Music

Correlation Between Relative Pitch and Age, Gender, or Musical Background

(from http://www.sciencebuddies.com)

Objective

The purpose of this project is to determine what percentage of the population can sing on pitch, and whether singing on pitch depends on the age, sex, or musical background of the subjects.

Introduction

With lots of practice, musicians can identify intervals between notes that they hear. Developing this skill is essential to "playing by ear." Musicians who have developed this skill are said to have *relative pitch*, meaning that, if they hear one note, they can sing or play another note at a given interval *relative* to the first note. For example, you play a middle "C" and a musician who has relative pitch can play or sing the "*G*" that is one-fifth higher. An even rarer ability is *absolute pitch*, which means that the person can identify any note that you play. It's as if they have the notes memorized somewhere in their mind, and can compare notes that they hear to the remembered notes.

The voice can be a musical instrument, too. How well can people sing on pitch? Do you think the ability would vary according to age, or gender, or musical training? In this project, the test subjects will hear recorded notes and then try to sing them, so this will be a test for relative pitch.

The following vocal range classifications are typically used in classical music (from highest to lowest). The ranges listed are typical, but actual vocal range differs from person to person, so these should be taken as general guidelines (Wikipedia contributors, 2006). You can use these ranges as a guide when selecting the note sequences to record for your tests.

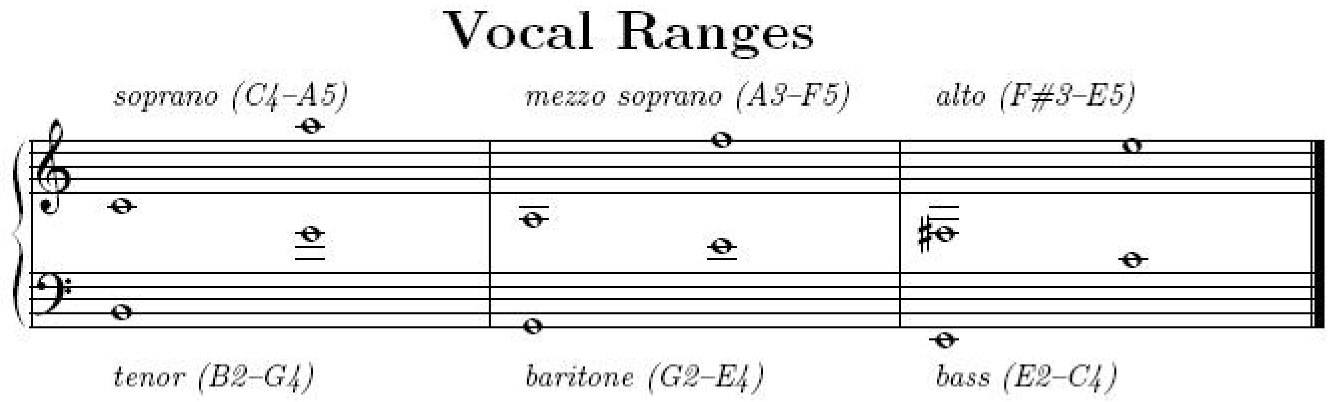

Figure 1. General guidelines for the vocal ranges of singers. The top line corresponds to high, medium, and low female voices, and the bottom line corresponds to high, medium, and low male voices.

Terms, Concepts and Questions to Start Background Research

To do this project, you should do research that enables you to understand the following terms and concepts:

- absolute pitch,
- relative pitch,
- interval,
- note,
- scale,
- frequency,
- vocal range.

Questions

- What notes would you expect to be within the vocal range of most adult females?
- What notes would you expect to be within the vocal range of most adult males?

Bibliography

- The following link offers a great introduction to absolute pitch and will help you develop some background knowledge for this project:
  Lee, K., 2005. "An Overview of Absolute Pitch," [accessed September 1, 2006] https://webspace.utexas.edu/kal463/www/abspitch.html.
- This article describes a UCSF study on the genetics of absolute pitch:
  Shiels, M., 2002. "Looking for Genetic Perfection," BBC News [accessed September 1, 2006] http://news.bbc.co.uk/2/hi/science/nature/1789179.stm.
- This link takes you to the home page for the UCSF study where you can look at the survey that they use for their study:

UC Regents, 2002. " University of California Absolute Pitch Study," University of California, San Francisco [accessed September 1, 2006] http://perfectpitch.ucsf.edu/.

- Wikipedia contributors, 2006. "Vocal Range," Wikipedia, The Free Encyclopedia [accessed September 1, 2006] http://en.wikipedia.org/w/index.php?title=Vocal_range&oldid=72971683.

Materials and Equipment

To do this experiment you will need the following materials and equipment:

- 50–100 volunteers for each group (e.g., males and females; musicians and non-musicians, etc.) you want to test (see the Science Buddies resource How Many Survey Participants Do I Need? http://www.sciencebuddies.org/mentoring/project_ideas/Soc_participants.shtml)
- questionnaire forms; ask each volunteer:
    - their age,
    - their gender,
    - the number of years taking music lessons,
    - if they think they will be able to sing three notes on pitch after hearing them.
- chromatic tuner:
    - available from a local music store or online,
    - many models are available; look for features similar to this one: Seiko SAT500 chromatic tuner;
- two recordings of a 3-note sequence:
    - for example, the notes B, C, G,
    - record one sequence for the female vocal range,
    - and one sequence for the male vocal range (see Figure 1);
- playback device for note sequences;
- Note: If obtaining recording and playback equipment is problematic, you can dispense with the recording and simply play the appropriate note sequence on a piano for each volunteer.

Experimental Procedure

Note: There are special considerations when designing an experiment involving human subjects. ISEF-affiliated fairs often require an Informed Consent Form for every participant who is questioned. In all cases, the experimental design must be approved by the fair's scientific review committee (SRC) prior to the commencement of experiments or surveys. Please refer to the ISEF rules for additional important requirements for studies involving human subjects: http://www.sciserv.org/isef/document/.

Preparation

1. Do your background research and make sure that you are knowledgeable about the terms, concepts, and questions, above.
2. Prepare the questionnaire forms. Check them on a small sample and make sure all your questions are clear before making copies for the project.
3. Make two recordings of the 3-note test sequence which your volunteers will sing. One recording will be for high voices, the other recording will be for low voices. (Again, if obtaining recording and playback equipment is problematic, you can dispense with the recording and simply play the appropriate note sequence on a piano for each volunteer.)
4. The chromatic tuner displays the frequency (pitch) of the note being sung and shows the deviation direction (flat or sharp) if the note is sung off-pitch. Practice using the chromatic tuner with your own singing voice until you are proficient with it. You should also get some practice with other volunteers before collecting data for your project. For example, you'll need to know how close the tuner has to be to the person singing, and how long the singer has to hold a note in order to get a good measurement.

Data Collection

For each volunteer:

1. Play the three-note sequence corresponding to the vocal range of the volunteer (recording or piano).
2. Have the volunteer practice singing each note.
3. Play the notes a second time.
4. Have the subject sing each note and use the chromatic tuner determine if the volunteer is on pitch or not.
5. Record if the volunteer is on pitch, flat, or sharp on each note. (If flat or sharp, write down by how much.)
6. Ask the volunteer if they thought that they had sung on pitch.

Data Analysis

***Here are some ideas for analyzing the data*:**

1. What percentage of each group sang all three notes on pitch?
2. What percentage of each group knew whether they were on pitch or not?

3. Analyze the errors that were made. Was singing flat more common, or singing sharp (or was it about even)?
4. Compare the performance of different groups. For example, you can divide your test subjects:
    - by age,
    - by gender,
    - by music training experience.
5. See the Variations section for more ideas.

Variations

- Devise a scale for measuring how close volunteers came to each note, and score all subjects' performances. Is there a correlation between number of years of music lessons and singing accuracy? For an example of correlation analysis, see the Science Buddies project Which Team Batting Statistic Predicts Run Production Best?.
- More advanced students should calculate the statistical significance of differences between groups.

Don't You Fret! Standing Waves on a Guitar

(from http://www.sciencebuddies.com)

Objective

The goal of this project is to investigate which standing wave patterns you can produce on a guitar string by playing harmonics.

Introduction

In this project, you'll investigate the physics of standing waves on guitar strings. You'll learn about the different *modes* (i.e., patterns) of vibration that can be produced on a string, and you'll figure out how to produce the various modes by lightly touching the string at just the right place while you pick the string. This technique is called playing *harmonics* on the string.

You'll need to understand some basic properties of waves to get the most out of this project. We'll provide a quick introduction here, but for a more complete understanding we recommend some background research on your own. The Bibliography section, below, has some good starting points for researching this project. We especially recommend exploring the "Sound Waves and Music" articles (Henderson, 2004).

What is sound? Sound is a wave, a pattern—simple or complex, depending on the sound—of changing air pressure. Sound is produced by vibrations of objects. The vibrations push and pull on air molecules. The pushes cause a local compression of the air (increase in pressure), and the pulls cause a local rarefaction of the air (decrease in pressure). Since the air molecules are already in constant motion, the compressions and rarefactions starting at the original source are rapidly transmitted through the air as an expanding wave. When you throw a stone into a still pond, you see a pattern of waves rippling out in circles on the surface of the water, centered about the place where the stone went in. Sound waves travel through the air in a similar manner, but in all three dimensions. If you could see them, the pattern of sound waves from the stone hitting the water would resemble an expanding hemisphere. The sound waves from the stone also travel much faster than the rippling water waves from the stone (you hear the sound long before the ripples reach you). The exact speed depends on the number of air molecules and their intrinsic (existing) motion, which are reflected in the air pressure and temperature. At sea level (one atmosphere of pressure) and room temperature (20°C), the speed of sound in air is about 344 m/s.

One way to describe a wave is by its speed. In addition to speed, we will also find it useful to describe waves by their *frequency*, *period*, and *wavelength*. Let's start with frequency (*f*). The top part of Figure 1, below, represents the compressions (darker areas) and rarefactions (lighter areas) of a pure-tone (i.e., single frequency) sound wave traveling in air (Henderson, 2004). If we were to measure the changes in pressure with a detector, and graph the results, we could see how the pressure changes over time, as shown in the bottom part of Figure 1. The peaks in the graph correspond to the compressions (increase in pressure) and the troughs in the graph correspond to the rarefactions (decrease in pressure).

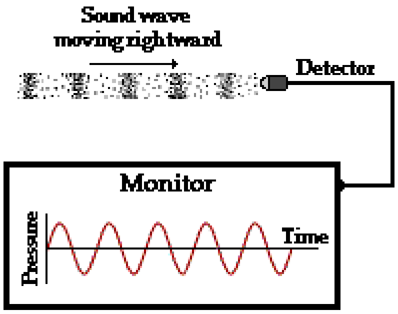

Figure 1. Illustration of a sound wave as compression and rarefaction of air, and as a graph of pressure vs. time (Henderson, 2004).

Notice how the pressure rises and falls in a regular cycle. The frequency of a wave describes how many cycles of the wave occur per unit time. Frequency is measured in Hertz (Hz), which is the number of cycles per second. Figure 2, below, shows examples of sound waves of two different frequencies (Henderson, 2004).

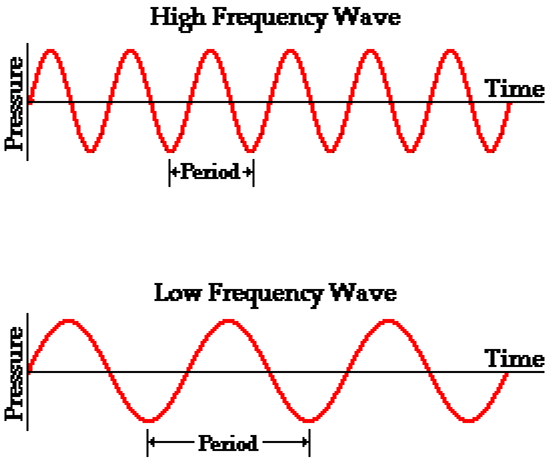

Figure 2. Graphs of high (top) and low (bottom) frequency waves (Henderson, 2004).

Figure 2 also shows the period (*T*) of the wave, which is the time that elapses during a single cycle of the wave. The period is simply the reciprocal of the frequency ($T = 1/f$). For a sound wave, the frequency corresponds to the perception of the pitch of the sound. The higher the frequency, the higher the perceived pitch. On average, the frequency range for human hearing is from 20 Hz at the low end to 20,000 Hz at the high end.

The wavelength is the distance (in space) between corresponding points on a single cycle of a wave (e.g., the distance from one compression maximum (crest) to the next). The wavelength (λ), frequency (f), and speed (v) of a wave are related by a simple equation: $v = f\lambda$. So if we know any two of these variables (wavelength, frequency, speed), we can calculate the third.

Now it is time to take a look at how sound waves are produced by a musical instrument: in this case, the guitar. For a scientist, it is always a good idea to know as much as you can about your experimental apparatus! Figure 3, below, is a photograph of a guitar.

Figure 3. Top view of an acoustic guitar.

The guitar has six tightly-stretched steel strings which are picked (plucked) with fingers or a plastic pick to make them vibrate. The strings are anchored beneath the *bridge* of the guitar by the bridge pins (see Figure 4). Each string passes over the *saddle* on the bridge. The saddle transmits the vibrations through the bridge to the soundboard of the guitar (the entire front face of the instrument). The soundboard, with its large surface area, amplifies the sound of the strings. (One way to see this for yourself is with the mechanism from a music box. First try playing it while holding it in the air. Then, place it in contact with the soundboard of the guitar and play it again. You'll see that the sound is greatly amplified by the wood.)

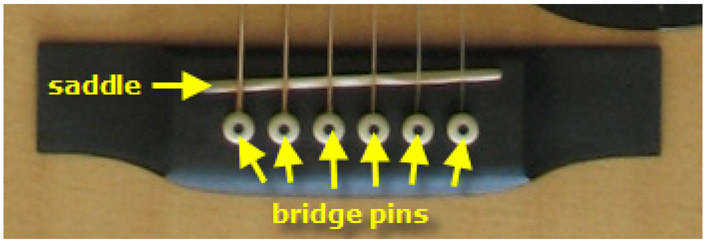

Figure 4. Detail view of an acoustic guitar bridge, showing the bridge pins and saddle.

The string vibrates between two fixed points:

1. where it is stretched over the saddle of the bridge (Figure 4) and
2. near the opposite end of the string, where it passes over the *nut*(Figure 5).

After passing over the nut, the strings wrap around tuning posts. A worm gear mechanism allows the posts to be turned in order to raise or lower the tension on the string.

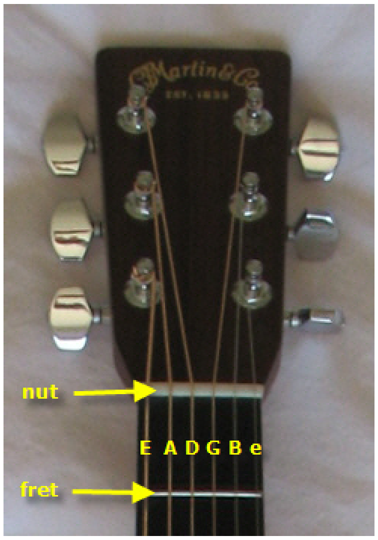

Figure 5. Detail view of an acoustic guitar headstock, showing the nut and tuning pins. The top portion of the neck (first fret) is also shown. The strings are labeled, from low "E" to the high "e."

When a guitar string is picked, the vibration produces a *standing wave* on the string. The fixed points of the string don't move (nodes), while other points on the string oscillate back and forth maximally (antinodes). Figure 6, below, shows some of the standing wave patterns that can occur on a vibrating string (Nave, 2006a).

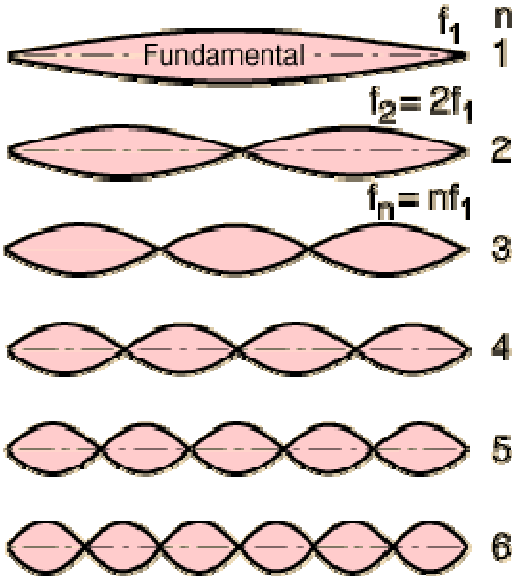

Figure 6. Standing waves on a vibrating string, showing the fundamental (top), first harmonic (middle), and second harmonic (bottom) vibrational modes. (Nave, 2006a)

The string can vibrate at several different natural modes (harmonics). Each of these vibrational modes has nodes at the fixed ends of the string. The higher harmonics have one or more additional nodes along the length of the string. The wavelength of each mode is always twice the distance between two adjacent nodes.

The fundamental mode (Figure 5, top) has a single antinode halfway along the string. There are only two nodes: the endpoints of the string. Thus, the wavelength of the fundamental vibration is twice the length (L) of the string.

The second harmonic has a node halfway along the string, and antinodes at the 1/4 and 3/4 positions. This standing wave pattern shows one complete cycle of the wave. Thus, the wavelength of the second harmonic is equal to the length of the string.

In addition to the endpoints, the third harmonic has a nodes 1/3 and 2/3 of the way along the string, with antinodes in between. The wavelength of this mode with be equal to 2/3 of the length of the string.

Remember that the relationship between wavelength and frequency depends on the speed of the wave. We can rewrite the equation presented earlier as $f = v/\lambda$. If we take the ratio between the frequency, f_2, of the second harmonic and the frequency, f_1, of the first harmonic, the velocity term cancels out:

$$\frac{f_2}{f_1} = \frac{v/L}{v/2L} = \frac{1}{1/2} = 2$$

You can continue the calculations for the higher harmonics yourself. What is the frequency of the third harmonic, relative to the fundamental?

Now you have enough of an introduction to sound waves and guitars so that you can understand how to predict the locations of the standing wave nodes on the strings. Using this knowledge, you can produce harmonics by lightly touching the strings instead of fretting them. The Experimental Procedure section, below, shows you how to explore this musical aspect of standing waves.

Terms, Concepts and Questions to Start Background Research

To do this project, you should do research that enables you to understand the following terms and concepts:

- Guitar parts:
  - Strings
  - Bridge
  - Saddle
  - Nut
  - Frets
  - Soundboard
- String vibrations
- Standing waves
- Nodes
- Antinodes
- Wavelength
- Frequency
- Musical intervals

Questions

- What is the relationship between the length of a string and the wavelength of the fundamental tone it produces when plucked?
- What is the relationship between the length of a string and the wavelength of the first harmonic it produces?
- How can you figure out the wavelength of the higher (second, third, fourth, etc.) harmonics?
- How can your figure out where on the string to place your finger to produce harmonics?

Bibliography

- Waves: the first reference is a good general introduction, and those that follow cover the specific topics indicated by their titles:
    - Henderson, T., 2004. "Sound Waves and Music," The Physics Classroom, Glenbrook South High School, Glenview, IL [accessed March 27, 2006] http://www.glenbrook.k12.il.us/GBSSCI/PHYS/CLASS/sound/u11l1a.html.
    - Nave, C.R., 2006a. "Standing Waves on a String," HyperPhysics, Department of Physics and Astronomy, Georgia State University [accessed March 27, 2006] http://hyperphysics.phy-astr.gsu.edu/Hbase/waves/string.html#c1.
    - Nave, C.R., 2006b. "Resonances of Open Air Columns," HyperPhysics, Department of Physics and Astronomy, Georgia State University [accessed March 27, 2006] http://hyperphysics.phy-astr.gsu.edu/Hbase/waves/opecol.html#c1.
- FlashMusicGames, 2007. "How Guitar Works," FlashMusicGames.com [accessed July 2, 2007] http://www.flashmusicgames.com/how_guitar_works.html.
- Here's a great article about harmonics on guitar strings:
  Lehman, S., 1999. "Understanding Harmonics," Harmony Central [accessed July 2, 2007] http://www.harmony-central.com/Guitar/harmonics.html.
- Here is a table showing guitar and piano note frequencies:
  Aubochon, V., 2004. "Musical Note Frequencies: Guitar and Piano," Vaughn's One-Page Summaries [accessed July 2, 2007] http://www.vaughns-1-pagers.com/music/musical-note-frequencies.htm.
- Here is the source of the diagram showing the fundamental frequencies corresponding to the 88 keys of the piano:
  Irvine, T., 2000. "An Introduction to Music Theory," VibrationData.com Piano Page [accessed July 2, 2007] http://www.vibrationdata.com/piano.htm.

Materials and Equipment

To do this experiment you will need the following materials and equipment:

- Guitar
    - As you can see from the pictures in the Introduction, we used an acoustic guitar for this project
    - An electric guitar—or other stringed instrument—can be used instead
- Guitar pick
- Electronic tuner (to tell you what note you've played)
    - One alternative is to use a computer with tuning software, such as enable Tuner® by Enable Software® http://enableencore.com/tuner.htm. To use this software, you'll need:

        - A Windows-based computer with a 16-bit soundcard
        - A microphone
        - A big advantage of this tuner is that it displays the frequency of the note that you played
    - Another alternative is to use a stand-alone electronic tuner. There are many models, available at most music stores. You want a chromatic tuner with a built-in microphone. It will sense the note that you play and indicate whether you are sharp (above) or flat (below), relative to the closest reference note. If you can find one that displays the frequency of the note you played, that is best.
- Sewing tape measure (best if marked in metric units)
- Lab notebook
- Pen or pencil

Experimental Procedure

1. Do your background research so that you are knowledgeable about the terms, concepts, and questions, above.
2. Measure the length of each of the strings on your guitar (or other stringed instrument). The string length for each string is the distance between the saddle (see Figure 4) and the nut (see Figure 5).
3. For each string, use your string length measurements and your knowledge of standing waves to calcuate the location of the first node point for each of the first three harmonics. (If you want to keep exploring higher harmonics, so much the better!)
4. Use your tape measure to figure out where the predicted node points fall on the strings. Some of the node points may fall right over a fret, while others may be just above or below a fret.
5. Get set up to play and record the notes with your tuner software (or chromatic tuner).
    - The experiment is best done with a guitar that is in tune, so the first step is to tune the guitar.
    - Place the microphone (or chromatic tuner) close enough to the guitar so that the tuner software (or tuner) registers the note even when you play softly.
6. Pluck the open high E string. From the readout of the tuner software (or chromatic tuner), write down the frequency of the note played.
    a. If you are using a chromatic tuner without a frequency readout, write down the note played from the chromatic tuner readout.

    b. You can look up the standard frequency of the note using Figure 7 (if you know how guitar notes correspond to the piano keyboard) or the table of note frequencies in the Bibliography (Aubochon, 2004).

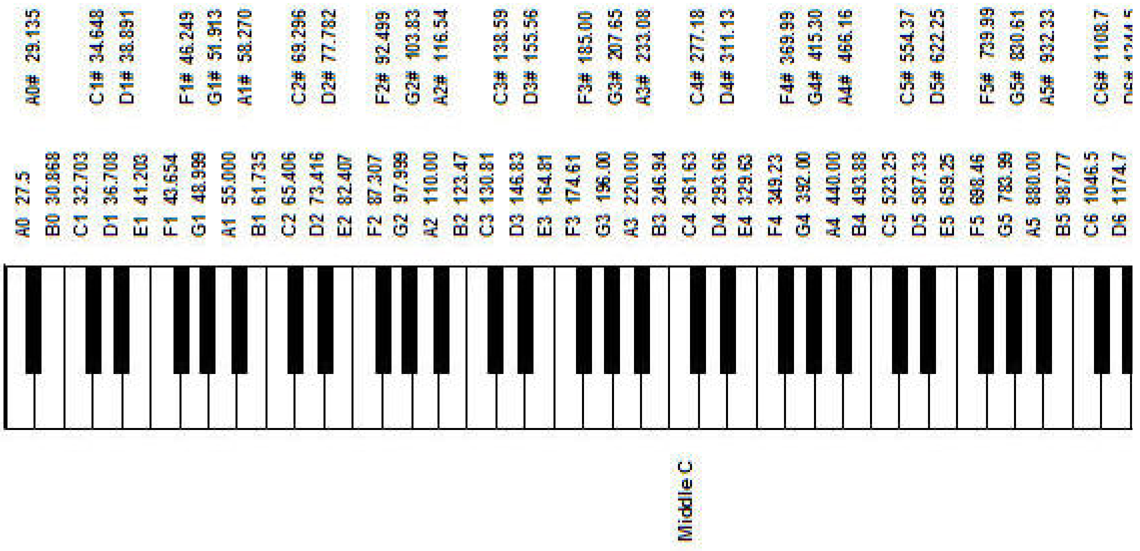

Figure 7. Fundamental frequencies of the 88 notes on the piano. (Irvine, 2000)

7. Place your finger lightly on the string at the predicted node point for the first harmonic.
8. Pluck the string again.
9. Make sure the note is clear and ringing, then write down the frequency of the note played. If the note does not sound properly, try again until it does. For the clearest sound, you need light pressure on the string. Tip: make sure that your picking (or plucking) sets the string vibrating parallel to the soundboard of the instrument. If the vibration is perpendicular to the soundboard, the vibration will be quickly muted by your finger.
    . If you are using a chromatic tuner without a frequency readout, write down the note played from the chromatic tuner readout.
    a. You can look up the standard frequency of the note using Figure 7.
    b. When using a tuner without a frequency readout, you will have to use your knowledge of music and careful listening to determine the correct octave of the note played. For example, the open high E-string on the guitar is E4 (329.63 Hz), while the first harmonic is E5 (659.25 Hz).
10. Repeat steps 6–8 for the second and third harmonics.
11. Repeat steps 5–8 for each of the other five strings.
12. How close do you have to be to the node point in order to produce a clear, ringing harmonic from the string? Try moving up or down the string slightly to find out.

13. Measure the actual distance for the first node point for each harmonic for each string.
14. For each string, what is the relationship between the position of the first node point for each harmonic and the length of the string?
15. For each string, what is the interval between the fundamental and each of the harmonics?

Guitar Fundamentals: Wavelength, Frequency, & Speed

(from http://www.sciencebuddies.com)

Objective

The goal of this project is to measure the frequency of the vibrations of a guitar string as the effective length of the string is changed by fretting it.

Introduction

In this project, you'll investigate the basic physics of standing waves on guitar strings. You'll learn how the *frequency* (perceived as pitch) of the string vibration changes as the effective length of the string is changed by fretting it.

You'll need to understand some basic properties of waves to get the most out of this project. We'll provide a quick introduction here, but for a more complete understanding we recommend some background research on your own. The Bibliography section, below, has some good starting points for researching this project. We especially recommend exploring the "Sound Waves and Music" articles (Henderson, 2004).

What is sound? Sound is a wave, a pattern—simple or complex, depending on the sound—of changing air pressure. Sound is produced by vibrations of objects. The vibrations push and pull on air molecules. The pushes cause a local compression of the air (increase in pressure), and the pulls cause a local rarefaction of the air (decrease in pressure). Since the air molecules are already in constant motion, the compressions and rarefactions starting at the original source are rapidly transmitted through the air as an expanding wave. When you throw a stone into a still pond, you see a pattern of waves rippling out in circles on the surface of the water, centered about the place where the stone went in. Sound waves travel through the air in a similar manner, but in all three dimensions. If you could see them, the pattern of sound waves from the stone hitting the water would resemble an expanding hemisphere. The sound waves from the stone also travel much faster than the rippling water waves from the stone (you hear the sound long before the ripples reach you). The exact speed depends on the number of air molecules and their intrinsic (existing) motion, which are reflected in the air pressure and temperature. At sea level (one atmosphere of pressure) and room temperature (20°C), the speed of sound in air is about 344 m/s.

One way to describe a wave is by its speed. In addition to speed, we will also find it useful to describe waves by their *frequency*, *period*, and *wavelength*. Let's start with frequency (f). The top part of Figure 1, below, represents the compressions (darker areas) and rarefactions (lighter areas) of a pure-tone (i.e., single frequency) sound wave traveling in air (Henderson, 2004). If we were to measure the changes in pressure with a detector, and graph the results, we could see how the pressure changes over time, as shown in the bottom part of Figure 1. The peaks in the graph correspond to the compressions (increase in pressure) and the troughs in the graph correspond to the rarefactions (decrease in pressure).

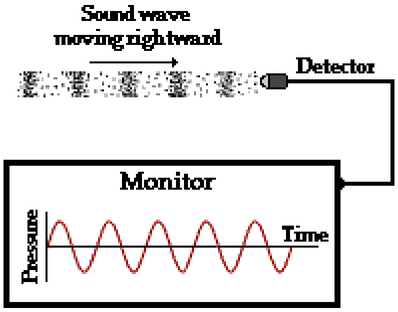

Figure 1. Illustration of a sound wave as compression and rarefaction of air, and as a graph of pressure vs. time (Henderson, 2004).

Notice how the pressure rises and falls in a regular cycle. The frequency of a wave describes how many cycles of the wave occur per unit time. Frequency is measured in Hertz (Hz), which is the number of cycles per second. Figure 2, below, shows examples of sound waves of two different frequencies (Henderson, 2004).

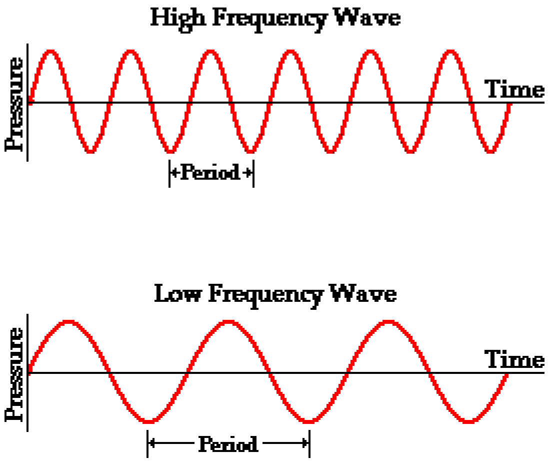

Figure 2. Graphs of high (top) and low (bottom) frequency waves (Henderson, 2004).

Figure 2 also shows the period (T) of the wave, which is the time that elapses during a single cycle of the wave. The period is simply the reciprocal of the frequency ($T = 1/f$). For a sound wave, the frequency corresponds to the perception of the pitch of the sound. The higher the frequency, the higher the perceived pitch. On average, the frequency range for human hearing is from 20 Hz at the low end to 20,000 Hz at the high end.

The wavelength is the distance (in space) between corresponding points on a single cycle of a wave (e.g., the distance from one compression maximum (crest) to the next). The wavelength (λ), frequency (f), and speed (v) of a wave are related by a simple equation: $v = f\lambda$. So if we know any two of these variables (wavelength, frequency, speed), we can calculate the third.

Now it is time to take a look at how sound waves are produced by a musical instrument: in this case, the guitar. For a scientist, it is always a good idea to know as much as you can about your experimental apparatus! Figure 3, below, is a photograph of a guitar.

Figure 3. Top view of an acoustic guitar.

The guitar has six tightly-stretched steel strings which are picked (plucked) with fingers or a plastic pick to make them vibrate. The strings are anchored beneath the *bridge* of the guitar by the bridge pins (see Figure 4). Each string passes over the *saddle* on the bridge. The saddle transmits the vibrations through the bridge to the soundboard of the guitar (the entire front face of the instrument). The soundboard, with its large surface area, amplifies the sound of the strings. (One way to see this for yourself is with the mechanism from a music box. First try playing it while holding it in the air. Then, place it in contact with the soundboard of the guitar and play it again. You'll see that the sound is greatly amplified by the wood.)

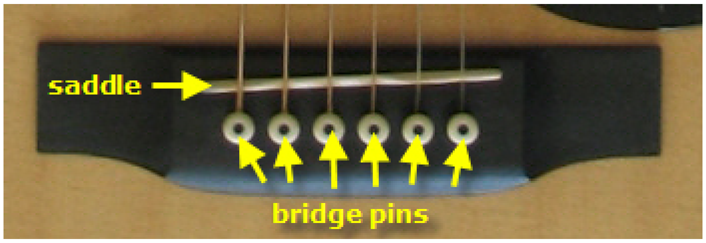

Figure 4. Detail view of an acoustic guitar bridge, showing the bridge pins and saddle.

The string vibrates between two fixed points:

1. where it is stretched over the saddle of the bridge (Figure 4) and
2. near the opposite end of the string, where it passes over the *nut*(Figure 5).

After passing over the nut, the strings wrap around tuning posts. A worm gear mechanism allows the posts to be turned in order to raise or lower the tension on the string.

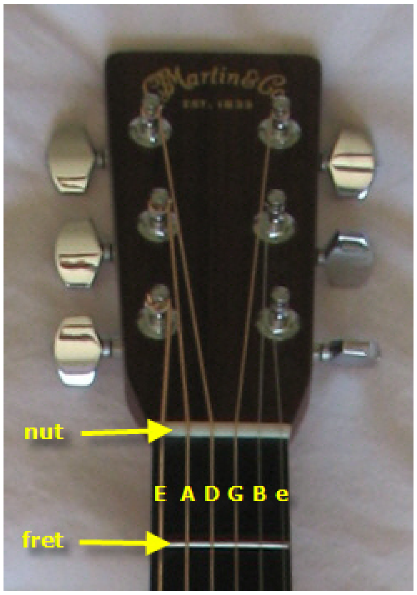

Figure 5. Detail view of an acoustic guitar headstock, showing the nut and tuning pins. The top portion of the neck (first fret) is also shown. The strings are labeled, from low "E" to the high "e."

When a guitar string is picked, the vibration produces a *standing wave* on the string. The fixed points of the string don't move (nodes), while other points on the string oscillate back and forth maximally (antinodes). Figure 6, below, shows some of the standing wave patterns that can occur on a vibrating string (Nave, 2006a).

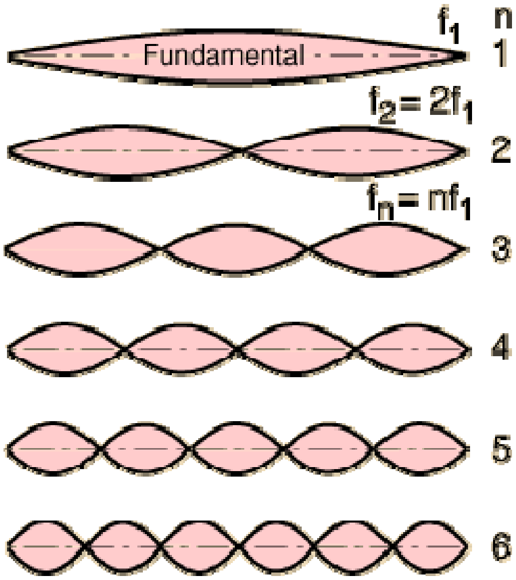

Figure 6. Standing waves on a vibrating string, showing the fundamental (top), first harmonic (middle), and second harmonic (bottom) vibrational modes. (Nave, 2006a)

The fundamental mode (Figure 5, top) has a single antinode halfway along the string. There are only two nodes: the endpoints of the string. Thus, the wavelength of the fundamental vibration is twice the length (L) of the string.

Figure 6 shows that the string can vibrate at several different natural modes (harmonics). Each of these vibrational modes has nodes at the fixed ends of the string. The higher harmonics have one or more additional nodes along the length of the string. In this project, we will be focusing on the fundamental mode of vibration, where the two endpoints are the only nodes of the standing wave. See the Variations sections for a project that goes a little further to explore the higher harmonics.

In this project you'll use the equation relating the speed, frequency, and wavelength of a wave ($v = f\lambda$) to predict how the fundamental frequency of vibration of the string will change as you change the effective length of the string by fretting it.

Terms, Concepts and Questions to Start Background Research

To do this project, you should do research that enables you to understand the following terms and concepts:

- Guitar parts:
    - Strings
    - Bridge
    - Saddle
    - Nut

    - Frets
    - Soundboard
- String vibrations
- Standing waves
- Wavelength
- Frequency
- Wave velocity

Questions

- What is the relationship between the length of a string and the wavelength of the fundamental tone it produces when plucked?
- What is the relationship between the velocity, frequency, and wavelength of a wave?

Bibliography

- Waves: the first reference is a good general introduction, and those that follow cover the specific topics indicated by their titles:
    - Note: all five lessons in this "Sound Waves and Music" section are worth reading!
      Henderson, T., 2004. "Sound Waves and Music," The Physics Classroom, Glenbrook South High School, Glenview, IL [accessed July 5, 2007] http://www.glenbrook.k12.il.us/GBSSCI/PHYS/CLASS/sound/u11l1a.html.
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    - Nave, C.R., 2006b. "Resonances of Open Air Columns," HyperPhysics, Department of Physics and Astronomy, Georgia State University [accessed July 5, 2007] http://hyperphysics.phy-astr.gsu.edu/Hbase/waves/opecol.html#c1.
- Here's an introduction to how the guitar works:
  FlashMusicGames, 2007. "How Guitar Works," FlashMusicGames.com [accessed July 5, 2007] http://www.flashmusicgames.com/how_guitar_works.html.
- This webpage shows the frequencies of the various notes you can play on the guitar:
  Aubochon, V., 2004. "Musical Note Frequencies: Guitar and Piano," Vaughn's One-Page Summaries [accessed July 5, 2007] http://www.vaughns-1-pagers.com/music/musical-note-frequencies.htm.
- This is the source for the piano keyboard/note frequency figure in the Experimental Procedure section:

Irvine, T., 2000. "An Introduction to Music Theory," VibrationData.com Piano Page [accessed July 5, 2007] http://www.vibrationdata.com/piano.htm.

- Here is an Excel® tutorial to help you get started with spreadsheets (if you want to use them for data analysis): James, B., date unknown. "Excel 101," University of South Dakota [accessed July 5, 2007] http://www.usd.edu/trio/tut/excel/.

Materials and Equipment

To do this experiment you will need the following materials and equipment:

- Guitar
    - As you can see from the pictures in the Introduction, we used an acoustic guitar for this project.
    - An electric guitar—or other stringed instrument—can be used instead.
- Guitar pick
- Electronic tuner (to tell you what note you've played)
    - One alternative is to use a computer with tuning software, such as enable Tuner® by Enable Software®. To use this software, you'll need:
        - A Windows-based computer with a 16-bit soundcard
        - A microphone
        - A big advantage of this tuner is that it displays the frequency of the note that you played
    - Another alternative is to use a stand-alone electronic tuner. There are many models, available at most music stores. You want a chromatic tuner with a built-in microphone. It will sense the note that you play and indicate whether you are sharp (above) or flat (below), relative to the closest reference note. If you can find one that displays the frequency of the note you played, that is best.
    - Yet another alternative is to work with a partner who has an electric keyboard or piano and who knows how to match notes to the guitar.
- Sewing tape measure (best if marked in metric units)
- Lab notebook
- Pen or pencil

Experimental Procedure

1. Do your background research so that you are knowledgeable about the terms, concepts, and questions, above.
2. For each string, measure:
    - The full length of the string. This is the distance between the saddle (see Figure 4) and the nut (see Figure 5).
    - The distance between the saddle and each fret.

    - The simplest way to do this is to tape the zero end of the sewing tape measure to the string right at the saddle. Line up the zero mark with the point where the string touches the saddle. Align the tape measure along the length of the string, and tape it in place at the nut end of the string. Now you can easily read off the total length of the string, and the string length at each fret.
3. Get set up to play and record the notes with your tuner software (or chromatic tuner).
    - The experiment is best done with a guitar that is in tune, so the first step is to tune the guitar.
    - Place the microphone (or chromatic tuner) close enough to the guitar so that the tuner software (or tuner) registers the note even when you play softly.
4. Pluck the open high E string. From the readout of the tuner software, write down the frequency of the note played. The screenshot in Figure 7 shows where to read the measured frequency from the enable Tuner software display.

Figure 7. Screenshot of the enable Tuner® software display, showing where to read the measured frequency of the note that was played. The target frequency of the open strings is displayed in the lower portion of the window, as shown.

    a. If you are using a chromatic tuner without a frequency readout, write down the note played from the chromatic tuner readout.
    b. You can look up the standard frequency of the note using Figure 8.
5. Now fret the string just behind the first fret.
6. Pluck the string again.
7. Make sure the note is clear and ringing, then write down the frequency of the note played. If the note does not play properly, adjust your fretting finger if necessary, and play the note again.

. If you are using a chromatic tuner without a frequency readout, write down the note played from the chromatic tuner readout.

   a. You can look up the standard frequency of the note using Figure 8, below.

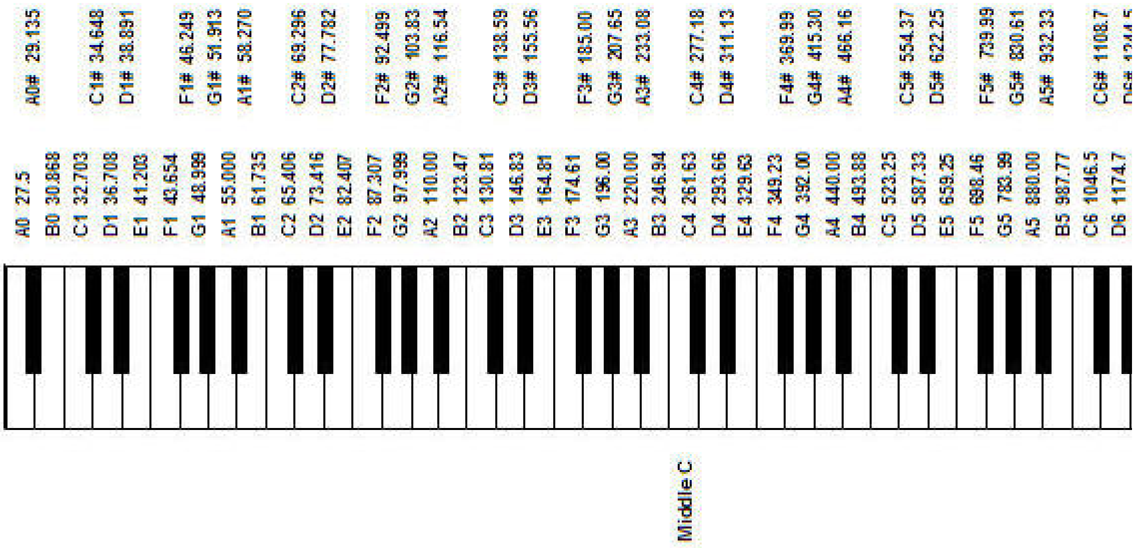

Figure 8. Fundamental frequencies of the 88 notes on the piano (Irvine, 2000). The six open strings on the guitar (E2, A2, D3, G3, B3, E4) are marked with blue asterisks.

   b. When using a tuner without a frequency readout, you will have to use your knowledge of music and careful listening to determine the correct octave of the note played. For example, the open high E-string on the guitar is E4 (329.63 Hz). When fretted on the twelfth fret, the note is E5 (659.25 Hz).

8. Repeat steps 5–7 for frets 2–12.
9. Repeat steps 4–7 for each of the other five strings.
10. You can organize the data you collect for each string in a table like the one below.

String ___		
fret	string length (cm)	frequency (Hz)
0 (open string)		
1		

2		
etc.		

11. Using your length and frequency data and the equation $v = f\lambda$, calculate the speed of the wave on each string. Remember that the wavelength of the fundamental (lowest) frequency of a vibrating string is *twice* the length of the string.

Variations

- Use a spreadsheet program (like Microsoft Excel® or WordPerfect QuattroPro®) to make your wave velocity calculations. The Bibliography has an Excel® tutorial to get you started working with spreadsheets (James, date unknown).

Guitar Jingle: Discovering the Locations of Harmonics

(from http://www.sciencebuddies.com)

Objective

To identify the locations of harmonics on an acoustic guitar and relate them to guitar string lengths.

Introduction

Have you ever watched little babies play with sound? They "blow raspberries," shriek, and squeal as they experiment with their voices. As they grow older, they blow bubbles in their milk with a straw and laugh at the funny sound it makes, or beat on pots and pans to see what kinds of clinks and clanks they can get out of them. Older still, they put cards in the spokes of their bikes, just to enjoy the rat-a-tat sounds as the wheels go round.

Like most children, musicians love to play with sounds, too. No matter what instruments they play, musicians love to "push the limits" to see what new strange or beautiful sounds they can get their instrument to make. Most instruments are held or played in a "standard way," but by varying the way an instrument is held, plucked, strummed, bowed, or breathed into, or by adding accessories, an instrument is often capable of a new sound—a new voice. This increases the richness and variety of the musical experience.

Guitars are no exception to this musical variety. Most people are familiar with watching someone strum a guitar, or play a wild solo at rock concert, but a guitar has a greater range of musical expression than this. For instance, the **body** of the guitar can be thumped or tapped, while playing the strings, to imitate drums, or to accompany the clicks from dancing shoes (flamenco style). A finger placed on the **fretboard** of the guitar, to play a note, can be pushed up slightly. This bends or stretches the note, giving the impression of crying or yearning (as in country or blues styles). Or, a finger from the left hand on the fretboard of the guitar can be vibrated rapidly from side to side, causing the **pitch** to change slightly, up and down, which gives the note a classical, singing style (called *vibrato*).

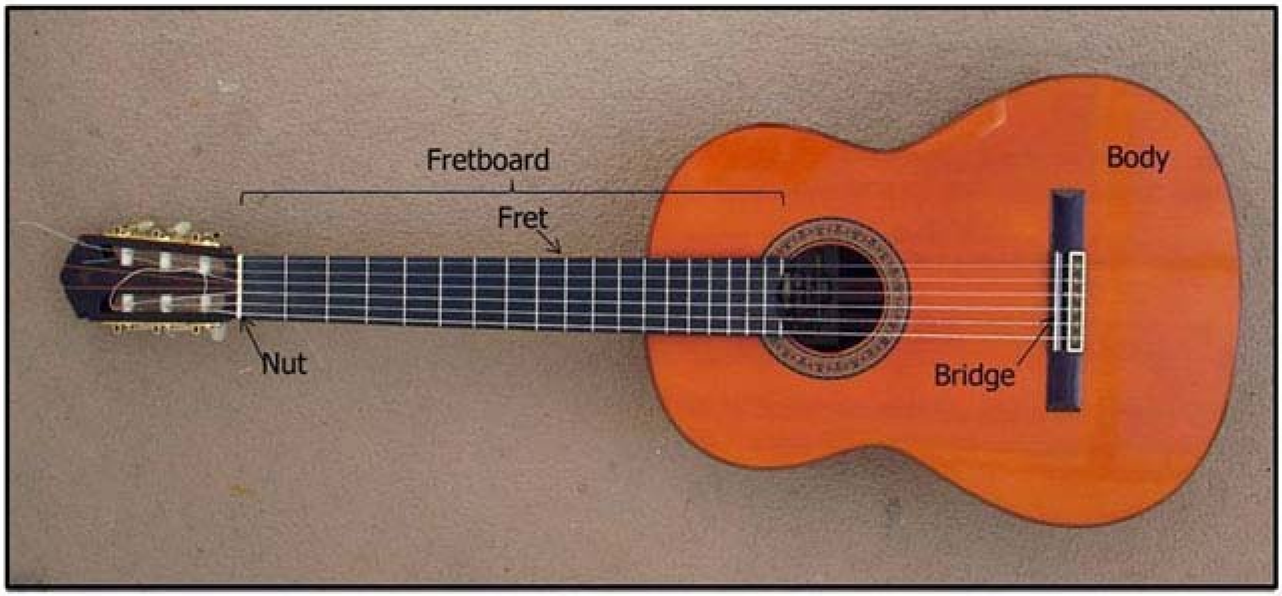

Figure 1. This photo shows some of an acoustic guitar's parts.

Examples of variety exist on the plucking side (the right-hand side), too. Notes can be strummed; finger-picked with shaped nails; picked with a **plectrum;** made crisp or more round-sounding, depending on positioning; or even made mesmerizing. Nowhere is this more true than in the beautiful tremolo. With **tremolo,** the same note is plucked rapidly with three different fingers. It is magical to listen to and creates a shimmering, longing sound.

In this music science fair project, you'll explore how to make a guitar produce special bell-like sounds, called **harmonics.** Harmonics sound different from plucked notes, because they are much simpler in terms of their **frequency** content. To picture this, imagine that you are holding one end of a long jump rope and a friend is holding the other end just a few feet away from you, so that the rope is hanging down between you. What happens when your friend holds the rope still, and you shake the rope up and down slowly? What happens when you shake the rope up and down more quickly? The **standing waves** that you imagine seeing in the rope are similar to what happens in a plucked string, only in a string, these slow-moving and fast-moving waves happen all at the same time.

When you pluck a string, you hear a **fundamental frequency,** resulting from the slowest up-and-down motion. You also hear **overtones,** resulting from faster up-and-down motion. These overtones are called harmonics because they happen at two times, three times, four times, five times, etc. the fundamental frequency. For instance, if the fundamental frequency is 440 hertz (Hz) (this happens when you pluck the A-string "open," with no fingers down on the fretboard), then the harmonics will occur at 880 Hz (two times 440), 1320 Hz (three times 440), 1760 Hz (four times 440), etc. Your ear hears all of these harmonics together, as a single tone. There are an *infinite* number of harmonics (they go on forever), but the amplitude or loudness of the higher harmonics is much smaller than that of the fundamental or first few harmonics, and your ear can't hear the highest harmonics once they get beyond the highest frequency that your ear can hear.

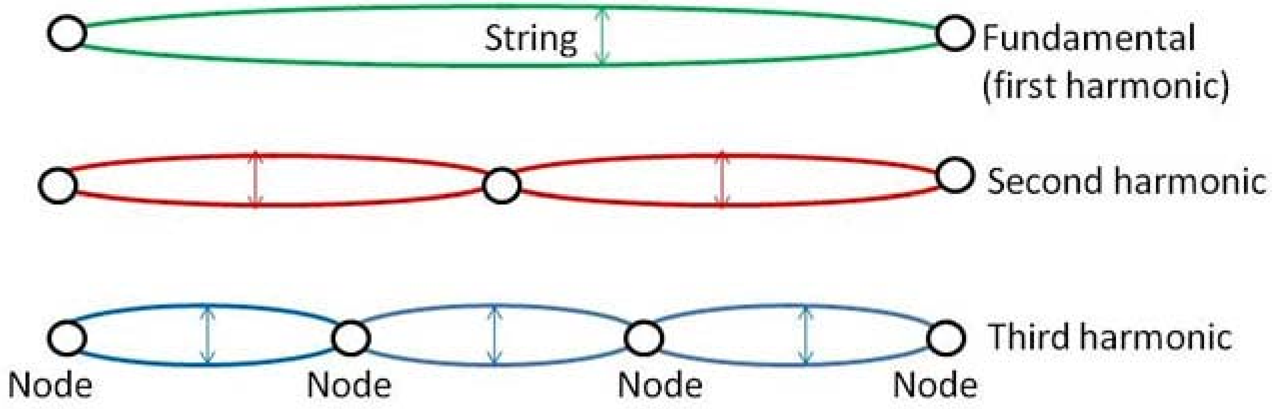

Figure 2. This drawing shows the first three harmonics on a string that is plucked "open," without any fingers from the left hand place down on the **fretboard.**

The motionless places on the string—where the string is attached on each end and where the string *does not vibrate* at various places along the middle—are called **nodes.**

To "play a harmonic" and coax a bell-like tone out of guitar, a finger on the left hand is placed *lightly* at a node, and then the string is plucked. This lightly placed finger **damps** or quiets all overtones that do not have a node near the location that has been touched. That is why playing a harmonic produces a sound with a frequency content that is simpler than the sound produced when plucking an open string. With the other overtones damped, the lowest-pitched overtone or harmonic takes over and rings the strongest, resulting in a bell-like sound.

Now you're ready to start your music science fair project and find out where these special places for bell-like sounds are located on a guitar string. It's a musical mystery!

Terms, Concepts and Questions to Start Background Research

- Body
- Fretboard
- Pitch
- Plectrum
- Tremolo

- Harmonic
- Frequency
- Standing wave
- Fundamental frequency
- Overtone
- Fretboard
- Node
- Wavelength
- Damp
- Fret
- Guitar nut
- Bridge

Questions

- What are the main parts of an acoustic guitar?
- When a guitar is held in the standard position, what are some ways the left hand can influence the sound that a guitar makes? What about the right hand?
- Why do a harmonic and a plucked open string sound so different?
- How would you play a harmonic on a guitar?

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These sources describe what guitar harmonics are:

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- Macfarlane, P. (2007). *Lesson 46: Harmonics.* Retrieved March 3, 2009, from http://www.guitarlessonworld.com/lessons/lesson46.htm

This source discusses overtones:

- Wikipedia Contributors. (2009, January 14). Overtone. *Wikipedia: The Free Encyclopedia.* Retrieved March 8, 2009, from http://en.wikipedia.org/w/index.php?title=Overtone&oldid=264085227

This video shows the technique for playing harmonics:

- Lorange, K. (2008). *Natural harmonics.* Retrieved March 8, 2009, from http://guitarforbeginners.com/media/harm.wmv

This link provides free open-source software that can help you study sound signals:

- Audacity Developer Team. (2000, May). *The Free, Cross-Platform Sound Editor.* Retrieved March 19, 2009, from http://audacity.sourceforge.net/

For help creating graphs, try this website:

- National Center for Education Statistics (n.d.). *Create a Graph.* Retrieved March 19, 2009, from http://nces.ed.gov/nceskids/CreateAGraph/default.aspx

Materials and Equipment

- Acoustic guitar, adult or child-size
- Cloth tape measure, metric
- Adult helper
- Lab notebook

Experimental Procedure

Note: If you are using an adult-sized guitar, your hands might be too small to wrap around the neck and play harmonics easily. An adult helper can help you by playing the harmonics while you listen and make all the observations.

Preparing for Testing

1. Practice playing harmonics at the *twelfth* **fret**, on multiple strings, until you can consistently achieve a bell-like sound in the twelfth fret. To find the twelfth fret, start counting frets from the **nut** (the nut is like zero), which is shown in Figure 5, below. Use Kirk Lorange's video, referenced in the Bibliography, to help you learn the technique for playing harmonics. Remember to place the ring finger on your left hand *lightly above* the 12th fret. Do not push your finger down onto the fretboard. Do not place the ring finger to one side of the fret (as is typically done when you play a note). Your ring finger needs to be *above* the fret, as shown in Figure 4, below.

Figure 4. This photo shows where to practice playing harmonics, and how to put your ring finger lightly above the twelfth fret as you pluck. Do not press all the way down.

2. Also, as shown in the video, after you pluck the string with your right hand, remove your left hand from the string. This will take some practice, so be patient, and keep trying.
3. Make a data table in your lab notebook that looks like the fretboard of your guitar:

Sample Data Table

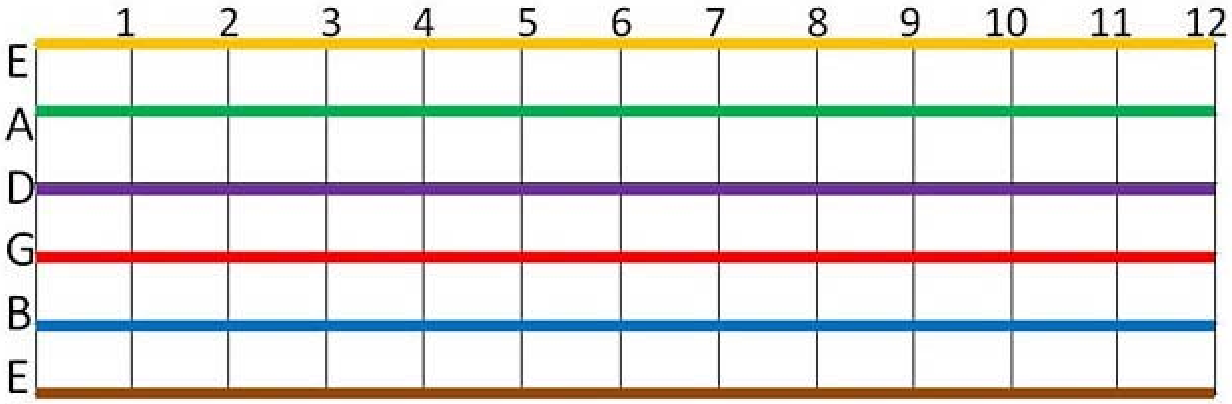

Figure 5. This drawing shows a data table that looks like the fretboard of a guitar.

- The numbers across the top mark the frets, the ridges across the fretboard of your guitar. In the data table, you can see frets as vertical black lines.
- The colored lines represent the strings on your guitar, with the lower-pitched strings (G, B, and E) on the bottom, and the higher-pitched strings (E, A, and D) on the top.

Finding Harmonics on Your Guitar

1. Select a string and *starting at the twelfth fret,* try to play a harmonic in that fret by lightly damping the string above the twelfth fret.
   a. If a harmonic is heard (and you hear a ringing, bell-like tone), then mark that location in your data table with a filled-in black circle.
   b. If a harmonic is not heard (if the string sounds dead or dull or makes no sound at all when plucked), then mark that location in your data table with an open circle.
2. Continuing on with the same string, repeat step 1 for all frets, from fret 11 down to fret 1.
3. Repeat steps 1–2 for two additional strings.

Relating the Location of the Harmonics to the Length of the Strings

1. Measure the length of one string, from the nut to the **bridge,** with the tape measure. (All strings are the same length on a guitar, so it does not matter which one you choose.) You will probably need a helper to take this measurement accurately. Write down your measurement in your lab notebook.

Figure 6. This photo shows how to measure the string length from the nut to the bridge.

2. Make a data table for each string tested, like the one below. The first entry in the data table is an example, so the numbers in your data table may look different. Continue reading the rest of the steps to understand the information you'll record and calculate. You will be calculating at what fraction of the string's length each of the harmonics were heard. As an example, row 1 in the data table shows you that the 2nd harmonic (as seen in the 5th column) was found at one-half the string's length (as seen in the 3rd column).

String 1 Data Table

Fret number where a harmonic was heard	Distance from the nut to the fret where a harmonic was heard (cm)	Fraction of the total string length (Distance from the nut to the fret, divided by the string's length)	Reciprocal of the fraction	Closest whole integer (harmonic number)
12	33 (example)	33/66 = $\frac{1}{2}$	2/1=2.0	2

3. Using the data table that looks like your fretboard, list all of the fret numbers where a harmonic was heard (all the filled-in circles) in the first column of the first string's data table.
4. Measure the distance from the nut to the fret where each harmonic was heard with the tape measure and record this value in the second column of your data table.
5. Calculate the fraction of the total string length by dividing the distance from the nut to the fret by the string length, and enter your calculation in the third column of the data table. In the example entry in the data table, the total string length is 66 cm, and the distance from the nut to the twelfth fret is 33 cm. Dividing 33 by 66 gives a fraction of the total string length as $\frac{1}{2}$.
6. Obtain the **reciprocal** of the fraction and enter that in the fourth column of the data table. In the example entry, the reciprocal of $\frac{1}{2}$ is 2/1. 2 divided by 1 equals 2.
7. Figure out the closest **whole number** to the reciprocal to obtain the harmonic number for the fifth column. In the data table example, the integer is 2. However, if your data produces a reciprocal that is not a whole number, such as 2.9, the closest whole integer to 2.9 is 3. If the reciprocal turned out to be 3.1, the closest whole number to 3.1 is also 3. This rounding process takes care of errors that occurred in measuring the string.
8. Repeat steps 3–7 for the other two strings that you tested.

Analyzing Your Data Tables

1. Make a scatter plot for each tested string, with the location where the harmonic was found (the fraction of the total string length) on the x-axis and the harmonic number on the y-axis. You can make the plot by hand or use a website like Create a Graph to make the graph on the computer and print it.
2. Looking at your scatter plot and the data table, do you notice that the second harmonic occurs at $\frac{1}{2}$ the string length? What do you notice about the third harmonic and the fourth? Did this pattern hold true for all strings? If you could not find a fifth harmonic right above a fret, where do you predict that you would find one? Give it a try and see!

Variations

- Extend the experimental procedure above to include fret numbers greater than 12. How do harmonics found at fret numbers greater than 12 relate to harmonics found at fret number less than 12? *Hint:* Think about what fraction of the string length each harmonic has. Where are the fractions the same?

- Use a guitar tuner or open-source software, like Audacity, to determine the frequency of an open string (the fundamental) and its harmonics. Plot the harmonic number on the x-axis and the frequency on the y-axis. Do you see a relationship between the frequency of a harmonic and the fundamental frequency?

How Tweet It Is: Bird Songs in Classical Music

(from http://www.sciencebuddies.com)

Objective

To determine which instruments are used to recreate bird songs and bird calls in classical music, and to investigate whether imitations or impressions are given.

Introduction

The glorious melodies of songbirds have long been a source of inspiration for composers of music. Some composers imitate **bird songs** to reflect the seasons or nature, or to create a sense of comfort or lightness in their music, while others use them to give the impression of conversation. Birds are very chatty, social creatures, after all! Still others use a fragment of bird song as a theme for an entire piece of music, just for its beauty alone.

Composers have also used **bird calls,** rather than bird songs, in their music. Bird calls are different from bird songs—they are simpler, more repetitive, and have less variation. Calls are used to signal danger, hunger, a food discovery, aggressiveness, to call groups together (called *flocking*), or to harass a predator. While both male and female birds engage in bird calls, bird songs—with more **pitch** and **rhythm** changes—are primarily done by the males who sing to attract female mates, and to defend territory.

Humans and some male birds share an impressive ability to make songs out of sounds they hear around them in the natural world. Birds that have this ability to **imitate** are some of the most accomplished **mimics** on Earth. Some forest-dwelling birds, for example, like the lyre birds of South Australia http://www.pbs.org/lifeofbirds/songs/index.html, can imitate 20 different species of birds, as well as other sounds they hear around them in the forest, like camera shutters from hikers and chain saws from loggers! Urban birds, on the other hand, like starlings, have been observed giving perfect renditions of cell phones and car alarms. Imitation is very important to some male birds because it can increase the complexity and variation in their songs, and females seem to prefer this, as it may indicate greater intelligence, which can help offspring survive. Singing also expends energy, so only the strongest male birds, with extra energy to spare, can afford to spend time singing loud and long. Each dawn, male birds practice their songs, each one trying to make a variation more beautiful and more complicated than the others. It's like a bird's version of *American Idol!*

In this music science fair project, you will investigate *human imitation* of bird songs and bird calls—the instruments that are used, as well as the fidelity with which the songs are imitated. Do composers try to imitate *exactly* the sounds of birds, or do they try to create an **impression,** a sense or idea of what the birds sound like? Do you think that flutes, with their ability to make high-pitched sounds and **trills,** are the only choice to recreate bird sounds in classical music? Try this science fair project and find out!

Terms, Concepts and Questions to Start Background Research

- Bird song
- Bird call
- Pitch
- Rhythm
- Imitation
- Mimic
- Impression
- Crescendo
- Staccato
- Trill

Questions

- Why do composers include bird sounds in their classical music?
- What are the differences between bird songs and bird calls?
- Why is the ability to imitate important to some birds?

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- Lewin, N. (2008, February 27). *Classical Music for the Birds.* Retrieved October 16, 2008, from http://www.npr.org/templates/story/story.php?storyId=33945288

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- Audacity Developer Team. (2000, May). *The Free, Cross-Platform Sound Editor.* Retrieved October 16, 2008, from from http://audacity.sourceforge.net/

These sources allow you to listen to calls of many varieties of birds:

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- Elliott, L. (2006). *Welcome to Learn Bird Songs!* Retrieved October 23, 2008, from http://www.learnbirdsongs.com/
- Davies, G.H. (n.d.). *The Life of Birds: Bird Songs.* Retrieved December 7, 2008, from http://www.pbs.org/lifeofbirds/songs/index.html

This source provides a global birdsong database map, with links to many online birdsong databases:

- Phillips, T. (2007, September 19). *Links to Other Birdsong and Birding Sites.* Retrieved October 23, 2008, from http://www.math.sunysb.edu/~tony/birds/links.html

Materials and Equipment

- Personal computer with Internet access
- Lab notebook

Experimental Procedure

1. Research and determine what kinds of birds are commonly imitated in classical music. Choose three of these birds to investigate.
2. Through research, determine which classical musical composers are noted for including bird songs or bird calls in their music. Select three of these composers who each have works imitating or giving an impression of your three chosen birds. A starting list of possible composers and their works is given below.

Starting List of Composers and Compositions Containing Bird Songs or Calls

Composer	**Composition**
Bartók	*Piano Concerto No. 3, second movement, adagio religioso*
Beethoven	*Symphony No. 6; 25th Piano Sonata (Op. 79)*
Biber	*Cock, Hen, and Quail*
Dvorak	*Wood Dove*
Handel	*Cuckoo and the Nightingale*
Haydn	*Lark Quartet, op. 64, no. 5; Symphony No. 57 (finale); The Bird*

Janequin	*Le Chant Des Oiseaux*
Messiaen	*Réveil des Oiseaux; Oiseaux Exotiques; La Grive des Bois*
Mozart	*Piano Concerto No. 17 in G major, K. 453; Musical Joke, K. 522;* "Pappageno/Pappagena Duet" and "Pappageno's 'Vogelfänger' (The Bird Catcher Aria) from *The Magic Flute*
Prokofiev	*Peter and the Wolf*
Rameau	*Le Rappel des Oiseaux*
Respighi	*Gli uccelli (The Birds); The Pines of Rome*
Schubert	*Die Vogel*
Stravinsky	*Song of the Nightingale*
Vivaldi	*The Goldfinch; Spring (from The Four Seasons); Summer (from the Four Seasons)*
Wagner	*Siegfried*
Zeller	*Der Vogelhändler (The Bird Seller)*

3. Listen to an online database, such as www.learnbirdsongs.com, of your three chosen birds to hear real examples of their calls or songs. Pay attention to things like the rhythm and the pitch. Is there a **crescendo** (a rise in volume) during the vocalization? Are the notes **staccato**—very crisp, distinct, and not overlapping? Or do they **trill?**
4. For each composer, choose a single segment of a composition that has an imitation or impression of your three chosen birds. You could obtain these compositions from a website such as Classical Music for the Birds http://www.npr.org/templates/story/story.php?storyId=33945288. Write down the titles and segments that you have chosen to evaluate; for example, "The end of the second movement of Beethoven's 6th Symphony." Note down anything that strikes you about the character or quality of the music as you listen to it.
5. For each composer, listen to your chosen segments, and identify, by listening or through research, the instrument used to make the imitation or impression of each bird, and record the instrument's name in your lab notebook in a data table, like the one below.

Data Table: Instrument Used to Imitate or Give an Impression of a Bird Song or Bird Call

Bird Type	Composer 1: Beethoven (example)	Composer 2:	Composer 3:
Nightingale (example)	Flute (example)		
Cuckoo (example)			
Lark (example)			

6. For each bird type, compare the bird's real song or call to its musical ones in the chosen segments of compositions. Do you think each composer gave an imitation or an impression? Record your observation in your lab notebook in another data table.
7. Analyze your data tables. Did composers use *multiple* instruments to imitate or give an impression of the birds that you chose, or just one? Do you think the complexity of the bird's sounds influenced the composer's choice of instrument? Were there any surprising choices of instruments? Were bird calls more likely to be imitated and bird songs more likely to be given impressions? Comparing composers, which ones were more likely to give impressions and which ones were more likely to give imitations?

Variations

- Choose a single bird and use free, open-source software, such as Audacity to evaluate the frequency spectrum of one of the bird's calls. Contrast and compare that spectrum with ones created from three pieces of classical music that try to imitate that bird's call.
- Choose a single composer and evaluate multiple compositions by that composer that contain bird impressions or imitations. Does the composer use the same instrument for the same bird across compositions? Does he or she always give impressions, or always give imitations of bird vocalizations, or is there a mix of both?