2026 ASEE ANNUAL CONFERENCE June 21–24, 2026 | Charlotte Convention Center, NC
Host Sponsor UNC Charlotte
Paper ID #51491

SHARE: Speech Production Topics and Lab Exercises Add Engineering Content to a Physiology Class

Dr. Lianne Cartee, North Carolina State University at Raleigh and UNC-CH

Lianne Cartee is the Asso. Chair for Education and Director of Undergraduate Studies in the Lampe Joint Department of Biomedical Engineering at the Univ. of North Carolina at Chapel Hill and North Carolina State University.

SHARE: Speech Production Topics and Lab Exercises

Add Engineering Content to a Physiology Class

ABSTRACT: Biomedical Engineering programs frequently teach physiology courses from a quantitative or systems point of view. A survey of ten top programs in biomedical or biological engineering indicated that eight required an engineering physiology course in the curriculum. Finding relevant engineering subjects to add quantitative content to a physiology course can be challenging.

The mechanisms of speech production are rarely if ever included in standard physiology texts. A survey of ten popular physiology textbooks showed that none included either anatomy of the larynx or an explanation of speech production. Additionally, three popular engineering-specific physiology textbooks also ignored the topic.

Objectives: Speech production exposes students to the concepts of frequency domain, filtering, resonance and fundamental physics of a vibrating string. When studying the anatomy and physics of the vocal cords, students predict the fundamental and harmonic frequencies produced by a standing wave in a string attached at both ends. Likewise, students predict formants from the passage of the output of the vocal cords through the vocal tract, introducing the concepts of simple filtering and resonant frequencies that produce the formants of speech. Students can measure the output of their own voices and compare the measured harmonics and formants to calculated values.

Implementation: Fundamental concepts can be introduced in lecture and reinforced with laboratory exercises. Recording software such as Adobe Audition gives students the ability to view frequency harmonics and formants in real time. A simple slide flute demonstrates the effect of changing tube length on frequency production, analogous to the length of the throat. Stringed instruments can be used to show the dependence of tension, mass per unit length, and string length on the frequency produced, explaining the behavior of the vocal cords. A child's party toy, the "groan tube" simultaneously produces two different resonant frequencies resulting in vowel-like sounds, reinforcing the relationship of formant frequencies to vowel production. Use of an electrolarynx in lab exposes students to current solutions to restore voice production to patients after laryngectomy.

Class discussion of electrolarynxes and tracheoesophageal punctures [3],[4] provides a launching point for discussions of limitations of current technologies and possible improvements. In addition, knowledge of the mechanisms of speech production may provide a basis for teaching speech recognition in more advanced classes.

Discussion: It's possible to scale the activities for a large class. Students only need a computer with a microphone and the necessary software. The fundamental lab exercises can be taught as an on-line, remote, hands-on learning opportunity if needed.

MOTIVATION: Biomedical engineering programs often integrate physiology with engineering applications, but identifying meaningful engineering content can be difficult. Speech production, often overlooked in physiology textbooks, offers a relevant example that reinforces filtering, resonance, string vibration, and time–frequency domain relationships.

LEARNING OBJECTIVES: After completing these activities, students should be able to 1) Identify the fundamental frequency, harmonic frequencies and formants of speech from a graph. 2) Calculate the fundamental frequency and harmonics of a vibrating string attached at both ends. 3) Calculate the resonance frequencies of a tube closed at one end and open at the other end. 4) Predict the speech output produced by filtering sounds through the throat for a given vowel. 5) Measure vocal output in time and frequency domains. 6) Describe the operation of voice replacement technologies.

IMPLEMENTATION: Lectures should introduce students to the fundamentals of speech production. This includes demonstrations of vocal cords and resulting sounds through resources such as *Beth's First Laryngoscopy* [1]. In addition, the governing equation for vibration of a string attached at both ends (equation 1) and its ability to predict the fundamental frequency and harmonics of the vocal cords with changes in vocal cord length should be introduced.

$$f_n = n\frac{v}{2L} = nf_1 \text{ for } n = 1, 2, 3 \ldots. \quad (1)$$

f_1 = the fundamental frequency and 1st harmonic; f_2 the 2nd harmonic; f_3 the 3rd harmonic
v= the velocity of the traveling wave down the vocal folds (not the speed of sound) dependent on the tension and mass per unit length of the string
L = length of the vocal cords

The output of the vocal cords as given in equation 1 is shown in the time domain in Figure 1 (top left) and frequency domain Figure 1 (top right).

Lectures should also introduce students to the filtering of sound produced by the vocal tract that results in formants. It's useful to introduce the simplest shape of the vocal tract, a straight tube closed at one end (the vocal cords) an open at the other (the mouth) as shown in equation 2. This is the approximate shape of the vocal tract when producing the vowel "eh" /ɛ/.

$$f_n = n\frac{v}{4L} = nf_1 \text{ for } n=1,3,5 \ldots. \quad (2)$$

f_n = the resonance frequencies of speech also known as formants
v= speed of sound = 340.29 m/s
L = length of the tube (vocal tract)

The filter produced by the vocal tract when producing the vowel "eh" /ɛ/ is shown in the middle panel of Figure 1. Students learn to predict the speech output produced by passing the output of the vocal cords through the vocal tract in the frequency domain (Fig. 1 bottom right) and, for completeness, see how the characteristic shape of speech in time domain (Fig. 1 bottom left) can be found from the frequency domain signal.

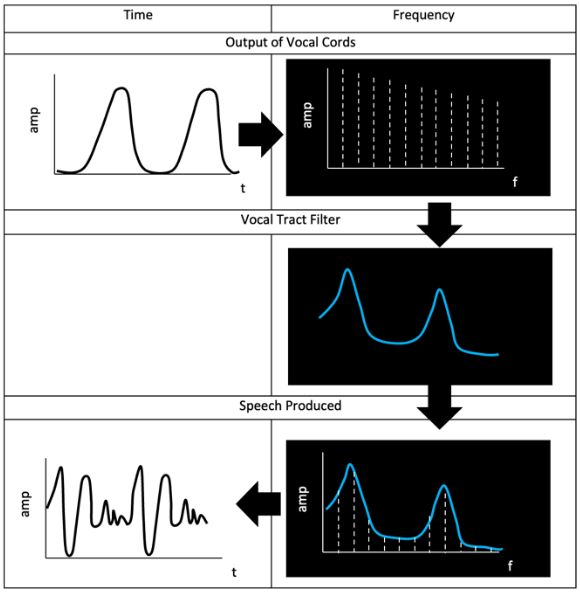

Figure 1: *Top—ideal vocal cord output in the time (left) and frequency (right) domains. Middle—acoustic filter of the vocal tract. Bottom—resulting speech after filtering, shown in time (left) and frequency (right) domains. Adapted from Rossing* [2].

In lab or at home, students should view their vocalizations in real-time in both the time and frequency domains using Adobe Audition or a free alternative such as Audacity. By singing different vowels, they can visualize the varying filters produced by the vocal tract. By changing their pitch, they can see how the fundamental and harmonic frequencies change. Concepts should be reinforced by comparing their data with predicted values from the equations..

For additional context, students can analyze their own musical instruments, which mirror speech production by using a reed or aperture to produce frequencies that are filtered by the instrument's shape. Alternatively, instructors can use inexpensive slide flutes to demonstrate how changing the tube's length alters fundamental and harmonic frequencies.

If funds permit, the instructor can introduce students to the use of an electrolarynx. The electrolarynx operation reinforces the fact that the initial source of vocalizations is a simple buzzing sound that becomes speech when it is filtered through the vocal tract. It also demonstrates the need for biomedical engineering advancements in voice replacement strategies.

DISCUSSION: Setting up a speech lab is straightforward and highly scalable. Using a computer and microphone, students can use Adobe Audition or the free alternative, Audacity, making the lab ideal for both large classes and online learning. Demonstrations can be low-cost using party toys or student provided instruments. Electrolarynxes ($200–$800) can be used to demonstrate voice replacement strategies and shared among groups. One drawback is the likely absence of written material in the assigned physiology textbook. To compensate, instructors can provide supplemental background readings or reference external resources like Rossing [2].

REFERENCES:

[1] B. Janicek, "Beth's First Larygyscopy- Vocal Cords in Action." YouTube.com. https://www.youtube.com/watch?v=iYpDwhpILkQ\ (accessed Jan. 20, 2026)

[2] T. D. Rossing, *The Science of Sound*, 2nd edition. Pearson, 1990.

[3] Centers for Disease Control and Prevention (CDC), "Tips from Former Smokers – Shawn W.'s Tip Ad." YouTube.com, https://www.youtube.com/watch?v=PbvOHUiIP2M (accessed Jan. 20, 2026)

[4] S.A. Shaghauyegh, C.B. Shires, K. Dewan and D. K. Chhetri, "Total tracheoesophageal puncture failure: A scoping review of patient characteristics and etiologies." *Head & Neck,* vol. 47, no, 1, pp. 90 – 97, Jan. 2025.

Appendix 1
Example Assessment: Speech Analysis Lab

Please collect and save all data. Questions and analysis will be in a homework assignment.

Tools needed for this lab

For this lab, you will need Adobe Audition. Please download and install the software before lab.

Introduction

Human vocal cords produce a buzzing noise with a broad spectrum of frequency content. The vocal cords themselves only produce a buzz, not words or complex sounds. The vocal cords produce sounds at a fundamental frequency with many higher order harmonics (tones at integer multiples of the fundamental frequency). Fig. 1 shows the time signal (top left) and the frequency spectrum (top right) of the ideal sounds produced by the vocal cords. The lowest frequency is the fundamental, and all other frequencies in the spectrum (harmonics) are integer multiples. Note that a higher pitch sound would have a higher fundamental frequency and greater spacing between the harmonics, while a lower pitch would have a lower fundamental frequency and less spacing between the harmonics.

Words are formed from the buzz produced by the vocal cords by changing the shape of the vocal tract using the mouth, tongue and lips. The vocal tract including the mouth, tongue and lips acts as a filter applied to the sound produced by the vocal cords. The filter passes some frequencies from the vocal cords, the resonant frequencies of the vocal tract, and attenuates others. Figure 1 (center) shows a hypothetical filter produced by the vocal tract. It passes two ranges of frequencies and attenuates the others. The final speech, the vowel or consonant sound that is heard, is the sound that passes through the filter. Figure 1 shows the frequency spectrum of the speech after passing through the vocal tract filter (bottom right) and the corresponding time domain signal for the speech (bottom left).

Musical instruments work in much the same way as the human voice. Each instrument has an excitatory source that produces a vibration of some sort. That vibration may be caused by a reed, a string, buzzing of the lips or blowing across a hole, for example. This is equivalent to the buzzing made by the vocal cords. The instrument itself will then have a characteristic shape that filters the excitatory sound. The pitch of the instrument is changed by changing the fundamental frequency of the excitatory source and/or the shape of the filter. You can change the filter shape of a woodwind instrument by pressing keys, for example.

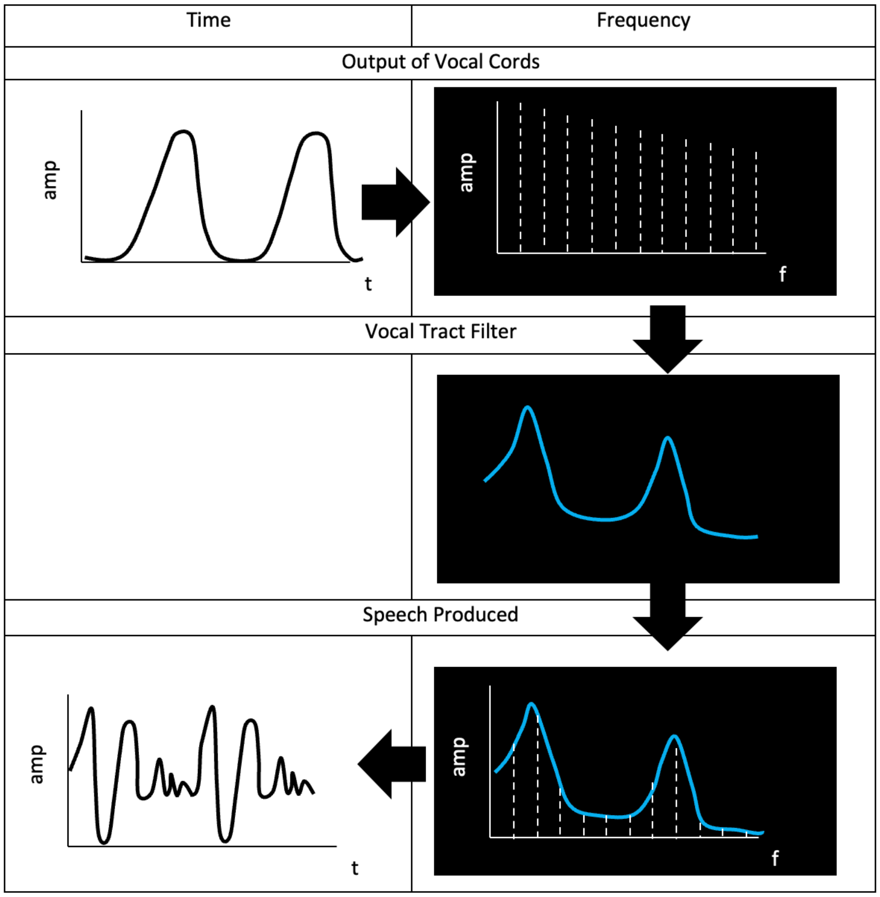

Figure 1: (top) Ideal output of the vocal cords in time (left) and frequency (right) domains. (middle) Acoustic filter produced by the vocal tract. (bottom) Speech produced by passing the output of the vocal cords through the vocal tract in time (left) and frequency (right). Adapted from Rossing (1990).

It is easy to calculate the peaks of the filter produced by a hollow tube to predict the resonant frequencies of the tube and the frequencies that would be attenuated by the tube.

For a tube that is closed on one end: $f_n = n\frac{v}{4L} = nf_1$ for n=1,3,5 … (1)

f_n = resonant frequencies (formants) passed through the tube
v= speed of sound = 340.29 m/s
L = length of the tube

The frequencies passed by the vocal tract filter (the peaks in Fig. 1 center) are known as formants. Vowel sounds are characterized by the presence of two or more formants. If a sound were composed of one frequency and its harmonics, it would sound like a note from a musical instrument. What makes vowels sound different is that two or more different frequencies are passed through the vocal tract filter.

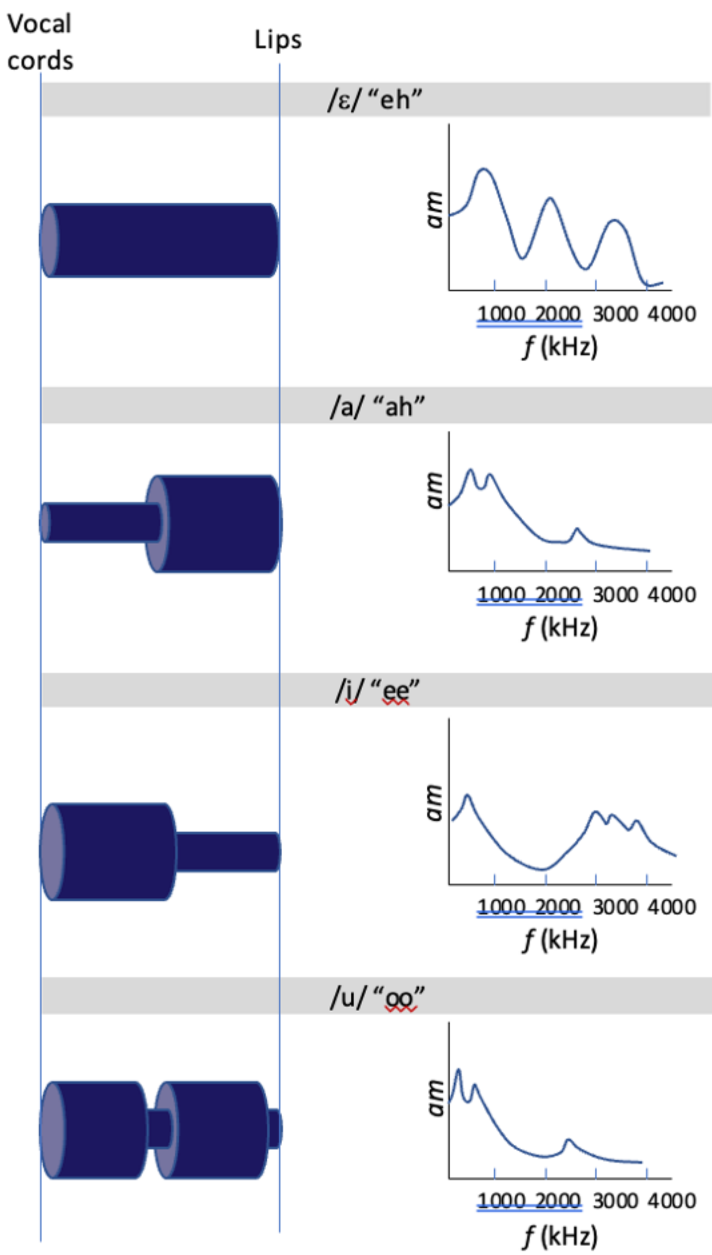

Figure 2: Vocal tract shape to produce four different vowels modelled by serial resonators (left) together with the approximate shape of the spectrum envelope (right) produced by passing sounds through the resonators. Adapted from Stevens (1972).

When the vocal tract is fully open as for the vowel /ɛ/ ("eh"), we consider it to approximate a hollow tube that is closed on one end as shown in Figure 2 (top left). The vocal cords create the closed end, and the mouth creates the open end. The vocal cords produce a fundamental sound and harmonics, and the frequencies from the vocal cords that pass through the fully open vocal tract can be calculated using equation (1) above for a hollow tube open at one end.

By changing the shape of our vocal tract, we can change the vowel sound we produce. Try saying (singing) the vowel /a/ (ah). You should feel the bottom of your vocal tract constrict while the top, mouth area, opens wide like the shape shown in Fig. 2 (2nd left). Now, try saying (singing) the vowel /i/ (ee). You should feel the bottom of your vocal tract open wide while the top constricts like the shape shown in Fig. 2 (3rd left). Finally, try saying (singing) the vowel /u/ (oo). You should feel a constriction in the center of your vocal tract and another constriction should be formed using your lips similar to the shape shown in the Fig. 2 (bottom left). It is beyond the scope of this class to calculate the frequencies passed by the vocal tract shapes shown in Figure 2 (other than that of a straight tube representing the vocal tract shape when producing the vowel /ε/ ("eh")). The figures on the right show the filter shapes. The fundamental and harmonics from the vocal cords pass through these filters, and the frequencies that pass without being attenuated (the peaks in the filter) are known as the formants.

Vowels are characterized by having more than one formant. We recognize vowel sounds by the relative locations of the 1st and 2nd formant frequencies. Fig. 3 shows the vowels produced in relation to the frequencies of the 1st and 2nd formant. Regardless of the fundamental frequency and harmonics produced by the vocal cords, if the first and 2nd formants fall within the ranges drawn below, we will hear the vowel sound indicated.

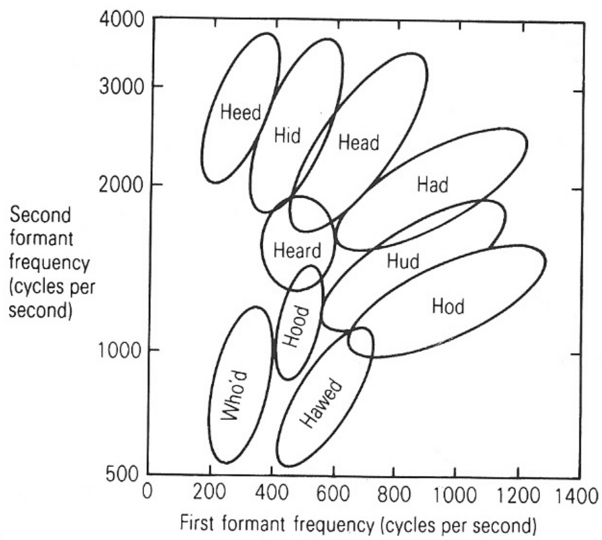

Figure 3: Values for first and second formants for various vowel sounds. From Alexander, R. McNeill (1992)

In this lab, you will examine the time and frequency content of vowels. To record successfully, you will need to sustain the vowels (sing them). Note that you can't sing a consonant. If you have a musical instrument available, you may also choose to examine the time and frequency of a musical instrument. A typical recording of a vowel in frequency domain may look like Fig. 4.

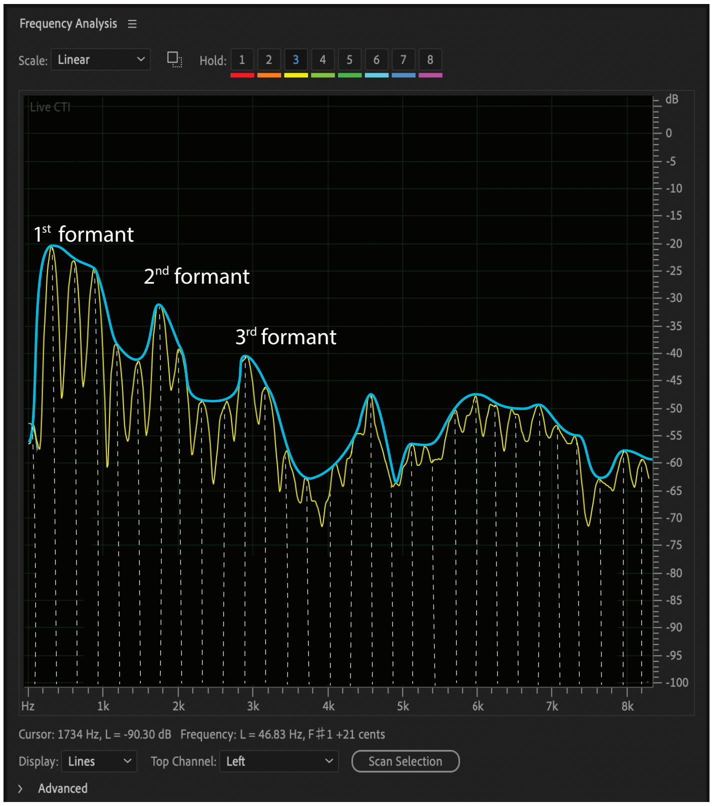

Figure 4: Speech production in frequency domain recorded using Adobe® Audition is shown in yellow. White lines mark the fundamental frequency and harmonics. The green line approximates the acoustic filter function. Local peaks in the filter function are the formants.

Superimposed on the computer output (the yellow lines) is an identification of the harmonics. The fundamental frequency and harmonics are shown by the dashed white lines. These would compare with the vertical lines in Figure 1 (top right). This is the frequency output of the vocal cords. When you measure the output of the vocal cords in the lab, you see the peaks in the spectrum, not straight lines, since the frequencies aren't sharply tuned to a single frequency as in Figure 1. *The green line superimposed* on the figure connects the peaks of the output, and approximates the filter produced by the vocal tract. This corresponds to the filter in Figure 1 (center). Local maxima in the filter are the formants. The 1st, 2nd and 3rd formants are identified. *Please note that you will only measure the yellow curve. You'll need to determine the placement of the dashed white lines and the green line yourself.*

The harmonics result from vibration of the vocal cords. The vocal cords act like a string attached at both ends. Equation (2) describes the frequencies produced.

$$f_n = n\frac{v}{2L} = nf_1 \text{ for } n = 1, 2, 3 \ldots \qquad (2)$$

When calculating the harmonic frequencies of the vocal cords, the velocity is not the speed of sound, but the velocity the cord vibrates.

v= the velocity of the traveling wave down the vocal cords (not the speed of sound)

$v = \sqrt{\frac{T}{\mu}}$ where T = tension and μ = mass per unit length of the vocal cords

L = length of the vocal cords

Instructions for using Adobe Audition

1. Start Adobe Audition
2. Make sure you are in the frequency view by selecting Window -> Frequency Analysis.

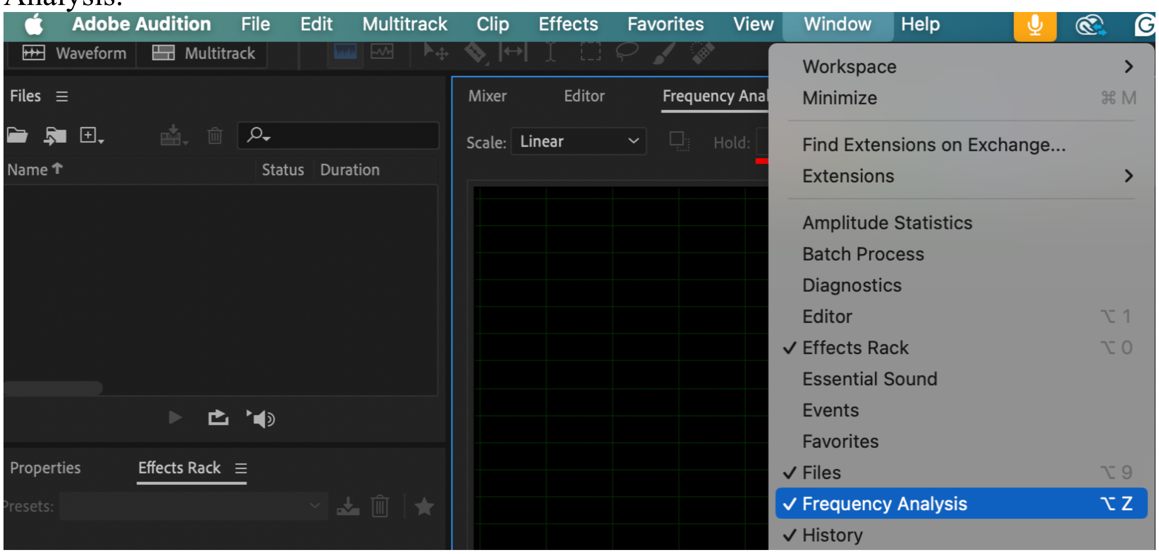

Figure 5: Adobe Audition Screen

3. Select the "Show Editor Panel Controls"
4. In the top right of the frequency panel, make sure that linear view is selected
5. For the remaining sections:
    a. To record, select the record button (red button) on the middle panel. Accept the default sampling rate.
    b. To pause the recording to measure values, use the pause button
    c. Periodically, stop the recording and select "new" from the *File* menu to clear the buffer
    d. If at any time, Adobe Audition stops recording, your file buffer is probably full. Stop the recording and select "new" from the *File* menu to empty the buffer.
    e. You may review previously recorded sounds by stopping the recording, highlighting the sound of interest in the time domain window, and pressing play.
    f. You can use the hold buttons to save segments for later viewing.

A. Measuring formants and pitch

Methods

1. Sing the vowel /ɛ/ (“eh”) into the microphone in a sustained voice. Try modulating the amplitude of your voice. Record the signal in frequency domain and pause at a moment when you have a strong, clean signal.
2. Using figure 4 as an example, measure the fundamental frequency and 1st and 2nd formant frequencies for the vowel /ɛ/ at several pitches: low, medium and high. Record your data below.
3. Using the hold buttons, sing the vowel /ɛ/ (“eh”) at several different frequencies, including very low and very high frequencies, and overlay the recordings. Take a screen shot of your superimposed recordings. Identify the 1st and 2nd formant frequencies from the overlaid recordings. You can do this by finding the envelope of all the superimposed recordings and looking for the local maxima.
4. Sing the vowels /a/ (“ah”), /i/ (”ee”) and /u/ (“oo”) and take a screen shot of your data.
5. Have one or two friends or people in your household (if available) sing the vowel /ɛ/ (“eh”) as well. (That way they can’t make fun of your singing!) Note their sex and height. It’s best to get data from someone who is a different sex if possible. Record the values of their fundamental frequency and 1st and 2nd formants. If no one is available, try to get data from a classmate.

Data to collect.

Your Sex:
Your Height:

	Fund. freq.	1st formant	2nd formant
Low pitch			
Medium pitch			
High pitch			
Multiple, overlaid pitches			
Expected formant frequencies			

Take a screen shot of the superimposed recordings.

Sing the vowels /a/ (“ah”), /i/ (”ee”) and /u/ (“oo”) and take a screen shot of your data. Include your screen shot below and sketch the shape of the filter produced by your throat for each vowel.

/a/ (“ah”)

/i/ (”ee”)

/u/ (“oo”)

Data from friends or other members or your household

Sex of participant:
Height of participant:

	Fundamental freq.	1st formant	2nd formant
Low pitch			
Medium pitch			
High pitch			

Sex of participant:
Height of participant:

	Fundamental freq.	1st formant	2nd formant
Low pitch			
Medium pitch			
High pitch			

B. **Pitch of the slide flute**

Methods

Your TA has a slide flute that can be disassembled. Look at the assembly of the slide flute. It is a tube of variable length closed at one end. Play with it and see how the spectral frequency changes with length of the tube. At 3 different positions of the slide, measure the length of the closed tube (starting from the hole in the mouthpiece) and record the primary frequency passed by the filter produced by the flute.

Length (cm)	Measured frequency

C. Stringed Instrument

- Pluck the strings of the stringed instrument. How does the pitch change when the mass per unit length of the strings increase? Is this what you would expect?
- While continually plucking on the string, increase the tension by twisting the peg connected to the string. How does the pitch change? Is this what you would expect?
- Place your finger on one of the strings and pin it to the fret board. By doing this, you are effectively shortening the length of the string. How does the pitch change when the length of the string decreases?
- Using Adobe audition, measure the fundamental frequency when you pluck one of the strings, and the length of the string.
- Change the length of the string by using your finger to pin the string to the fret board and measure the new fundamental frequency.

String length	Fundamental freq.

D. Voiced and unvoiced consonants

Not all consonants engage the vocal cords. Place your fingers near your larynx and sustain the consonants "z" and "s." Note how your lips and mouth position change when you pronounce each consonant. Can you feel the vocal cords engage when you speak the letter "z?" We say that "z" is voiced, because the vocal cords are closed and vibrate like a string when air is passed through them, and "s" in unvoiced since the vocal cords are partially open. Speak the consonants "z" and "s" in a sustained manner and record the frequency response. Take a screen shot of your recordings.

"s"

"z"

E. Electrolarynx

1. Practice using the electrolarynx. Simply mouth the words without saying them.

2. Try to say “sat” and “zat” with the electrolarynx. What is the result?

F. Resonators

Your TA will have two tubes that act as resonators. These tubes mimic the shape of the vocal tract when producing the vowels /a/, /i/ and /u/ (see Fig. 2 above). For this demonstration, the electrolarynx produces the “buzz” that would be produced by the vocal cords, and the tubes act like the shape of the vocal tract for the vowels /a/, /i/ and /u/ (one tube can be flipped to produce both /a/ and /i/). Place the electrolarynx at the left-hand side of the tube as drawn above in Fig. 2. The electrolarynx should fit snuggly with the opening. Record the responses for each of the tubes, find the filter shape produced by the tube, and compare the filter shape to the filters shown in fig. 2. Can you hear the vowels produced?

/a/ (“ah”)

/i/ (”ee”)

/u/ ("oo")

G. Groan Tube

The groan tube has a moveable restriction that contains a reed. (Ask your TA to show you the disassembled groan tube.) The reed provides the excitatory source for the tube. The constriction divides the tube into two sections, a tube that is closed on both ends and a tube that is open on one end.

For a tube open on one end: $f_n = n\dfrac{v}{4L} = nf_1$ for odd n

For a tube closed on both ends: $f_n = n\dfrac{v}{2L} = nf_1$ for n = 1, 2, 3 ….

v= speed of sound = 340.29 m/2

The reed produces a broadband sound composed of many frequencies (like the vocal cords) and each section of the tube forms a filter that passes select frequencies from those produced by the reed (like the vocal tract). The frequencies passed by the tube can be calculated from the equations above. Each half of the tube produces a formant (a peak in the filter). The presence of two formants gives the impression of vowel production. Play with the groan tube and notice how the sounds it produces sound like vowels and how the sounds produced by the groan tube are distinct from the sounds of the slide flute. Try to record the response of the groan tube to see the formants of the sound.

References

Alexander, R. M. (1992) *The Human Machine: How the Body Works.* Columbia University Press.

Rossing, T.D. (1990) *The Science of Sound*, 2nd edition. Pearson.

Stevens, K.N. (1972) "The Quantal Nature of Speech: Evidence from Articulatory-Acoustic Data," in *Human Communication: A Unified View*, p. 51, Eds., E. E. David, Jr., and P.B. Denes. New York: McGraw Hill.

Analysis

A. Measuring formants and pitch: *Please use your personal speech lab data to answer the following questions. Include the data you collected with your assignment submission.*

1. How do the measured *fundamental* frequencies compare among different people? Is there a relationship to height and/or sex?

2. Are the formant frequencies the same for different pitches sung by the same person? Explain.

3. How do your personal formant frequencies compare to the chart of vowel formant frequencies. Should your measured formant frequencies for the vowel /ɛ/ ("eh") match the expected formant frequencies? Why or why not?

4. In the table below, rank each of the rows of data from 1-4 with 1 being the theoretically best experimental method to measure the true formant frequencies and 4 being the theoretically worst experimental method to measure the true formant frequencies.

	Rank theoretical best to worst (1-4) for measuring the true formant frequencies
Low pitch	
Medium pitch	
High pitch	
Multiple, overlaid pitches	

5. The shape of the vocal tract when producing the vowel /ɛ/ can be modeled by a hollow tube that is closed at one end (closed at the vocal cords) and open at the opposite end. From your data, calculate the approximate length of your vocal tract if it were a straight tube.

6. An average length of female vocal cords is 14.5 mm and of male vocal cords is 17.5 mm. Using the appropriate vocal fold length for your sex, calculate the velocity of the traveling wave in the vocal cords at the fundamental frequency you recorded for your personal data.

B. Pitch of the slide flute

1. Calculate the theoretical frequency for the lengths you measured.

2. How does the calculated frequency compare to the measured frequency?

C. Stringed Instrument

1. Using the values you measured, calculate the velocity of the traveling wave in the string when you plucked it.

2. Using your value for the velocity of the traveling wave, predict the frequency produced by the 2nd string

3. When you shorten the length of the string on the stringed instrument, the pitch increases. However, humans increase the length of their vocal cords to increase their pitch. Give the relevant equations, how can this be true?

D. Voiced and unvoiced consonants

How do your recordings of "s" and "z" differ? Why?

E. Electrolarynx

How do "sat" and "zat" differ when spoken through the electrolarynx? Why?

F. Resonators

How does the sound passed through the resonator match the filter shape of the corresponding vowel

Analysis Solution

A. Measuring formants and pitch: *Please use your personal speech lab data to answer the following questions.*

1. How do the measured *fundamental* frequencies compare among different people? Is there a relationship to height and/or sex?

   Your answer depends on your data, but typically, we expect the fundamental frequency to be lower in males and lower in taller individuals since males and taller individuals tend to have a larger throat and larynx. The fundamental frequency is dependent on the pitch sung, for example, a high note or a low note.

2. Are the formant frequencies the same for different pitches sung by the same person? Explain.

   Yes, the actual formant frequencies are the same since the shape of the throat should be the same. However, at different pitches, the points where the filter produced by the throat is sampled are different, so the formant frequencies may appear to be different.

3. How do your personal formant frequencies compare to the chart of vowel formant frequencies. Should your measured formant frequencies for the vowel /ɛ/ ("eh") match the expected formant frequencies? Why or why not?

   The measured formant frequencies should match the expected formant frequencies. Having the first and second formants fall within the expected ranges is what characterizes each vowel sound.

4. In the table below, rank each of the rows of data from 1-4 with 1 being the theoretically best experimental method to measure the true formant frequencies and 4 being the theoretically worst experimental method to measure the true formant frequencies.

	Rank theoretical best to worst (1-4) for measuring the true formant frequencies
Low pitch	2
Medium pitch	3
High pitch	4

Multiple, overlaid pitches	1

5. The shape of the vocal tract when producing the vowel /ɛ/ can be modeled by a hollow tube that is closed at one end (closed at the vocal cords) and open at the opposite end. From your data, calculate the approximate length of your vocal tract if it were a straight tube.

   $$f_n = n\frac{v}{4L} \quad for\ n = 1,3,5\ \cdots$$

   $$f_1 = \frac{v}{4L}$$

   v= speed of sound = 340.29 m/s
   L = length of the tube

   Using the value of your first formant, calculate the value of L

6. An average length of female vocal cords is 14.5 mm and of male vocal cords is 17.5 mm. Using the appropriate vocal fold length for your sex, calculate the velocity of the traveling wave in the vocal cords at your own fundamental frequency.

   $$f_n = n\frac{v}{2L} \quad for\ n = 1,2,3\ \cdots$$

   $$f_1 = \frac{v}{2L}$$

   since this behaves like a string attached at both ends

   Assuming a fundmental freq. of 600Hz for a female (your measurement may be different) NOTE: your answer should use the lowest harmonic you recorded, not the lowest formant

   $$v = 600 * 2(0.0145\ \mathrm{m}) = 17.4\ \mathrm{m/s}$$

   Assuming a fundmental freq. of 500Hz for a male (your measurement may be different)

   $$v = 500 * 2(0.0175\ \mathrm{m}) = 17.5\ \mathrm{m/s}$$

B. Pitch of the slide flute

1. Calculate the theoretical frequency for the lengths you measured.

$$f_n = n\frac{v}{4L} \quad for\ n = 1,3,5\ \cdots$$
$$f_1 = \frac{v}{4L}$$

v= speed of sound = 340.29 m/s
L = length of the tube

The flute will produce the resonant frequencies for a tube that is closed on one end and open on the other

2. How does the calculated frequency compare to the measured frequency?

Depends on your measurement, but they should be similar values

C. Stringed Instrument

1. Using the values you measured, calculate the velocity of the traveling wave in the string when you plucked it.

$$f_n = n\frac{v}{2L} \quad for\ n = 1,2,3\ \cdots$$

$$f_1 = \frac{v}{2L}$$

$$v = f_1 * 2L$$

Using the values of the fundamental frequency and the length of the string, calculate the velocity of the traveling wave.

2. Using your value for the velocity of the traveling wave, predict the fundamental frequency produced by the 2nd string.

$$f_n = n\frac{v}{2L} \quad for\ n = 1,2,3\ \cdots$$

$$f_1 = \frac{v}{2L}$$

Using your value for v from the previous question and the length of the string, calculate the fundamental frequency. Compare it to your measured value.

3. When you shorten the length of the string on the stringed instrument, the pitch increases. However, humans increase the length of their vocal cords to increase their pitch. Give the relevant equations, how can this be true?

$$f_n = n\frac{v}{2L} \quad for\ n = 1,2,3 \cdots$$

$v = \sqrt{\frac{T}{\mu}}$ where T = tension and μ = mass per unit length of the vocal cords

Examining the equation for the fundamental frequency, if all values remain constant, the pitch (frequency) should increase when the string length decreases. For a stringed instrument the tension on the string remains the same, and the mass per unit length of the string remains the same.

In humans, when the vocal cords are lengthened, their tension increases and their mass per unit length decreases. Both these changes increase the velocity of the traveling wave in the vocal cord.

If $\Delta V > \Delta L$ (the increase in velocity is greater than the increase in the length), the pitch (frequency) will increase.

D. Voiced and unvoiced consonants

How do your recordings of "s" and "z" differ? Why?

Since "z" is voiced, and the vocal cords are engaged, you should see a fundamental frequency and harmonics. "s" should appear more like random noise.

E. Electrolarynx

How to "sat" and "zat" differ when spoken through the electrolarynx? Why?

They won't differ. All speech produced using an electrolarynx is voiced. Trained users can use their cheek muscles to produce unvoiced speech, but this isn't easy.

F. Helmholtz Resonators

How does the sound passed through the Helmholtz resonator match the filter shape of the corresponding vowel

The two recordings should have similar formant values.