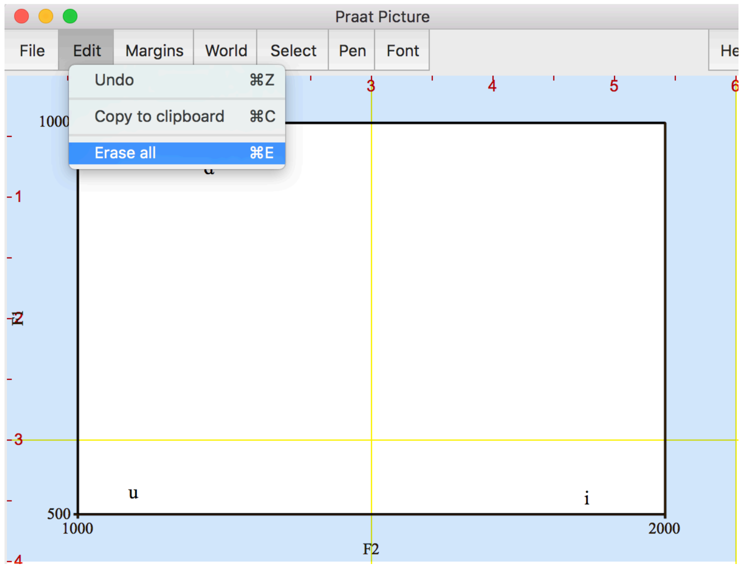
Another important aspect in the interpretation of a graph is what aspect of a particular research question it is supposed to shed light on. In the context of our class, there were two major questions we left unanswered:

1. How do the acoustic representations of speech relate to the articulatory ones?

2. Is there a one–to–one mapping function between simple features of acoustic representations and articulatory representations of speech?

By now, you should be able to give at least a partial answer to question 1 above, given your data, especially if you were able to produce the most informative version of the plot we started to construct above. However, we can only give a very tentative kind of answer to question 2. This is because even if you

Figure 16: Praat – Erasing plots from Picture window



were able to notice a one–to–one mapping between acoustic and articulatory features, we can only be certain that it holds for the particular individual you happened to have analyzed. In order to make a well–supported generalization, we would need data from more individuals and see whether the pattern you observed in one person holds across multiple individuals.

Putting the graph in context, part I. By now, you should have observed that there is a particular link between features of the acoustic representation of vowels in terms of its spectrogram and their articulatory features. The question you need to answer is whether the pattern you observed in the individual holds in a larger population of speakers of the same dialect.

Fortunately for us, some people have already collected the relevant data for American English, and this data is already packaged as a Praat *Table* object. Go to `New` > `Tables` > `Create formant table (Peterson and Barney 1952)`, as shown in figure 17. This will load up a *Table* object containing the measurements of F0, F1, F2 and F3 from Peterson and Barney (1952) on 33 males, 28 women and 13 children. All we need to do is plot the F1 and F2 values from that database and we will have a clearer sense of whether your original observation holds for a larger population. At this point, you should have a *Table* object *pb* on your `Objects` list (figure 17). If you click on `View & Edit`, you can inspect it (see figure 18).

Follow the next steps:

Figure 17: Praat – Loading Peterson & Barney 1952 data

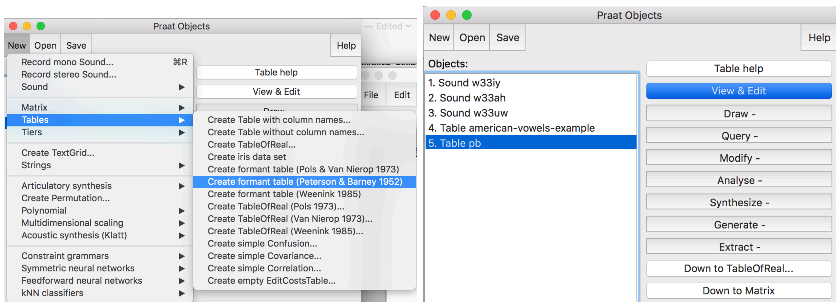
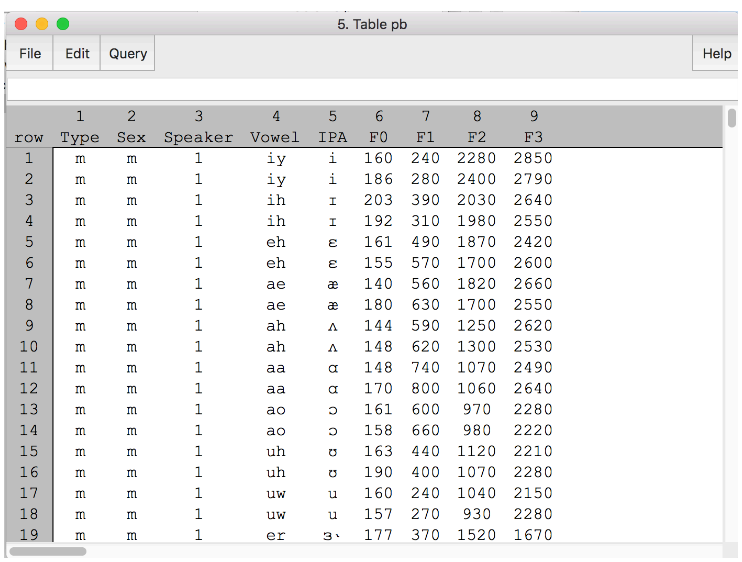
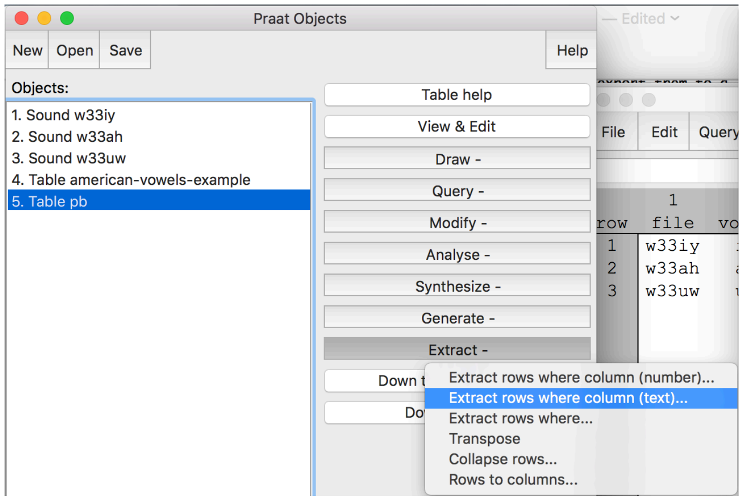


Figure 18: Praat – Inspecting Peterson & Barney 1952 data



row	1 Type	2 Sex	3 Speaker	4 Vowel	5 IPA	6 F0	7 F1	8 F2	9 F3
1	m	m	1	iy	i	160	240	2280	2850
2	m	m	1	iy	i	186	280	2400	2790
3	m	m	1	ih	ɪ	203	390	2030	2640
4	m	m	1	ih	ɪ	192	310	1980	2550
5	m	m	1	eh	ɛ	161	490	1870	2420
6	m	m	1	eh	ɛ	155	570	1700	2600
7	m	m	1	ae	æ	140	560	1820	2660
8	m	m	1	ae	æ	180	630	1700	2550
9	m	m	1	ah	ʌ	144	590	1250	2620
10	m	m	1	ah	ʌ	148	620	1300	2530
11	m	m	1	aa	ɑ	148	740	1070	2490
12	m	m	1	aa	ɑ	170	800	1060	2640
13	m	m	1	ao	ɔ	161	600	970	2280
14	m	m	1	ao	ɔ	158	660	980	2220
15	m	m	1	uh	ʊ	163	440	1120	2210
16	m	m	1	uh	ʊ	190	400	1070	2280
17	m	m	1	uw	u	160	240	1040	2150
18	m	m	1	uw	u	157	270	930	2280
19	m	m	1	er	ɝ	177	370	1520	1670

Figure 19: Praat – Extracting subset of data in the Peterson & Barney 1952 dataset



1. Make sure you are starting with a blank `Pictures window`. If your `Pictures window` has already a plot on it, just erase its current contents by clicking `Edit` > `Erase all`.
2. Select the *Table pb* on the `Objects window`, then go to `Extract` > `Extract rows where column (text)`..., as in figure 19.
3. This should open a dialog window asking which rows to extract. The goal here is to extract the data only from the group of people you analyzed. Thus, if you analyzed the data from a male individual, you extract the data from only the male participants in the dataset. Conversely, if you analyzed the data from a female individual, you should extract only the data from the female participants in the dataset. You can extract the correct rows by setting `Extract all rows where column is`... to *Type*, select `is equal to` and set the `text` to *w* if you want to extract only the data from the females in the dataset, and to *m* if you want to extract the data from the males (see figure 20 for example).
4. You should now have another copy of the *Table pb* with only the data you selected included.
5. Choose this new table and click on `Draw` > `Draw Ellipses` (figure 21).
6. This will open a dialog box much like the one you used to input your original plot's parameters. Use the same parameters here, but change the

Figure 20: Praat – Extracting the data from the females in the Peterson & Barney 1952 data

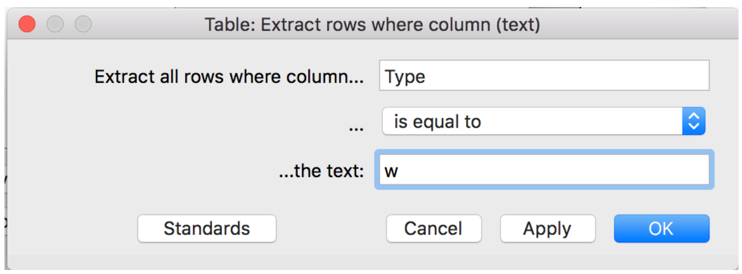


Figure 21: Praat – Drawing ellipses in F1–F2 space for each vowel category in the Peterson & Barney 1952 data – data from females only

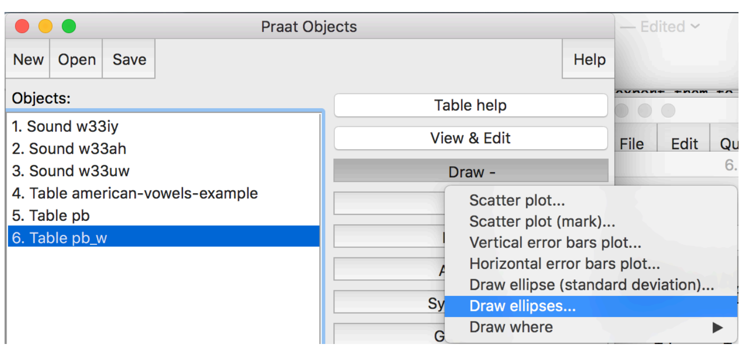
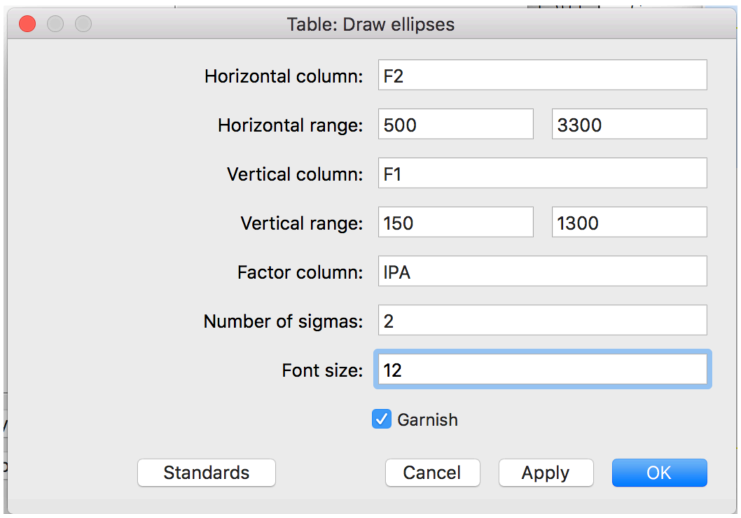


Figure 22: Praat – Drawing 2 Standard Deviation ellipses in F1–F2 space for each vowel category in the Peterson & Barney 1952 data – data from females only



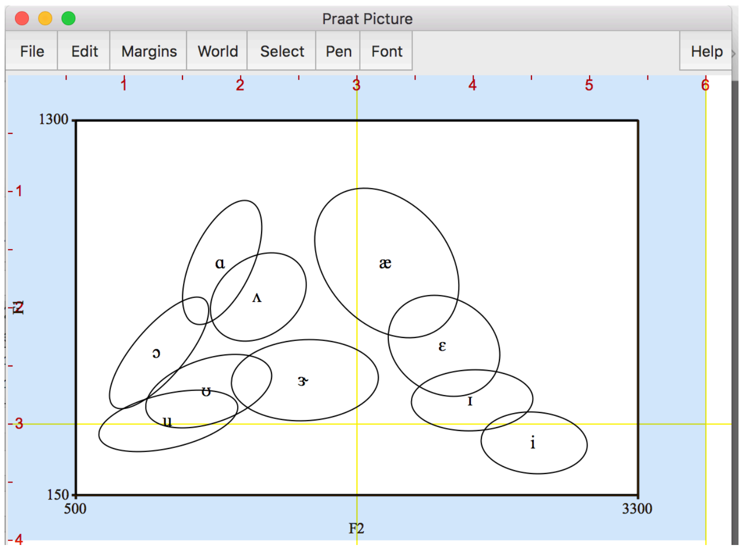
`Number of sigmas` to *2*. This will create ellipses capturing 2 standard deviations of F1 and F2 values in the dataset (figure 22).

7. You will produce a figure like figure 23.

With this figure in hand, you can start answering the question of whether the pattern you observed in the data from the single participant you analyzed holds across multiple participants. Does it? In what way? Does this new pattern present any challenges to the idea that there are one–to–one mappings between the acoustic and articulatory representations of vowels?

Putting the graph in context, part II. Finally, you can try to visualize how the data you originally observed would look like when overlaid on the plot you just produced. You should first change the plot color to red (or another color of your choice) by going to the `Pen` > `Red`, in the `Picture` window (figure 24). Then, you should select the table containing your data from the `Objects` list (if your data is not there anymore, you will need to reload it), and recreate the plot of the F1 and F2 values you measured. If you use the same ranges for both axes and uncheck the option `Garnish`, you should just plot in red the original data you measured on top of the larger dataset of Peterson and Barney (1952). I will not show you what this figure would look like, since at this point you should be able to produce it by yourself.

Figure 23: Praat – Ellipses capturing 2 standard deviations in the F1–F2 space for each vowel category in the Peterson & Barney 1952 data – data from females only

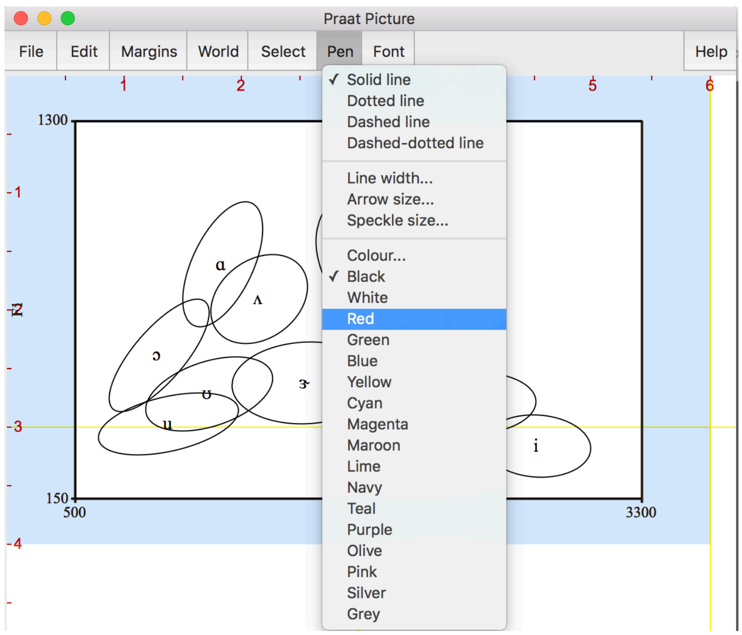


Once you create this new figure, you are finally in a position to see how the data you analyzed fit within the larger dataset of F1–F2 values for American English vowels. Do all your observations fit within the 2 standard deviation ellipses? Do they happen to fit into another vowel category's ellipsis? Finally, what does this final plot tell you about the potential of there being a simple one–to–one mapping between simple acoustic features and articulatory representations of vowels? Can you think of any way in which this could be improved upon?

2.3 What you should hand in.

1. The formant values you measured. This could easily be done by including the `csv` file you used to read your data into Praat into your final submission.
2. A short write up of your efforts and your major conclusions based on the data you analyzed and graphed during this lab. You should use the questions I present to you in each section as a way of structuring your report. This report should also contain:
   (a) A plot of the formant values of each vowel you measured (all in one plot), a small description of how you obtained them (did you use

Figure 24: Praat – Changing the plot color for overlaying a new plot on top of an existing one.



Praat's formant track function or did you use the mouse cursor?), the problems you encountered and how you overcame them. Try to motivate your decisions during the process. It would also be best if you selected the most informative version of this plot you could make.

(b) A plot of the 2 standard deviation ellipses for the relevant group of individuals in the Peterson and Barney (1952)'s dataset (males, if you analyzed the data from a male, females otherwise).

(c) A plot overlaying the data you originally measured on top of the plot described immediately above.

3 Part 1B: Finding and measuring acoustic correlates of stop consonants

3.1 Overview

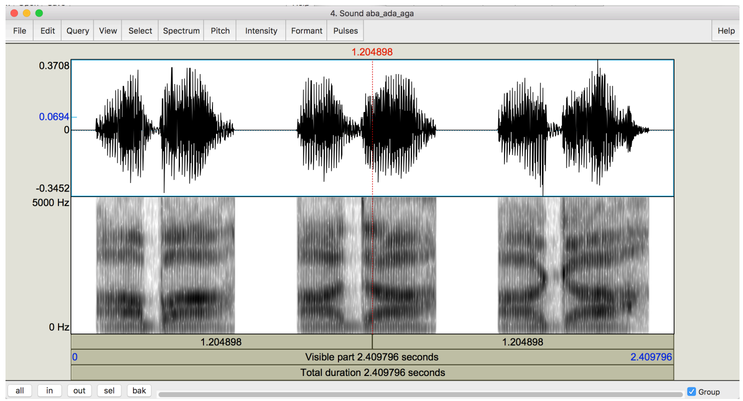
In the first part of this lab, you explored the spectrographic representation of different vowels of English. Remember that the driving force behind this was the idea that our "one–to–one mapping" hypothesis about speech perception was worth exploring. In other words, we were exploring the idea that there are pieces of acoustic information that are reliably and univocally associated with segmental representations (=vowels and consonants). We started with vowels because in a way they are the "simplest" case of speech sounds.

You should think about what the first part of the lab has taught you. As far as vowels are concerned, do you think that the "one–to–one" mapping hypothesis is plausible? Do you think the consonant data we will analyze will be consistent or inconsistent with what we have seen for vowels so far?

By now you already know how to (a) produce a spectrogram, (b) identify and extract formant information from a spectrogram, (c) plot data in Praat. Therefore, the instructions from now on are going to be less detailed.

Now we will proceed to the logical extension of our hypothesis testing, i.e., we will be looking for acoustic correlates of stop consonants in English.The stop consonants we will be looking at are [p b t d k g]. This is the full inventory of stop consonants in English. Stop consonants receive that name because they are basically a full obstruction of the air flow, produced by either the closure of lips ([p b]), the touch of the tip of the tongue against the alveolar ridge ([t d]) or the touch of the back of the tongue against the velum ([k g]). The place where the flow of air is interrupted is called the *place of articulation* of the consonant.

Figure 25: Praat – Spectrograms of *aba ada aga*



3.2 Acoustic correlates of place of articulation in stop consonants

3.2.1 Before you start

As you have probably realized by now, formants can be very visible or hard to see, depending on the vowels and the quality of the recording. In this part of the lab, you will be looking at full syllables. As you are going to realize, the shape of the formants seems to be an important piece of information about consonants. However, you can only analyze their shape if you can see them, right? In general, Praat's automatic formant tracking helps identifying the relevant formants, but here we will be analyzing high quality synthetic syllables created by Stephens and Holt (2011), and the formants should be quite visible in the spectrograms without the automatic formant tracking from Praat. Therefore, I strongly suggest that you turn the formant tracking off before you start analyzing the sound files in this part of the lab. You can click on `Formants` > `Show formants` and deselect this option.

3.2.2 aba ada aga

Load the file *aba_ada_aga.wav* in Praat. Once the file is loaded, select it on the `Objects` window and then, open the `View & Edit` window. It should look like figure 25:

Write–up: Once you have the triplet of utterances optimally displayed in front of you (i.e., no red dots indicating the automatic formant tracks), try to figure out what the differences between the consonants are. What looks different in each spectrogram? Does the pattern of formants change according to the consonants you see uttered? What about the shape of individual formants? Try to characterize as best as you can the differences you see. Do you think you can, at least tentatively, characterize the different consonants? That is, do you think you can come up with an acoustic definition of what [b] [d] and [g] are?

Remember to save a picture of your display[1] and put it in your write up, so I can see what you saw. Once you have a tentative acoustic definition of each consonant, move on to the next comparison.

3.2.3 ibi idi igi

Do the same thing you did for the previous file, but now based on the file *ibi_idi_igi.wav*.

Write–up: Compare the three utterances. What are the differences between the syllables starting with the different consonants? Are they consistent with the ones you observed for the first triplet? What about the tentative acoustic definitions for the consonants you derived from the previous triplet, do they hold for this new series of syllables? Remember to save a picture and put it on your write up. Once you have finished this comparison and written it up, move on to the next one.

3.2.4 ubu udu ugu

Do the same thing you did for the previous two files, but now based on the file *ubu_udu_ugu.wav*.

Write–up: Compare the three syllables starting with different consonants. What are the differences between them? Are they consistent with the ones you observed for the first and/or second triplet? What about the tentative acoustic definition for the consonants you derived from the previous triplets, does it hold for this new series of syllables? Remember to save a picture and put it on your write up. Once you have finished this comparison and written it up, move on to the next one.

3.2.5 idi ada udu

Do the same thing you did for the previous three files, but now based on the file *idi_ada_udu.wav*.

[1] If you do not know how to do that, google "Print Screen" or "Screen capture" together with your operating system name. In case you want to edit (cropping, for instance) the image you captured, you'll have to use an image editor.

Write–up: Compare the three syllables that now, unlike the other cases, *start with the same consonant*. Instead of having three different consonants and trying to characterize the differences between them, we are looking at the same consonant; therefore you should try to characterize the similarities between the graphs. By now, you have seen spectrograms for different syllables starting with [d]. Have they been consistent so far? Pay close attention at the shape of the formants. What consequences do you think this has for our "one–to–one mapping" hypothesis? Remember to save a picture and put it on your write up. Once you have finished this comparison and written it up, you can move to the final part of the lab.

3.3 What you need to write up

All the parts marked as *Write–up* in the instructions above should be incorporated in your lab write–up, together with any plots that may be required. Try to articulate your impressions and results the best you can, in full coherent sentences (no bullets, please).

4 Part 1C: Finding and measuring acoustic correlates of voicing

4.1 Before you start

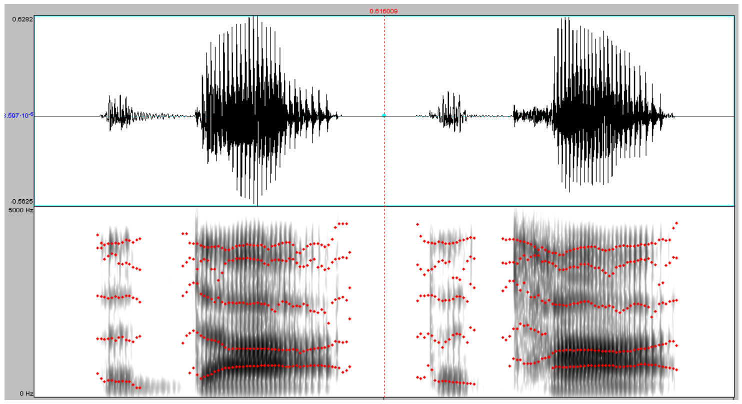
In this part of the lab we will be trying to identify and measure the acoustic correlates of the articulatory feature of *voicing*. We will still be using Praat to do the analysis and measurements, but we will now use a spreadsheet to collect the measurements and plot the data. In what follows, I am assuming the usage of Microsoft™ Excel[2], but I assume any other spreadsheet program like LibreOffice or Googlesheeets will probably work as well with minimal modifications.

4.2 Overview

So far we have looked at the following consonants: [b], [d] and [g]. However, they constitute only half of the inventory for the English stop consonants. The other half, [p], [t] and [k] are remarkably close in articulatory terms to [b], [d] and [g] — namely, they respectively share their place of articulation. In fact, the only difference between the two subsets is what phonologists call "voicing". The easiest way to grasp what "voicing" is is to say [pa] and [ba] with your index and middle fingers on your throat. Notice the difference? Your vocal chords vibrate more when you articulate the latter than when you articulate the former.

[2]The figures were generated in an older version of Microsoft™ Excel, so it may not match the visual interface you will get when using the newer versions, but the functionality should be equivalent.

Figure 26: Praat – Spectrogram of *the dot, the tot*



Locate the sound file `thedot_thetot.wav`, which contains the recording of a native speaker of English uttering the following two words in close succession: *the dot, the tot*. Open this file in Praat by clicking on `Read` > `Read from file`...) and once the file is in the `Objects` window, click on it and press the `View & Edit` button to open the sound editor window. It should look like figure 26.

Write–up: Can you see the difference between the voiced (*dot*) and unvoiced (*tot*) consonants? What is it? (Tip: you should look at the waveform as well, since it is also informative). Once you have figured this one out and written it up, move on.

Write–up: The difference you observed between the two consonants ([d] and [t]) is called the "burst", and it is the flow of air following the release of the stop. Notice how it has energy spread over a wide range of frequencies (the big relatively uniform grayish area before the vowel), and how it is especially salient for [t]; [d] has barely any visible burst on the display. The time between the onset of the burst (i.e., the stop release) and the onset of voicing (in this case, the vowel) receives the name of Voice Onset Time, or simply VOT. Since this seems to be the acoustic cue that sets voiced and unvoiced stop consonants apart, we are going to be measuring it.

Your task now is to open the files containing the recordings of a different native speaker of American English saying the two words (*the dot, the tot*) and measure the VOT of both consonants.

Here's how you do it. First, zoom in in the *the tot* utterance, as shown in figure 27. Now, try to find and select the chunk of time between the onset of the burst and the onset of the vowel, as shown in figure 28.

Figure 27: Praat – Spectrogram of *the dot, the tot* – zooming in

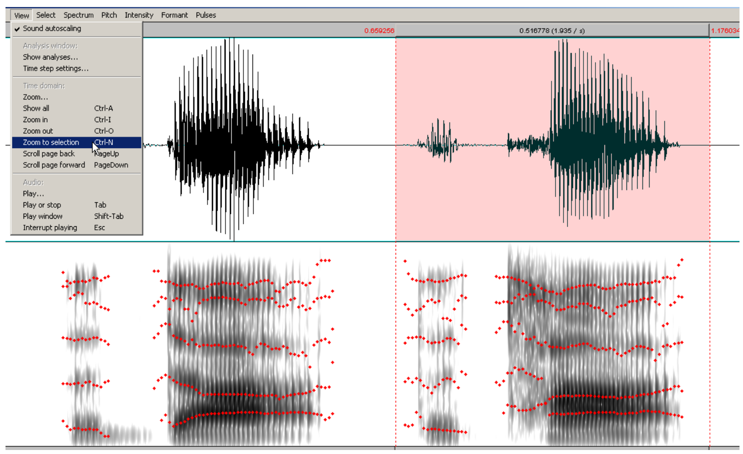


Figure 28: Praat – Spectrogram of *the dot, the tot* – Measuring the VOT of [t]

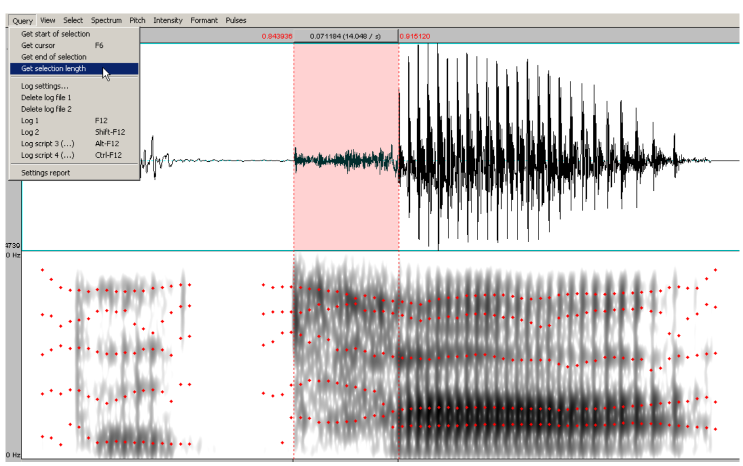
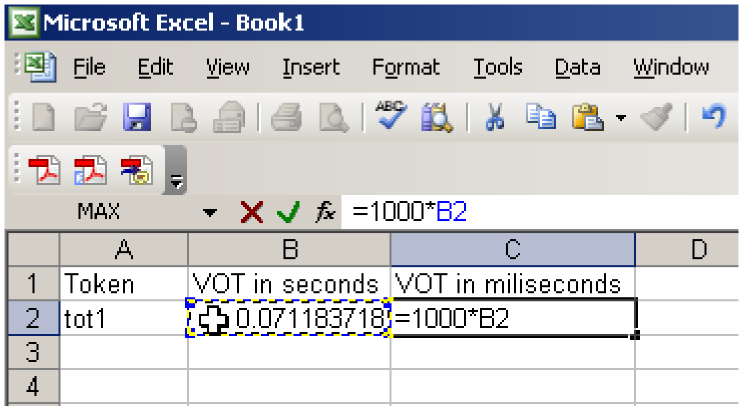


Figure 29: Microsoft™ Excel – Saving your measurements



Once you are confident in your selection, go to `Query` > `Get selection length`, and copy and paste the value you get into a spreadsheet, as shown in figure 29 — notice the little trick to transform the measurements from seconds to miliseconds.

Now you should try to measure the VOT of [d]. Unzoom from where you are (`View` > `Show all`) and zoom in on the first utterance. As you can see in figure 30, the VOT is much smaller than the one for [t]. In fact, it is very possible you will need to zoom in some more in your own recordings to see the burst at all, since the quality of the recording will probably not be as good. Once you are satisfied with your selection, get the values into the spreadsheet.

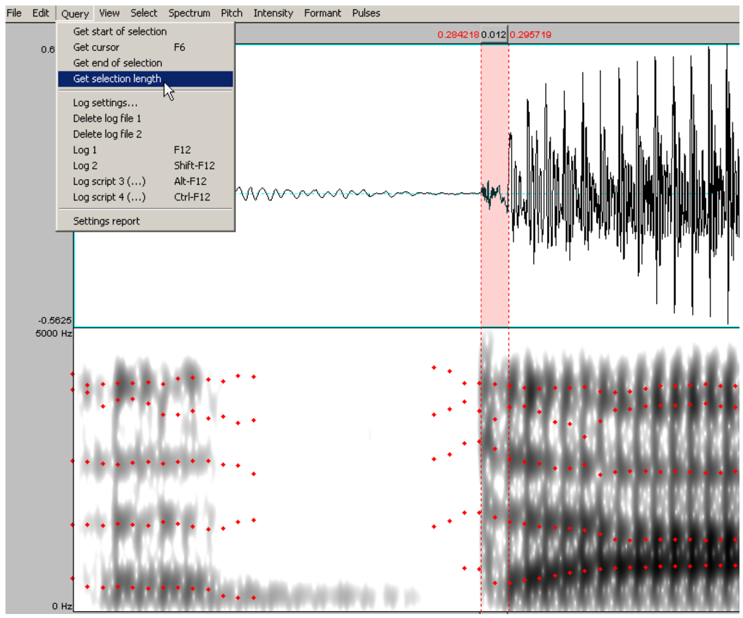
Try to get the values of the 15 repetitions files. By the end, your spreadsheet should look something like figure 31.

Write–up: Notice the time–bins (0–10, 10–20, ..., 90–100) on the bottom of the spreadsheet, with two empty columns, one under [t] and one under [d]. Your task now is to populate these columns with the counts of how many observations you had in each time–bin. For instance, if you had two [t] VOTs falling into the bin 60–70ms, then you should input "2" on the column "[t]" next to the bin "60–70". Once you are done, you should plot a bar graph of the data you collected, with the time–bins as the x–axis and the counts on the y–axis, as shown in figure 32. What can you conclude from your graph? Does VOT constitute a good acoustic cue to differentiate voiced and unvoiced stops?

4.3 What you need to write up

All the parts marked as *Write–up* in the instructions above should be incorporated in your lab write–up, together with the plots they require. Try to articu-

Figure 30: Praat – Spectrogram of *the dot, the tot* – Measuring the VOT of [d]



late your impressions and results the best you can, in full coherent sentences (no bullets, please).

References

Hillenbrand, J., Getty, L. A., Clark, M. J., & Wheeler, K. (1995). Acoustic characteristics of american english vowels. *The Journal of the Acoustical society of America*, *97*(5), 3099–3111.

Peterson, G. E., & Barney, H. L. (1952). Control methods used in a study of the vowels. *The Journal of the acoustical society of America*, *24*(2), 175–184.

Stephens, J. D., & Holt, L. L. (2011). A standard set of american-english voiced stop-consonant stimuli from morphed natural speech. *Speech communication*, *53*(6), 877–888.

Figure 31: Microsoft™ Excel – What your spreadsheet should look like

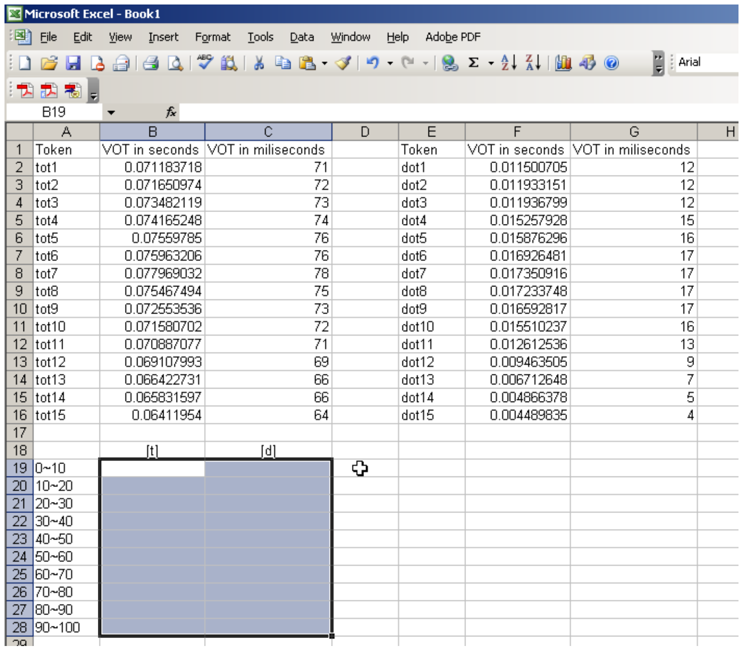


Figure 32: Microsoft™ Excel – Plotting the VOT bar graph