

# PSYCH-UH 3516EQ: Lab in Psychology of Language

## Lab 1: Acoustic Phonetics

### Basic Acoustic Measurements

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## Contents

<b>1 Overview</b>	<b>3</b>
<b>2 Part 1A: Vowel Formant Analysis</b>	<b>3</b>
2.1 Overview . . . . .	3
2.2 What you will need . . . . .	4
2.2.1 The sound files . . . . .	4
2.2.2 Using Praat to measure the formant values . . . . .	5
2.2.3 Plotting the Formant values . . . . .	12
2.3 What you should hand in . . . . .	24
2.4 Deadline . . . . .	24
<b>References</b>	<b>24</b>

## List of Figures

1	Praat – Main Windows . . . . .	6
2	Praat – Reading from a file . . . . .	6
3	Praat – Object in List . . . . .	7
4	Praat – View and Edit Window . . . . .	8
5	Praat – View and Edit Window: Selection of part of the waveform for inspection . . . . .	9
6	Praat – Getting the Formants automatically – Selecting the <i>steady state</i> of the vowel . . . . .	9
7	Praat – Getting the Formants automatically – Automatically cal- culate F1 . . . . .	10
8	Praat – Getting the Formants automatically – Getting the mean F1 value over the vowel’s <i>steady state</i> . . . . .	10
9	Microsoft™ Excel – Saving the Formant values of each recording	11
10	Praat – Read your data from <i>comma separated value</i> file . . . . .	13
11	Praat – Newly created <i>Table</i> object in the <i>Objects</i> window . . . . .	14
12	Praat – Visually inspecting <i>Table</i> object . . . . .	14
13	Praat – Visually inspecting <i>Table</i> object . . . . .	15
14	Praat – Scatterplot dialog box . . . . .	16
15	Praat – Scatterplot result . . . . .	16
16	Praat – Erasing plots from Picture window . . . . .	17
17	Praat – Loading Peterson & Barney 1952 data . . . . .	19
18	Praat – Inspecting Peterson & Barney 1952 data . . . . .	19
19	Praat – Extracting subset of data in the Peterson & Barney 1952 dataset . . . . .	20
20	Praat – Extracting the data from the females in the Peterson & Barney 1952 data . . . . .	20
21	Praat – Drawing ellipses in F1–F2 space for each vowel category in the Peterson & Barney 1952 data – data from females only .	21
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 . . . . .	21
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 . . . . .	22
24	Praat – Changing the plot color for overlaying a new plot on top of an existing one. . . . .	23

# 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.

## 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 i: d]
2. hid – [h ɪ d]
3. head – [h ε d]
4. had – [h æ d]
5. hod – [h ə: d]
6. hawed – [h ɔ: d]
7. hood – [h ʊ d]
8. who'd – [h u: 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 — Googlesheets, 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*) or 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”; [ɜ]
  - 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 i: d] – iy
2. hid – [h ɪ d] – ih
3. head – [h ε d] – eh
4. had – [h æ d] – ae
5. hod – [h ə: d] – ah
6. hawed – [h ɔ: d] – aw
7. hood – [h ʊ d] – uh
8. who'd – [h u: 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

### 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.

Figure 1: Praat – Main Windows

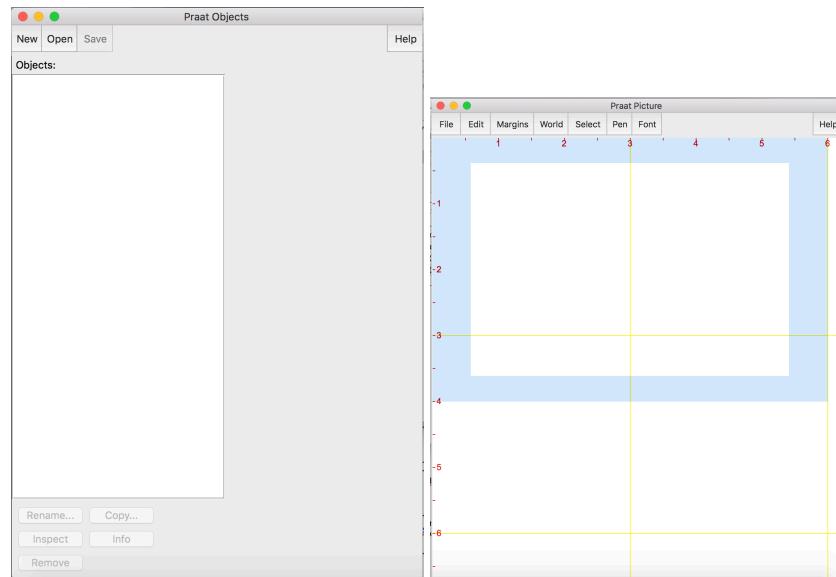


Figure 2: Praat – Reading from a file

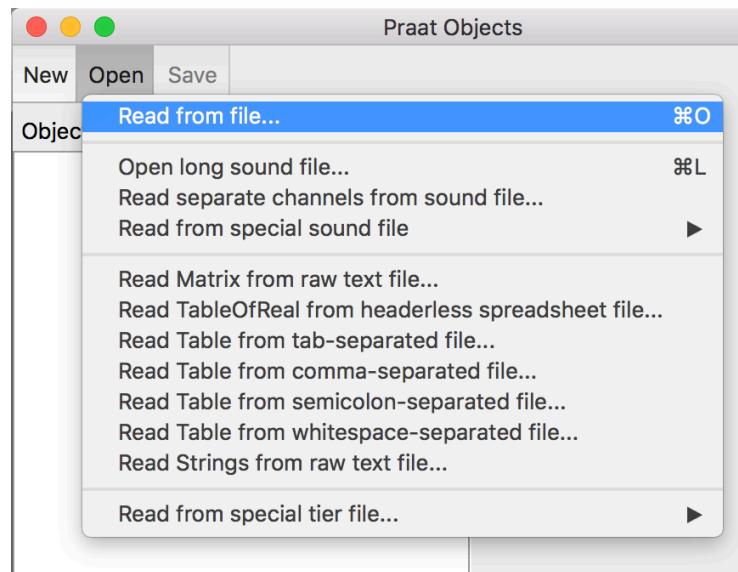


Figure 3: Praat – Object in List

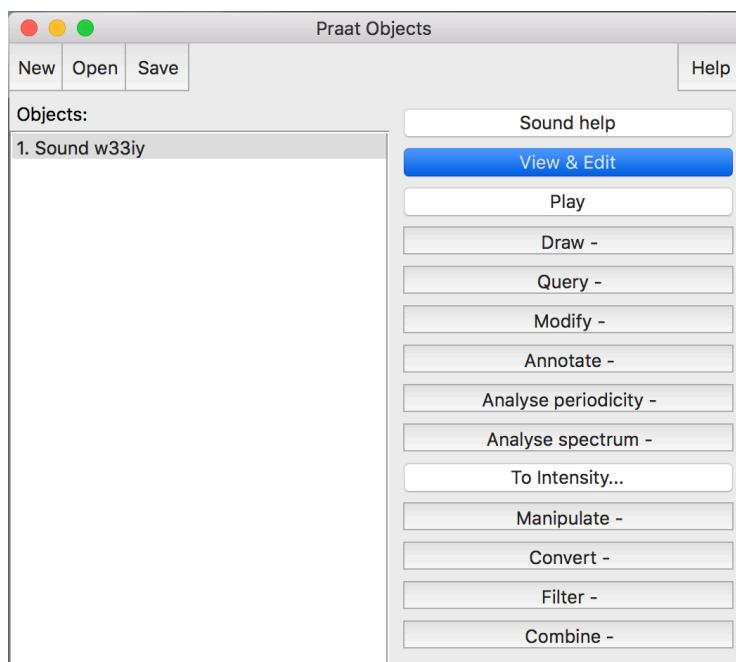
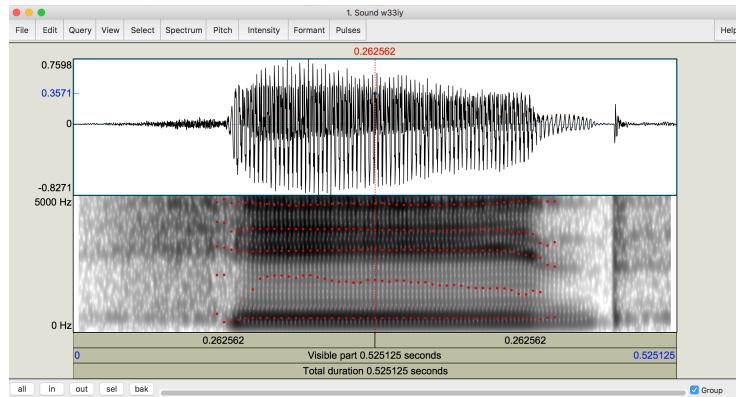


Figure 4: Praat – View and Edit Window



**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 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 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

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

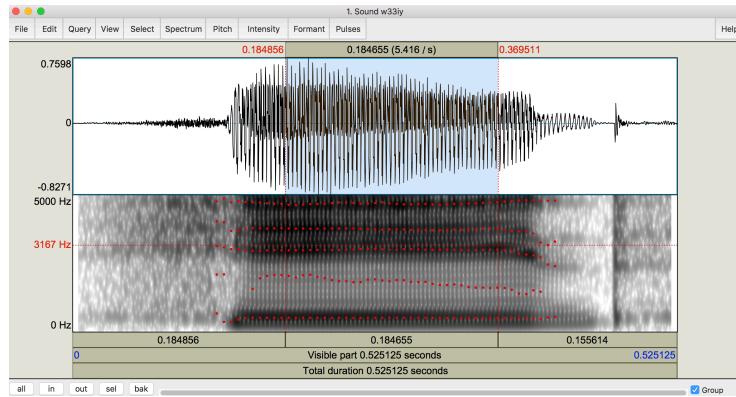


Figure 6: Praat – Getting the Formants automatically – Selecting the *steady state* of the vowel

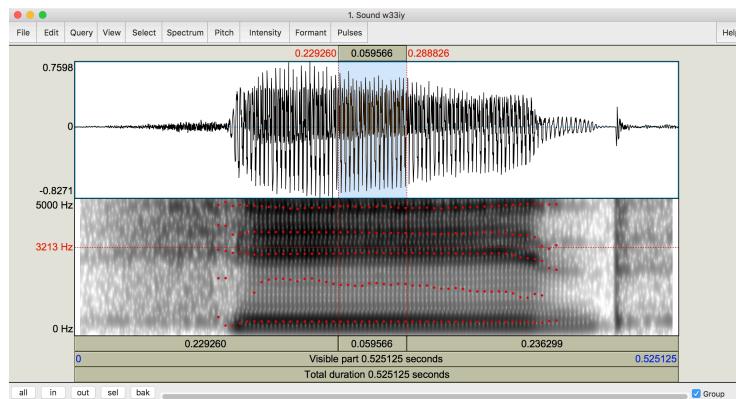


Figure 7: Praat – Getting the Formants automatically – Automatically calculate F1

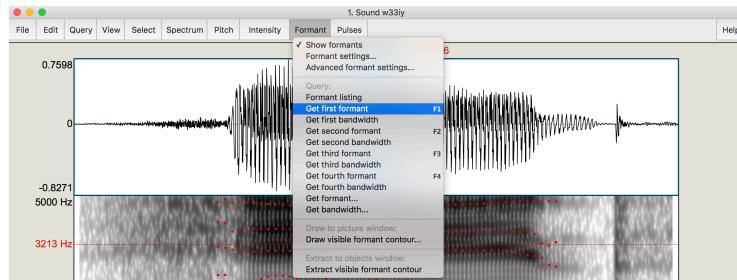


Figure 8: Praat – Getting the Formants automatically – Getting the mean F1 value over the vowel's *steady state*



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					

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 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: i = \ic
3. w33eh.wav: e = \ef
4. w33ae.wav: æ = \ae
5. w33ah.wav: a= \as
6. w33aw.wav: o= \ct
7. w33uh.wav: u = \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], [a] and [u]) for the *w33* participant.

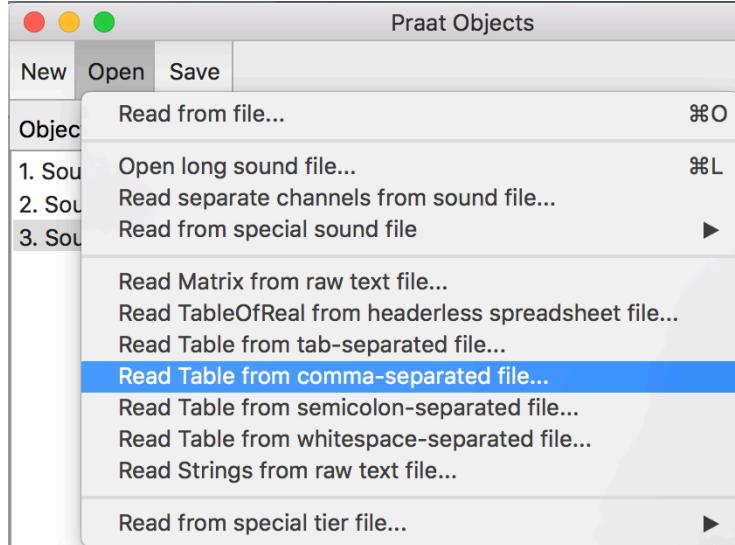
### 2.2.3 Plotting the Formant values

**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 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

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



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.

**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.

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

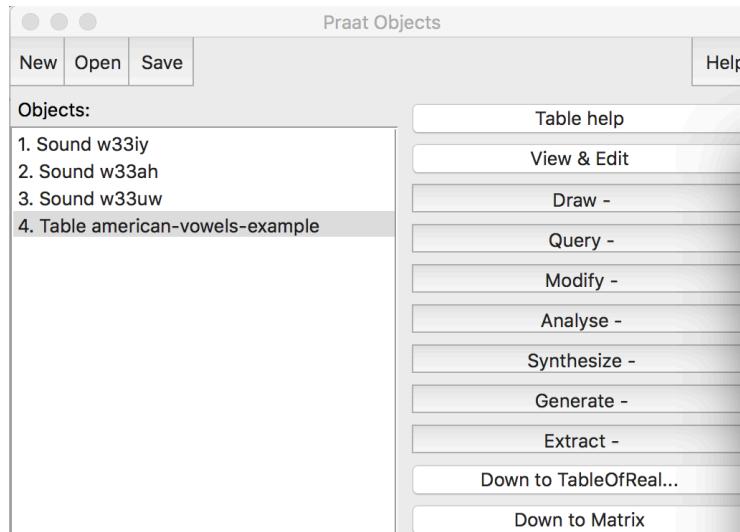
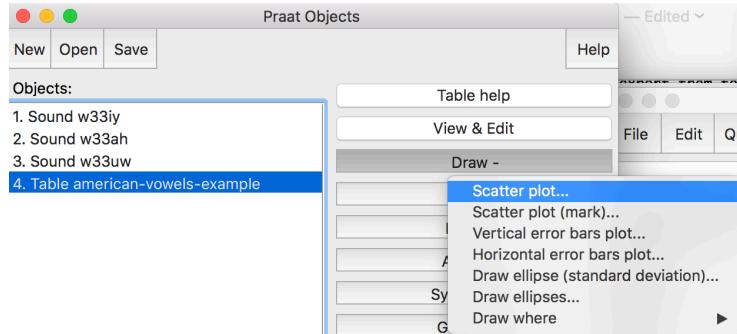


Figure 12: Praat – Visually inspecting Table object

The screenshot shows the '4. Table american-vowels-example' window. The title bar includes buttons for 'File', 'Edit', and 'Query'. The main area displays a table with the following data:

row	1	2	3	4	5
	file	vowel	IPA	F1	F2
1	w33iy	iy	i	519	1869
2	w33ah	ah	ɑ	941	1228
3	w33uw	uw	u	527	1096

Figure 13: Praat – Visually inspecting Table object



**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 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

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

Figure 14: Praat – Scatterplot dialog box

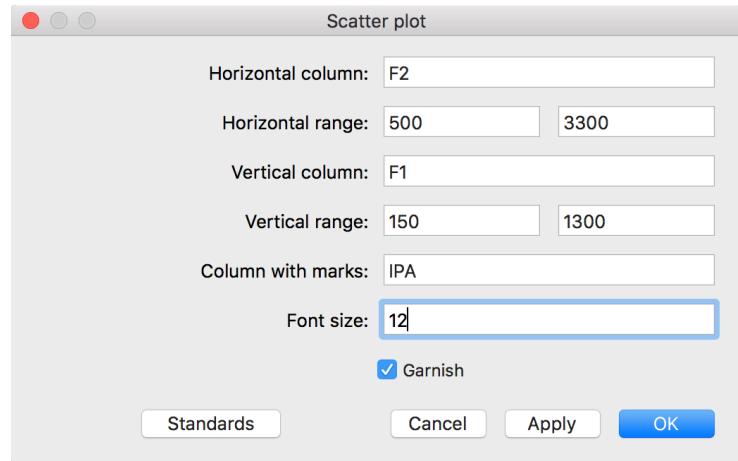


Figure 15: Praat – Scatterplot result

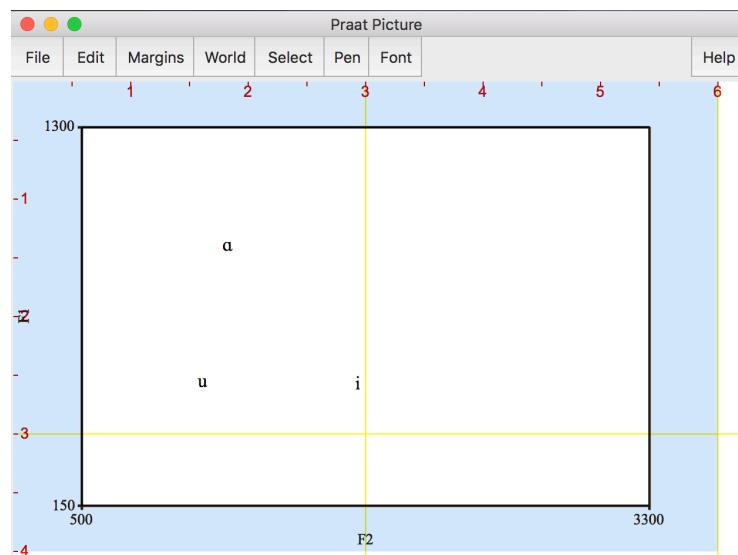
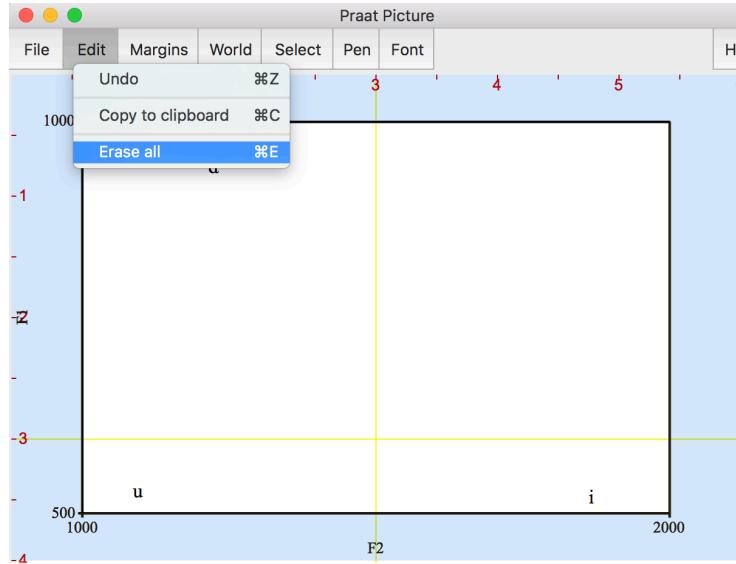


Figure 16: Praat – Erasing plots from Picture window



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.

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 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:

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

Figure 17: Praat – Loading Peterson & Barney 1952 data

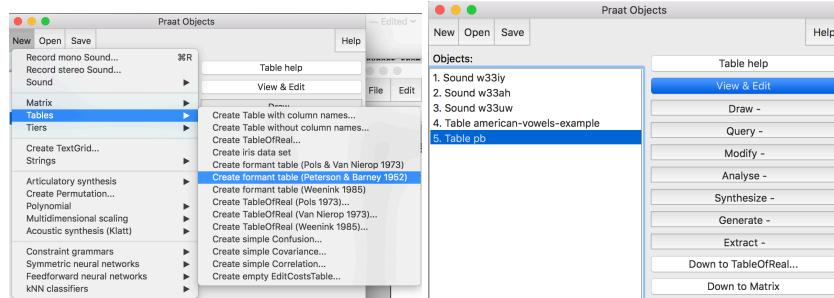


Figure 18: Praat – Inspecting Peterson & Barney 1952 data

row	1	2	3	4	5	6	7	8	9
	Type	Sex	Speaker	Vowel	IPA	F0	F1	F2	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	r	203	390	2030	2640
4	m	m	1	ih	r	192	310	1980	2550
5	m	m	1	eh	e	161	490	1870	2420
6	m	m	1	eh	e	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	ə̄	177	370	1520	1670

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

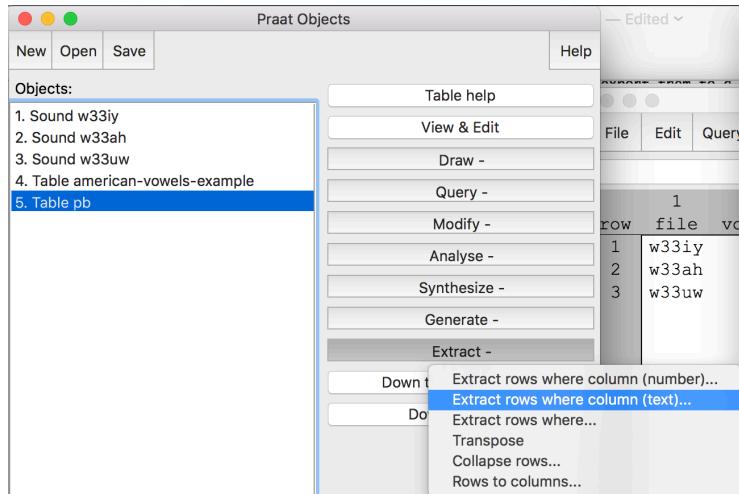
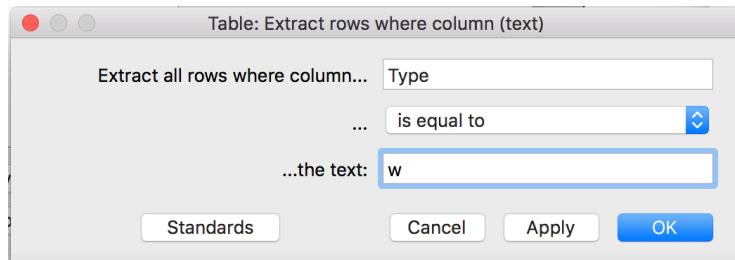


Figure 20: Praat – Extracting the data from the females in the Peterson & Barney 1952 data



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).

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

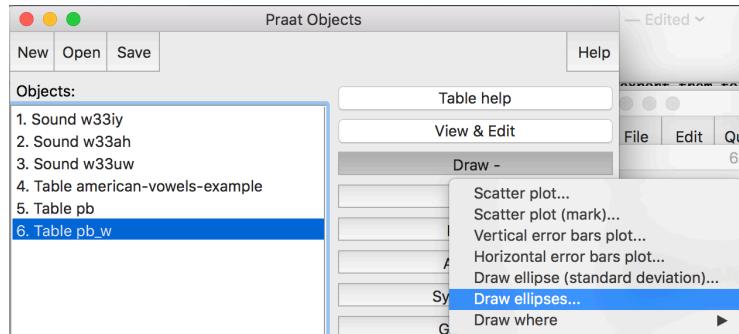
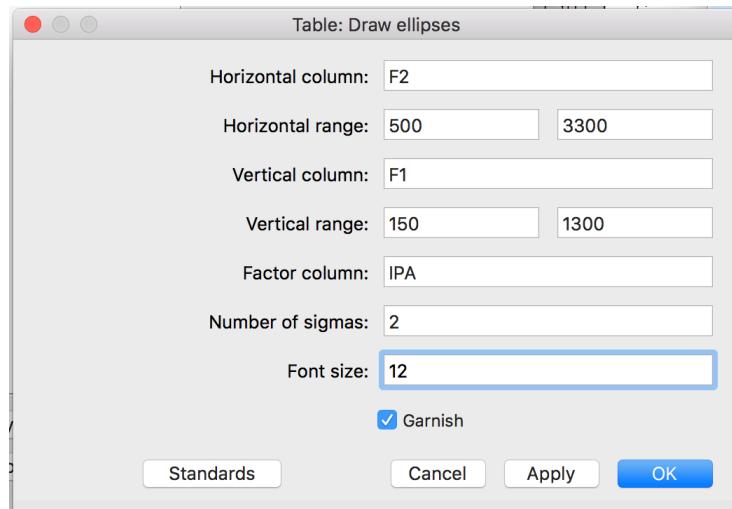


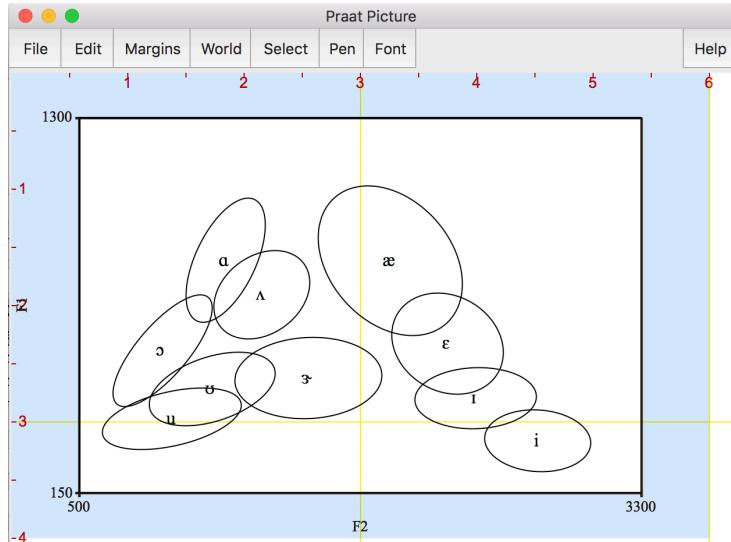
Figure 22: Praat – Drawing 2 Standard Deviation ellipses in F1–F2 space for each vowel category in the Peterson & Barney 1952 data – data from females only



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 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

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

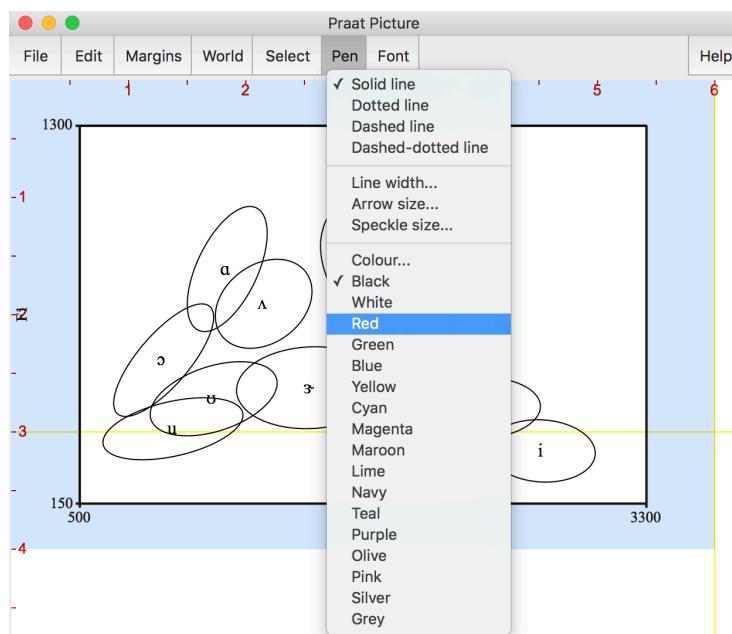


the pattern you observed in the data from the single participant you analyzed holds across multiple participants. Does it? In what way? Does this new pattern present any challenges to the idea that there are one-to-one mappings between the acoustic and articulatory representations of vowels?

**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.

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

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



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 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.

### 2.4 Deadline

This part of the lab (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 F1 and F2 measurements.

There will *no penalties* for handing in this part of the lab after the deadline, however, 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.

## 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.