NAME THAT TIMBRE! AN INTERACTIVE DEMONSTRATION FOR TEACHING CONCEPTS OF HARMONIC CONTENT IN MUSICAL SOUNDS

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A fundamental, yet nontrivial, concept in analyzing sounds is the notion that most sounds consist of combinations of single-frequency tones. In an advanced physics or engineering course, this concept can be described rigorously through the use of Fourier analysis. For a less technically trained audience, however, the concept is more effectively conveyed using audio demonstrations. One such demonstration is to filter the recording of a steady note from a bowed or blown musical instruments such that individual harmonics are heard in succession; the same recording is also filtered so that harmonics are progressively added throughout the note. The first version helps people understand the nature of the “building blocks” of the note: that they are pure tones of specific frequencies. The second version dramatically conveys how the individual components sum to create the familiar sound a particular instrument. This paper describes an enhanced version of this demonstration that actively engages an audience or class. The activity is structured as a game, similar to the classic television show “Name That Tune”. Whereas the object of the original game show was to identify a familiar tune after hearing only a few notes, this activity has audience members compete to identify an instrument after hearing the fewest component harmonics. An assessment of the efficacy of this activity in an introductory college course on musical acoustics, as well as in public outreach demonstrations, will be presented.

Keywords: acoustics education, interactive demonstration, harmonics

1. Introduction

This paper describes an interactive acoustics demonstration (activity) designed to reinforce the concept that sounds are composed of tonal components. The activity and the underlying acoustic concepts are suitable for students at the early high school through introductory college levels, either as a classroom activity or as part of a public lecture.

The activity is based on an audio demonstration that employs a sequence of audio recordings of a single note from a musical instrument which have been filtered so that the contribution of individual frequency components can be discerned. Such filtered sounds have been used by the author in public lectures and in introductory level physics courses at Central Washington University to convince listeners that familiar sounds are composed of “building block” tones, and to demonstrate how the ear perceives
the superposition of harmonics. Consistent enthusiastic response to this demonstration has motivated the development of an augmented version that involves active student participation.

The pedagogical effectiveness of active engagement by students is well documented [1, 2, 3]. When students actively participate in a task that requires cognitive involvement and the application of new ideas, they are more likely to retain those ideas and incorporate them into their framework of understanding. This is especially valuable for overcoming preconceived ideas that students often have about physical laws that pertain to everyday experience.

The remainder of the paper is structured as follows: section 2 describes specific learning objectives for students who participate in this activity; section 3 provides details for creating the necessary sound files, structuring the game, and implementing the web-based student response software; section 4 describes how student response data can be used to assess student learning.

2. Learning objectives

The “Name That Timbre!” game is designed to reinforce concepts of superposition, specifically the addition of harmonics that comprise the sound of tonal musical instruments. This activity, and the underlying audio demonstration, addresses a conceptual gap that many people have regarding how sounds differ from each other. Most people can describe, often with great precision, differences in pitch, loudness, and duration, yet they struggle to characterize timbre (tone color), even though they can readily discern the sound of an oboe from that of a clarinet. Although musicians develop a vocabulary to describe timbre (e.g. “warm,” “bright,” “dark,” “full,” “tall,” “rich”) that is widely shared, simple classroom experiments show that there can be disagreement about how these terms apply to specific sounds. The goal, then, is to help students recognize and apply the component theory of sound, in part so that they can better describe and differentiate sounds, but also because it is the foundation for understanding how musical instruments create their unique sounds.

The activity is most effective when participants have already seen and heard examples of how pitch corresponds to frequency, how amplitude corresponds to loudness, and how sounds with the same pitch and loudness (and duration) can differ in other ways. For many students, especially those who have not studied music, the term “timbre” will be new to their vocabulary.

After hearing some preliminary audio demonstrations and playing the game, students (participants) should be able to articulate the following:

- the difference between a pure tone and a complex tone
- that most familiar sounds are complex tones that are made up of combinations of pure tones
- the harmonic series contains tones separated by familiar musical intervals
- complex sounds with a definite pitch are composed of harmonics
- how the timbre of a sound depends on the number and relative amplitude of harmonics

3. Sound modification and game design

In this game, which can consist of multiple rounds, students compete to be the first to identify a sound as harmonics are added. At the beginning of each round, a list of four to six sound names or descriptions are displayed and each sound is played once or twice in its original form. The competition begins when a filtered version of one of these sounds begins playing. As described in section 3.2, the sound is filtered such that only one harmonic or partial (usually the fundamental) is heard initially, followed by the addition of subsequent harmonics. As harmonics are being added to the sound, students press their “clicker” when they recognize which sound in the list is being played.
3.1 Types of sounds to compare

Many kinds of sounds can be used for this game, although it is important that attributes other than timbre, such as vibrato, are similar within a set of sounds used in a single round. For simplicity, it is best to avoid sounds with distinct temporal variations.

There are two methods of presenting filtered sounds, depending on whether the sound has finite duration (such as a piano or guitar note) or whether it can be sustained at constant amplitude for several seconds (e.g., a note from a wind instrument or a bowed string). These are described in detail in the next section. All the sounds in a given set should be of the same presentation type.

3.2 Filtering sounds and preliminary audio demonstrations

It is important to start with a high quality recording in digital format. Many sound samples are available for free online, but the most reliable source is to make a good recording. There is a variety of free or inexpensive software for manipulating or analyzing sounds, such as Audacity (https://www.audacityteam.org/download/) or Raven (http://ravensoundsoftware.com/). Such tools have the capability of displaying the spectrum of an audio recording and allowing the user to apply a low-pass or band-pass filter to any portion of the sound. Examples of filtered waveforms and corresponding spectrum plots are shown in Fig. 1.

Two approaches to filtering a sound recording are described below; each is suitable for a particular demonstration.

3.2.1 Sequential harmonics

To demonstrate the existence of individual harmonic components of a sound, a band-pass filter is applied to each harmonic that is to be heard. This is useful as a prelude to the demonstration of layered harmonics, since it helps students recognize the sound of individual pure tone components, as well as the harmonic relationship among them.

If the sound is steady and has a duration of at least two seconds, then a single recording can be divided into segments, each of which is band-passed to allow a different harmonic. For example, in a recording of a cello playing the note C3 for three seconds, the first .3 s is filtered so that only that fundamental is heard; the next .3 s is filtered so that only the 2nd harmonic is heard; and so on until the 10th harmonic is the last to be heard. This results in a quick succession of harmonics that does not sound at all like the original recording, but it efficiently conveys the tones that are present in the sound.

For sounds with a finite duration, such as a piano note, then it is more practical to filter the entire sound for each harmonic, then play them sequentially. The demonstration takes more time, but it allows the listener to appreciate that each harmonic follows some version of the amplitude envelope.

3.2.2 Layered harmonics

In this demonstration, harmonics are added on, or layered, as the sound progresses (or is repeated). A steady sound can be edited as described above, except that Nth segment is low-pass filtered so that the first N harmonics are heard, rather than band-passed to allow only the Nth harmonic. The edited sound file is played once, with the sound building from just the fundamental to a recognizable instrument in a matter of seconds.

Transient sounds are low-pass filtered in their entirety; a separate edited sound file is created for each number of harmonics remaining. The files can be played one after the other. If done quickly, the listener can discern the latest harmonic added, while recognizing the evolution of the timbre. Three examples of a filtered piano note, along with the original recording, are shown in Fig. 1.
Figure 1: Excerpts of the waveform (left column) and corresponding spectrum (right column) of a piano note that is filtered to contain an increasing number of component harmonics. The top three rows correspond to two, three, and four harmonics, respectively; the bottom row is the original recording (the full spectrum has been truncated for space). These images can be displayed along with the corresponding audio as part of a preliminary demonstration.

3.3 Constructing and playing the game using a classroom response system

The game consists of one or more questions; each question is associated with a particular sound that participants try to identify from a short list. Since the objective of the game is to improve student understanding of timbre and its relationship to harmonic content, the sounds listed in a given question should not be distinguishable by characteristics other than timbre. For example, a sound with a definite pitch should be grouped with sounds that have the same pitch.

A web-based classroom response system, such as Kahoot or Top Hat, is used to record participant responses. These tools have the capability of recording individual response times, as well as the specific choice that is made for each question. The instructor sets up the game within the online system by
creating a set of possible answers for each question. Before the game begins, participants log into the system using their smart phones and provide a temporary user name; no personal information is required for participation.

Each question has two stages: preliminary and competition. The preliminary stage consists of displaying the list of possible answers (sound descriptors) and playing an audio file of each sound in its original form. This is done separately from the classroom response software; a Powerpoint slide with embedded audio would be a convenient format. The purpose of the preliminary stage is to ensure that all participants are acquainted with every sound that is a possible answer to the question.

The competition stage is initiated when the instructor selects a question in the classroom response system and plays the audio file containing the associated layered sound. As described in section 3.2, the quiz audio consists of a sequence of filtered versions of one of the sounds in the list, in which successive harmonics are restored to the sound. Participants tap their phone when they recognize which sound in the list is being played.

The classroom response software tracks the response time of each participant and assigns points accordingly. After several questions (rounds), the student with the most points can be recognized.

4. Assessment using student response data

The timing data captured by the classroom response software can be used to compare how readily different kinds of sounds are recognized. For example, the response time might plausibly be shorter for a question set that includes different types of wind instruments (brass, reed, flute) than for a set consisting of only reed instruments. This data can be shared with students to serve as a topic of discussion, e.g. “Why is it so much easier to identify a trumpet vs. an oboe than it is to identify a clarinet vs. an oboe?”

The results also help instructors identify students who may benefit from extra practice with hearing differences in timbre. This is an ability that is comparable to discerning shades of color in a painting or flavors in food; it is not practiced by most people, yet it contributes to a deeper appreciation of the audible world most of us inhabit.

REFERENCES