Headphone Essentials 1:

Basics of Musical Sound

Note: this is the first unit in the instructional series Headphone Essentials.

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Sound and frequency

Music is made from *notes*, such as middle C, and each note is a series of pulses of air pressure change occurring at a regular rate:

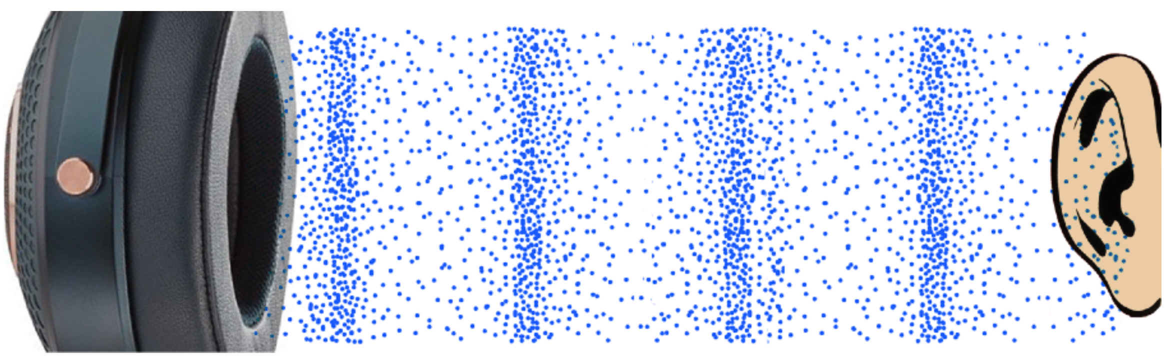

Fig. 1: sound = rapid pulses of air (gas molecules) compression

The blue dots in Fig. 1 represent the gas molecules in air. Inside the headphone ear cup on the left is a vibrating surface that gives the air molecules a regular sequence of jostles which they then pass on to the air molecules to their right. Eventually this jostle reaches the eardrum inside the ear, passing on the jostle to it. Fig. 1 would be something like a 1/1000th second snapshot, since we're only seeing a few pressure waves passing from ear cup to ear.

The regular rate of pressure change, such as 100 pulses per second, is called the pitch or *frequency* of the note (how frequently the waves of pressure change follow each other). The usual shorthand for this is simply *cycles per second,* instead of cycles of pressure changes per second.

The slowest frequency humans can hear is about 20 cycles per second. Much slower than that the waves are felt separately by touch rather than perceived by hearing. Only the largest pipe organs and some electronic instruments produce notes below the 27½ cycles per second of the deepest note on a piano. Even the lowest note of a double bass in only 33 cycles per second and the lowest human *basso profundo* note is only about 64 cycles per second.

The fastest frequency humans can hear is very much age-dependent. A young child *might* be able to hear 20,000 cycles per second. But by the teens that number will be reduced to approximately 18,000. And by 30 it might be more like 15,000 … and the number just keeps getting smaller as we age.

Ears-on

To hear what these numbers actually sound like, go to the Online Tone Generator in your browser:

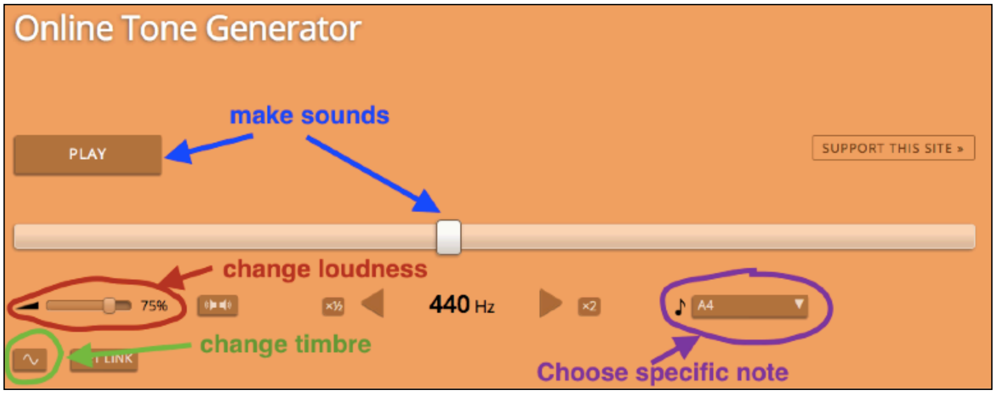

Fig. 2: Online Tone Generator controls

As the blue arrows point to, simply move the big slider or type in a frequency number, then click PLAY or press the space bar to hear what 250 or 1000 or any other number of cycles per second actually sounds like. Though they're invisible, you're causing a sequence of rapid air pressure changes. And they happen at the rate shown by the black number in the centre below the slider. These pressure changes are most likely produced by a loud speaker rather than a drum. If it's a tiny loud speaker like the one in the laptop on which I'm typing this, it simply can't produce the lowest frequencies (below maybe 100 cycles per second) of human hearing.

The frequency numbers are notated in Hz, which stands for *hertz*. But hertz is just another term for (air pressure) cycles per second. So 800 Hz equals 800 cycles per second. Any number from 1000 on up is usually abbreviated to kilohertz. So 1000 Hz is the same as 1 kHz.

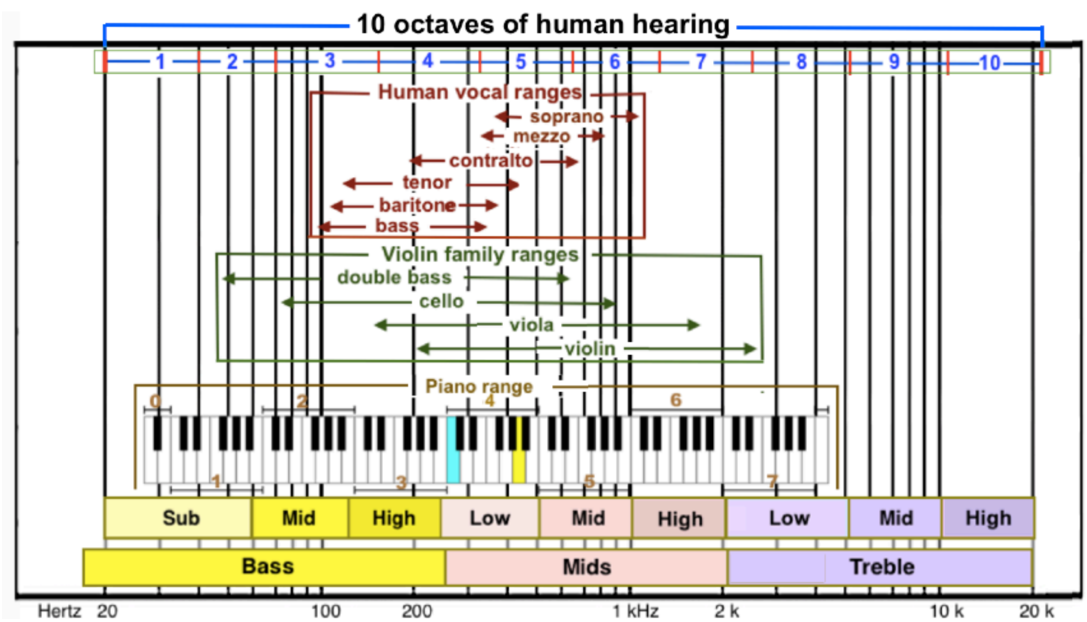

Fig. 3: some familiar voice and instrument ranges
(an *octave* is a doubling of frequency, e.g. 20 Hz to 40 Hz)

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Frequency range vocabulary

That's nice. Now we know what 377 Hz or 2012 Hz sounds like. But to translate that into something useful, the chart in Fig. 3 above shows the lower and upper frequencies for some familiar musical sounds. For example, the soprano human voice typically has a range from the fourth note C to the sixth note C on a piano keyboard, and in numerical terms that's 262 to 1047 Hz. So if you play 262 Hz and 1047 Hz in the Tone Generator you're hearing the lowest and highest pitches of the soprano range.

You'll further need to know the terminology used in the audio world to divide the frequency range up into portions shown in the bass-mids-treble boxes in Fig. 3. The bass frequencies extends from the more-felt-than-heard 16 Hz of the tallest pipe organ pipe to the 262 Hz of middle C (C4). These frequencies are sub-divided into low or sub-bass, middle-bass, and high or upper-bass. Ditto for the mids and treble. (Bizarrely, audio enthusiasts invariably refer to the frequencies in the lower treble, roughly 2000 to 4000 Hz, as being *upper mids* instead of lower treble.)

Drill yourself by having an accomplice move the slider out of sight until you can place the sound of any random slider position in its appropriate category, such as mid-bass or low-mids, and make a reasonable guess as to its frequency number. This ability to relate pitch to words and numbers will prove invaluable in reading reviews or forum posts or communicating with other enthusiasts.

Notes are simply specific frequencies used in making music. I've circled in purple in Fig. 2 bottom right a selection tool in the Tone Generator app for choosing any of the notes used in Western music. You can actually play a tune by clicking on a note like A5, then turning it on and off with the space bar. For example, play C4, C4, G4, G4, A4, A4, G4. You likely recognize the sequence. So see if you can complete it by locating the next seven notes.

The highest note on a piano is just over 4000 cycles per second (C8), even the piccolo ventures no higher. So it might seem irrelevant to music whether we can hear higher frequencies, except for …

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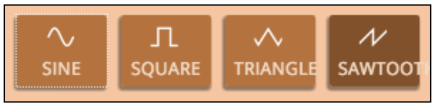
Timbre

Sung or played musical notes are actually fusions of multiple related pitches. Our brains identify the deepest of those pitches as being the important one, called the *fundamental*. But the higher pitches serve to define the character, or *timbre* (pronounced tam ber), of the note.

A flute and a guitar can both play the note middle C, but the flute sound differs from the guitar sound due to the higher pitches, called *overtones*, that are produced automatically along with the fundamental. The flute has fewer and quieter overtones than most instruments, giving it a sweet, un-biting timbre. The violin and harpsichord are the opposite. Their prominent overtones go far higher in pitch than the fundamental and some of them are actually louder than the fundamental as well. This gives these instruments a biting or edgy character. But, except for the highest overtones of the highest notes of instruments like the violin and harpsichord, the majority of music is made up of frequencies rarely reaching higher than about 8,000 cycles per second. At the other extreme, as mentioned, only the largest pipe organs and some electronic instruments produce notes below the 27½ cycles per second of the deepest note on a piano.
Directly below the loudness slider on the left in the Tone Generator app I've circled in green a



selection tool with options for sine, square, triangle, and sawtooth timbres. Try changing between these options as a tone sounds. The sine wave option is a pure single frequency. The other three wave forms are different artificial timbres created by mixing in a specific recipe of overtones on top of the fundamental tone in each case.

But voice and instrument timbres are in large measure a combination of frequencies that are multiples of the fundamental. Open the Tone Generator app in three tabs or windows (all with sine wave selected). In one of them select the note A4, in another select A5, and in the third select E6. Now use the space bar to get all of them sounding at once. You are in effect producing a (very simple) timbre by sounding these frequencies simultaneously. In this case the timbre might vaguely resemble that of a flute. (Leave these tabs open momentarily, they're needed below.)

Loudness

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Frequency tells us how low- or high-pitched a note sounds. But how loudly a note sounds, from whisper to roar, is equally important. Notice there is also a little slider just under the big frequency slider on the left side that I've circled in red in Fig. 2. When you move this slider left or right while a tone is sounding you change how forcefully the sound pulses strike your eardrums. *Loudness* is the subjective experience of this forcefulness. We can measure the force of a sound as its *sound pressure level* or SPL. But the corresponding loudness has to be inferred since it happens inside our brains. The SPL scale is calibrated in *decibels* or dB. But we don't need to delve into what that means.

Our ears/brains are especially sensitive to sound between 1000 and 4000 Hz (1 and 4 kHz) frequency. Lower and higher frequencies take more force (SPL) to produce the same perception of loudness. Return to the three copies of the Tone Generator app from the timbre experiment. Try changing the loudnesses of each of them as they sound together to create different timbres from the same three frequencies.)

Combining frequency and loudness

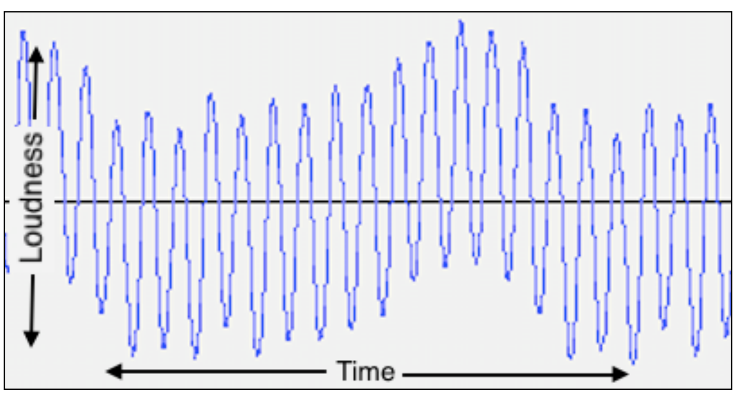

Fig. 4: musical waveform

Fig. 4 shows a common way of graphing sound with loudness/pressure on the vertical scale and the passage of time (not frequency) on the horizontal scale. The jaggedness of the blue line is a result of the mixture of multiple frequencies pressurizing the air at the same time. The multiple frequencies arise from some mixture of timbre and multiple instruments or voices sounding at once.

Both of our ear drums vibrate according to the same jagged blend of pressure changes of all the sounds being produced around us happening at the same time. Our brains then analyze this jumble and separates it back again into separate and distinct sounds, each coming from a different direction at a particular loudness and with a particular timbre.

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Natural reverb and amplification

All the above are idealized considerations. In reality sound happens in a complex physical environment that interacts with the source sounds — and almost always does so in complex ways. If you are in conversation with a friend and walk from outdoors to indoors, the sounds of your voices suddenly start reverberating (bouncing) off the walls and other objects in the enclosed space indoors. Our brains work valiantly to edit this out, so we rarely notice a difference in voice sounds from indoor to outdoor or from one room to another. In an auditorium, cathedral or sports arena the space is so large and reverb times are relatively so long that we usually do notice the echo effect. (An echo is simply a reverberation that takes so long to return, yet remains loud enough to hear, that it resembles a repeat of the original sound.)

In one way reverberations just create extra work for our brains. But in another our brains also use reverberations to determine where the original sound source is located. Try having a friend jangle keys at various locations around your head while your eyes are closed or blind-folded. Now try the same thing but push your ears forward while listening. Notice how much less ability you now have to point to the location of the sound.

Another environmental factor that effects sound involves amplification. I mentioned in the previous section that we're especially sensitive to sound from roughly 1000 to 4,000 Hz. Similarly, room reverberations naturally amplify lower frequencies and diminish or even cancel out others.

All of this is part of the domain of the science of acoustics. Concert venue architects, instrument builders, and audio equipment creators are all immersed in the challenges of shaping acoustics to their needs.

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And that's it. If we were learning to make music we would delve more deeply into note names, staff notation, etc. But for purposes of music listening the above will do nicely.

Be sure to proceed on to the next exciting instalment of this blockbuster series, *HE-2: The Basics of Headphone Sound* at Headphone Essentials.

Further resources

By simply typing the word *sound* into the YouTube search bar I found these videos that nicely summarize and expand on these concepts:

- What is Sound? The Fundamental Science Behind Sound
- Sound: Crash Course Physics #18
- How Sound Works — The Physics of Sound Waves
- Professor Julius Sumner Miller's Demonstrations in Physics series: Sound