Sound
PSY 310
Greg Francis
Lecture 28

Why doesn’t a clarinet sound like a flute?

Other senses

- Most of this course has been about visual perception
  - Most advanced science of perception
  - Perhaps the most important human sense
  - Relatively easy to show many effects
  - Many topics apply to other senses
- For the rest of the course we discuss other senses, in less detail
  - Sound (up to third exam)
  - Touch
  - Smell
  - Taste
Auditory perception

- As for visual perception, auditory perception (hearing) provides information about the world around us.
- Sounds can be heard even when objects are out of sight:
  - Behind other objects
  - Night time
- We are quite good at recognizing sounds:
  - Demonstration
Sound stimulus

- The stimulus of sound is pressure changes
  - Usually in the air, but can also be produced in water or other mediums
  - Vibration makes sound
  - e.g., hitting a tuning fork

- Air around the fork is pushed back and forth
- This makes small changes in the pressure of particles in the air
- Pressure is the density of particles in the air
- When particles are pushed, they move, and push their neighbors. The energy travels along.
Sound stimulus

- Air around the fork is pushed back and forth
- This makes small changes in the pressure of particles in the air
- Pressure is the density of particles in the air
- When particles are pushed, they move, and push their neighbors. The energy travels along.

Sound stimulus

- There are both compressions and rarefactions to produce a sound wave
  - Pushed away from source in compressions
  - “Sucked” back in during rarefactions
- It doesn’t really matter what the source of the pressure changes is, a string is a good as a fork
Sound stimulus

- If you could see the particles in the air with a sound wave, they would look like this

![Diagram of sound waves with compressions and rarefactions]

- So sound is a pressure wave
- We can describe a simple sound with a sine wave

![Diagram of a sine wave and sound wave]

NOTE: "C" stands for compression and "R" stands for rarefaction.
Sound stimulus

- Different properties of the wave generally correspond to different perceptual aspects of sound.

Sound is a Pressure Wave

NOTE: "C" stands for compression and "R" stands for rarefaction.

Sound stimulus

- The frequency of the wave corresponds (roughly) to pitch.
- Here is the wave for middle C:
  - Play the sound.
- A Hertz is the number of cycles of the wave in a second of time.

A look at 0.01 second of 262 Hz; Middle C
Sound stimulus

- Increasing the frequency of the wave changes the pitch
- Here is the wave for middle A
  - Play the sound

![Waveform of middle A](image)

Sound stimulus

- Increasing the frequency of the wave changes the pitch
- Here is the wave for high A
  - Play the sound

![Waveform of high A](image)
Sound stimulus

- What we perceive as loudness corresponds (roughly) to the amplitude of the wave
  - How much pressure is changed
  - This is a matter of how much energy is involved in pushing the air
- A sound spreads out across an area, and the energy is constant
  - So sound waves have a smaller amplitude with increasing distance
  - Inverse square

Measuring amplitude

- The easiest way to physically measure amplitude would seem to be just measure the changes in pressure
  - Micropascals (one-millionth of a pascal)
  - Pascals are used to measure pressure for atmospheric changes
- But this proves to not be useful because variations in amplitude are perceived variations in loudness
- People have varying sensitivity to sound wave amplitude
- We discriminate small differences when the amplitude is small
  - Whisper versus talk quietly
- We cannot discriminate big differences when the amplitude is big
  - Jet engine versus jet engine and someone shouting
A measure that is relatively similar to human perception of loudness is the decibel scale. Take the ratio of a sound’s amplitude relative to some fixed sound amplitude. Take the logarithm. Multiple by 20 (or whatever, it just scales the number). 

\[ dB = 20 \log\left(\frac{p}{p_0}\right) \]

Note, you can get negative decibels. When your sound amplitude is smaller than the reference. Psychologists use a reference of 20 micropascals, which is just about the faintest sound you can hear. When the decibel value equals zero, the sound amplitude is the same as the reference.

\[ dB = 20 \log\left(\frac{p}{p_0}\right) \]
Many people (including our textbook) suggest that the decibel scale is better than just amplitude because it allows us to work with a smaller range of numbers.

It is true that sounds in the environment cover a very large range of values:
- Faintest sound is 20 micropascals
- Whisper is 630 micropascals
- Loud radio 6,300,000 micropascals
- Jet engine 6.3 billion micropascals

But changing the numbers is not the reason for using the decibel scale:
- Who can’t work with big numbers but can work with logarithms of ratios?

The real motivation for the decibel scale is that the numbers it assigns to different pressure amplitudes follow a pattern fairly similar to our perceptions of loudness.

Consider different sounds and how loud they are:
- Loudness demo
Different wave forms

- We hear lots of sounds that are not sine waves
  - Demos of flute, clarinet
- If sound is a vibration that produces a sine wave, then what produces non-sine wave sounds?
- Fourier analysis / synthesis
  - All wave patterns can be broken down into sine waves
  - A lot of different sine waves combined together produce a wave that is not a sine wave

Fourier analysis

- A function can be described either in space (x)
  - Or in terms of the Fourier coefficients \(a_0, a_1, ..., b_1, b_2, ...\)
- Each of the coefficients refer to a sine wave of a given Hertz

\[
f(x) = \frac{|x|}{\pi} \quad a_0 = \frac{1}{2} \quad a_n = \frac{-4}{(n\pi)^2} \quad b_n = 0
\]
Complex sounds

- Different sounds can be described by the Fourier coefficients that correspond to the shape of the wave

400 Hz sine wave

400 Hz square wave

400 Hz sawtooth wave

400 Hz triangle wave
Complex sounds

- As sound changes, the frequencies involved change over time
  - Play crescendo

Conclusions

- The physical properties of sound
  - Pressure
  - Frequency
  - Amplitude
- Description tied to what people actually hear
  - Same as with light
Next time

- Perception of sound
- Range of hearing
- Loudness
- Pitch
- Auditory System