Georgia Institute of Technology

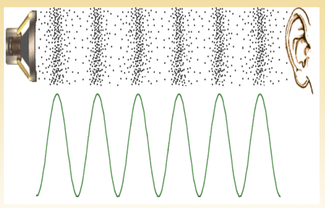
Georgia Tech EUROPE — Georgia Institute of Technology Lorraine

The Science of the Opera

The purpose of this project is to utilize signal processing techniques to discover what makes an opera singer's voice so special, especially when compared to the voice of an untrained singer. We hope that this information will help you better appreciate the science behind the beauty of opera singing.

Mechanics of Sound

Sound is produced when air vibrates, moving the air particles back and forth in a periodic motion. This periodic motion travels through the air to the human ear, where the vibration moves the eardrum back and forth. This vibration of the eardrum is interpreted by the brain as sound.

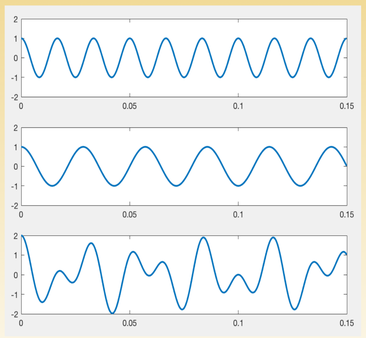


The periodic motion of the sound wave travelling through the air can be characterized by its frequency. This characteristic is measured in hertz, where one hertz is equal to one cycle per second.

Mechanics of Voice

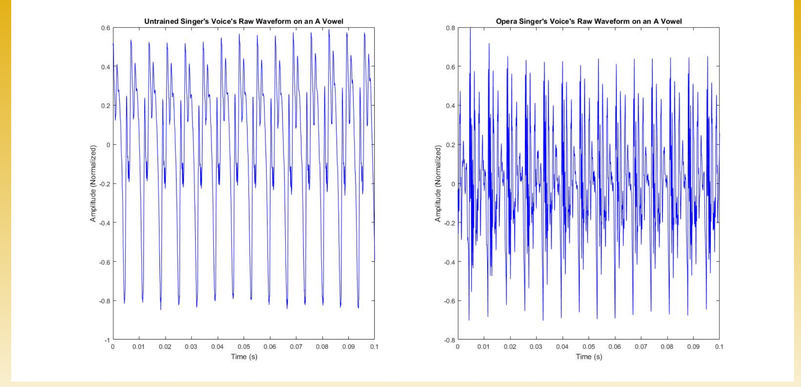
Voice is produced when air flows through the lungs and vibrates the vocal folds. This vibration produces the sound. The shape of the mouth and tongue alters the vibrations of air to produce letters, words, phrases, and musical notes.

What makes the human voice interesting is that the sound signal that comes from the mouth does not have just one frequency. In fact, there are many different signals of various frequencies that are added together to produce the final signal.



This image demonstrates that two signals of different frequencies can be added together to create a third, completely different signal. The top two signals are added together to create the bottom signal, which looks much more like human speech.

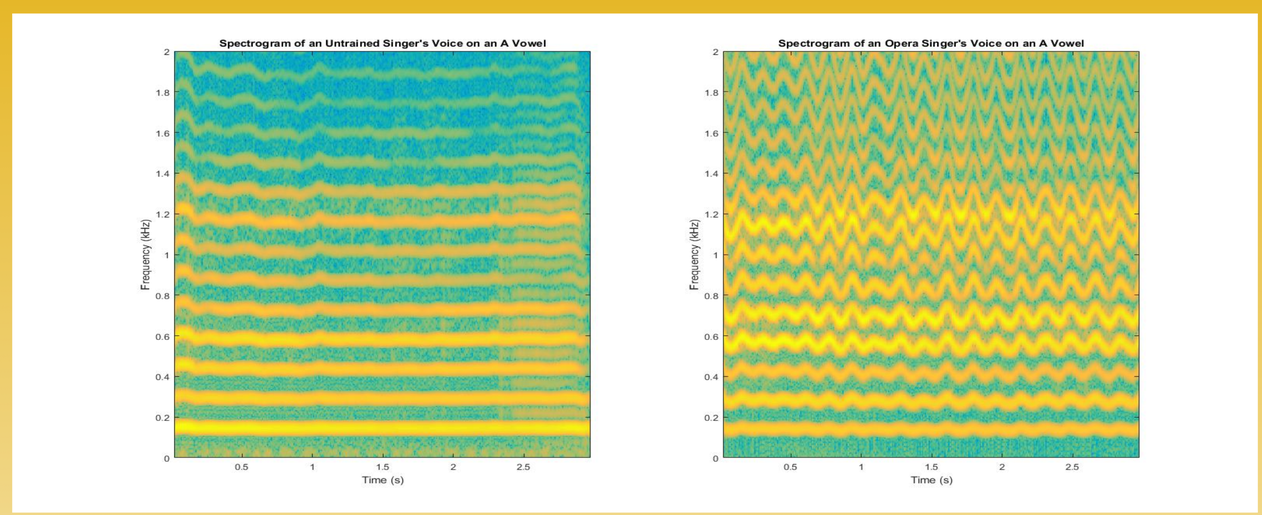
Raw Waveform



From first glance, notice that there are not that many differences between the trained and untrained singers' raw waveforms. The only notable difference is the volume with the trained singers being louder than the untrained. To extract more meaningful insight as to how exactly the two waveforms differ, it is necessary to use signal processing.

Spectrogram

A spectrogram is a tool for visualizing a wave's frequency over time. The horizontal axis represents time, the vertical axis represents frequency, and the color represents intensity. When describing the frequency of a voice, we generally refer to it as the *pitch* of the voice.



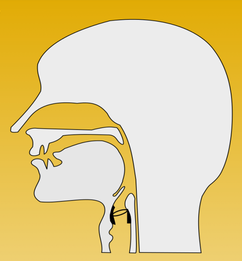
Vibrato is the modulation of pitch in order to create an aesthetically pleasing sound. This can be visualized in the spectrogram by the "Zig-Zag" bright patterns towards the bottom right.

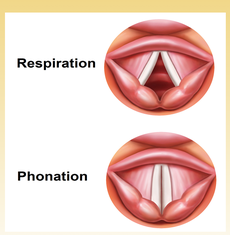
We can see that the trained opera singers can sustain pitch while adding vibrato to a greater degree of precision as compared to the untrained singers.

Finally, analyzing the harmonics (these are seen on the spectrogram as the discrete horizontal quasi-rectangles), note that the trained singers tend to have fewer, stronger harmonics. The opposite applies to the untrained singers, who have many more weak harmonics, which implies that they do not hold their pitch as well as the trained singers.

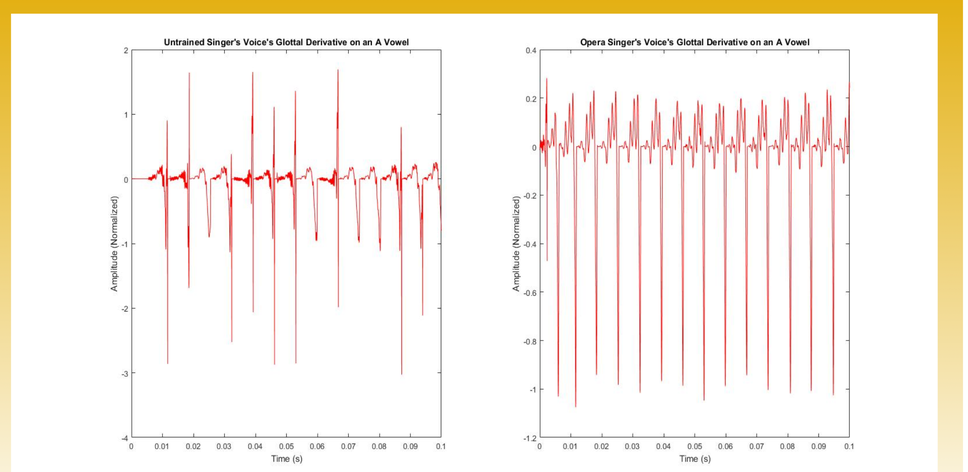
Glottal Analysis

The human voice is created by air flowing out of the lungs through the larynx. Inside the larynx, air passes through two muscles which are called vocal folds, and causes them to vibrate. The glottis is the opening between the two vocal folds. Vocal fold vibration causes the glottis to open and close very quickly as a person sings.





Analyzing the glottal derivative, which is a measurement of how quickly the glottis opens and closes, is a fascinating new metric to analyze opera singers. It is immediately apparent that opera singers are overwhelmingly more consistent than untrained singers in their glottal openings and closures, leading to richer, more consistent pitch.



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