Why Whistles Whork

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Abstract:

In this experiment, we analyzed the harmonic content and qualitatively analyzed the source and production of human hums and whistles in order to more fully understand the human hum-whistle. Using recordings of performances by the experimenters and a MATLAB script developed by Professor Steven Errede, we were able to produce a variety of recordings and analyses. These demonstrate that sideband behavior in human hum-whistles arise as a result of one source producing separate hum and whistle sounds.

Background/Theory:

The human whistle is perhaps the easiest of the sounds we analyzed to conceptualize. To produce a whistle, the mouth creates a Helmholtz chamber. The effect of a Helmholtz chamber is to resonate air at a frequency proportional to the volume of the cavity involved - a whistler changing tones alters their embouchure to adjust the cavity volume and opening.

Human whistles, when analyzed harmonically, display a single, dominant frequency and its overtone harmonics. An ideal whistle would thus only contain one frequency and larger, integer multiples of that frequency. This is consistent with the action of any Helmholtz resonator, however, small effects of air passing through the mouth may also factor into the sound produced.

The human hum, however, involves the vibration of vocal chords, much like the physical mechanism that produces the human voice, but with less interplay of tongue positioning to stem airflow. (This can easily be observed if one presses their lips shut and attempts to speak a sentence, keeping their lips firm throughout; bursts of hum will be heard.)

The human hum also has a dominant frequency, associated with it, however, does not pick up harmonics as the human whistle does.

Sounds produced by the same source are said to be coupled; the harmonics displayed by these sounds produce a harmonic spectrum that is non-linearly contrived - the individual sounds do not add as a superposed sum. Frequencies that arise by these non-linear dynamics are, as one would expect, lower in intensity than the dominant frequency, and are called sidebands. This effect arises because the vibrations of air producing the sounds must be coupled if they are passing through the same source - in the case of the hum-whistle, air produced by the hum is already vibrating when it passes through the Helmholtz chamber, which further modulates it.

The goal of this experiment was to qualitatively observe different additions of human hums and whistles, and to verify that the sideband behavior of the human hum-whistle is an effect of non-linear dynamics.

Methods:

We looked to study the harmonic content of whistles first. We used recording equipment to record the whistles of each member of the group. Each person was recorded whistling three times for each type of whistling: exhaling and inhaling. In addition, each member was recorded three times whistling and humming simultaneously (a hum-whistle), in order to study how this differs from a simple whistle.

All of the recordings, inhale whistle, exhale whistle, and hum-whistle, were analyzed by the same wave-analysis software. This software is a MATLAB script designed and written by Prof. Steven Errede. The software takes the audio recordings and analyzes the intensity of the sound at various frequencies, at which point the user can identify particular frequencies on which the program will conduct further analysis.

Following the initial analysis of the recordings, additional recordings were made. First, we recorded each individual’s hum and hum-whistle at the same pitch. This was done in order to compare the harmonic content of a hum and a whistle separately compared with that of a hum-whistle. Next, we recorded a series of recordings in which one individual whistled into the microphone while another individual hummed into the microphone. This was done to compare the harmonic content of a hum-whistle done by one person with that of the two-person hum-whistle.

These recordings were analyzed by the same wave-analysis program as the other recordings.

Results and Discussion:

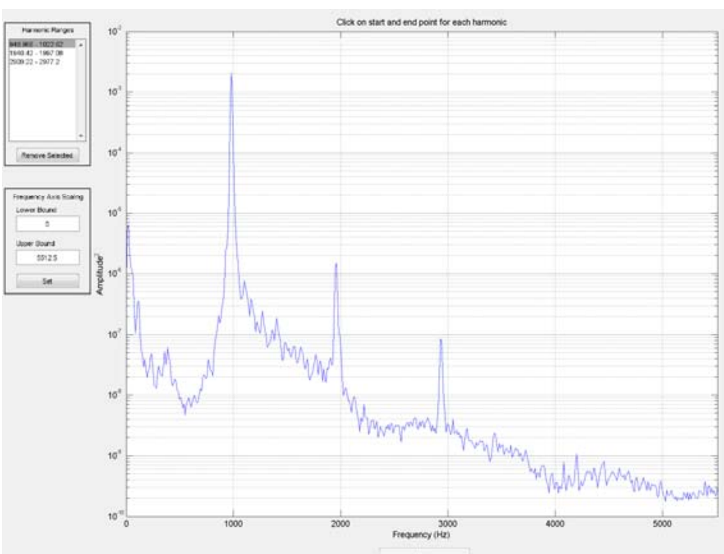

Figure 1. Intensity vs. Frequency Plot of an Exhale Whistle (Joe Mirabelli)

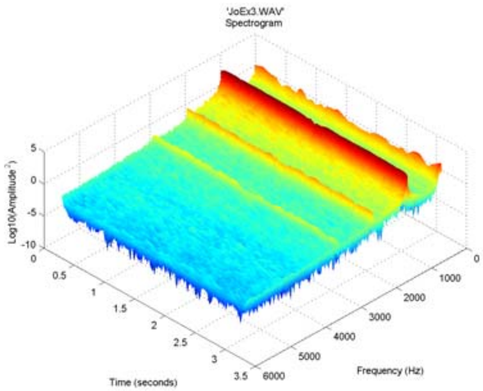

Figure 2. Intensity vs. Frequency plotted against time for an Exhale Whistle (Joe Mirabelli)

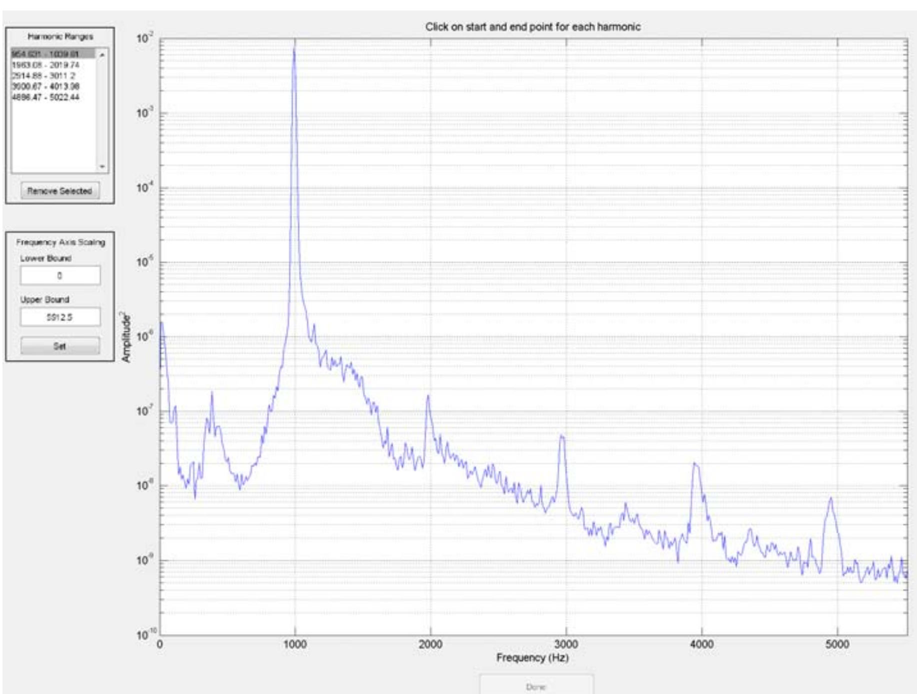

Figure 3. Intensity vs. Frequency Plot of an Inhale Whistle (Xulai Xu)

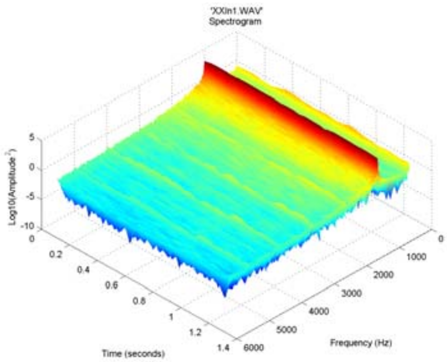

Figure 4. Intensity vs. Frequency plotted against time for an Inhale Whistle (Xulai Xu)

Discussion for Exhaling and Inhaling Whistles:

By the intensity vs. frequency plots (Figure 1 and Figure 3) for both exhaling and inhaling whistle, it is quite apparent that both whistlings are fundamentally of the same nature for both show very similar features in terms of harmonics they produce. We concluded from the intensity vs. frequency plots that whistles display a single and dominant frequency, which is the peak that we observe in both plots, and several smaller peaks which we identified to be the overtone harmonics.

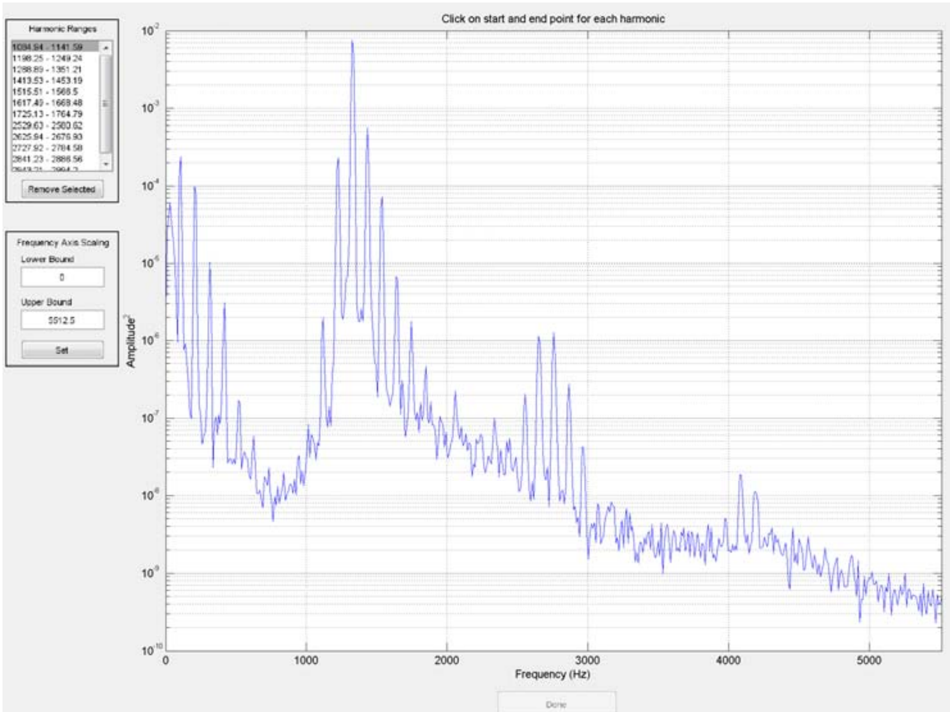

Figure 5. Intensity vs. Frequency Plot of a Hum-Whistle (Itamar Allali)

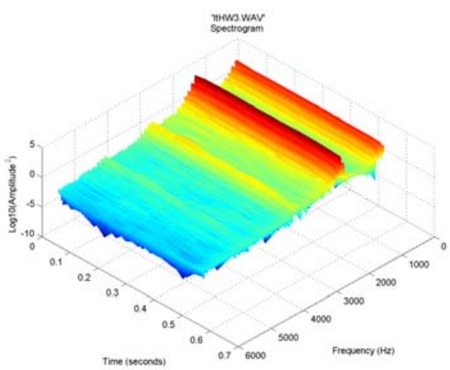

Figure 6. Intensity vs. Frequency plotted against time for a Hum-Whistle (Itamar Allali)

Discussion for Hum-Whistle from the same source (same person):

As expected, the addition of hum to the plain human whistle made a huge difference in the Intensity vs. Frequency plots. Because of the involvement of the vibration of vocal chords, we observe from Figure 5 that although the general shape of the intensity resembles that with plain whistling, numerous sidebands appeared around each peaks.

We have decided that this unexpected excess of sidebands is due to the fact that both the humming and whistling of which the hum-whistle is comprised come from the same source i.e. the same person; therefore, it is highly likely that the hum and whistle would couple together thus creating sidebands.

Next, we did a comparison experiment to prove our postulation.

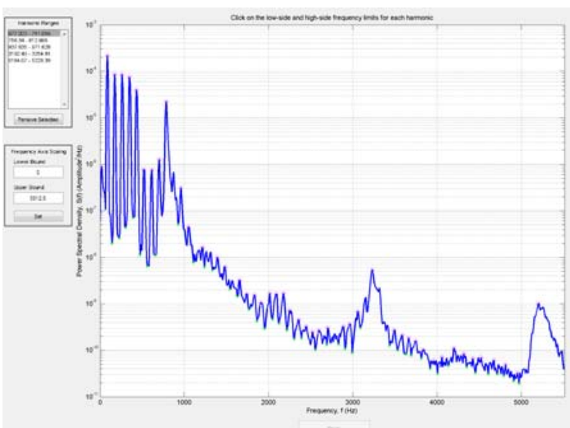

Figure 7. Intensity vs Frequency for a Hum (Xulai Xu)

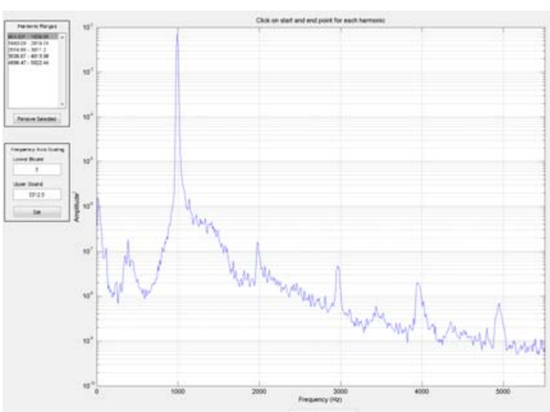

Figure 8. Intensity vs Frequency for a Whistle (Xulai Xu)

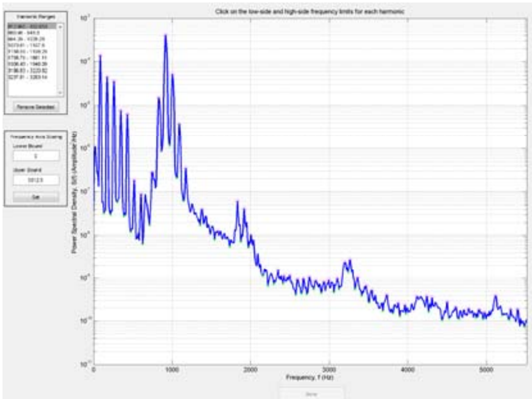

Figure 9. Intensity vs Frequency of a Hum-Whistle

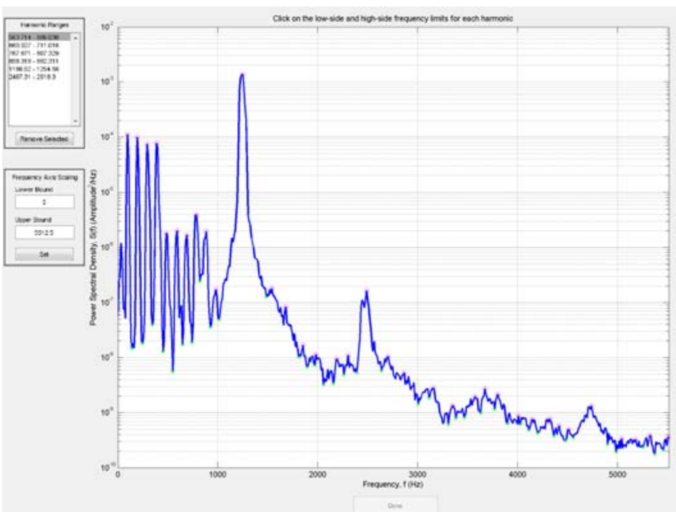

Figure 10. Intensity vs Frequency of a Hum (Xulai Xu) and a Whistle (Joe Mirabelli) Together

Discussion for Hum-whistle from two different sources (two persons):

The Intensity vs Frequency plot of the hum whistle from two separate sources (Figure 10) differs from the plot from the same source (Figure 9) only by the absence of sidebands we observed before. Making sure that humming and whistling from different sources guarantees the uncoupling of hum and whistle. The fact that Figure 10 shows little sign of sidebands proves our suspicion that when the humming and whistling are produced from the same source, they tend to be coupled together to create sidebands around prominent harmonics.

Conclusion:

In our experiments, we analyzed the harmonic content of human whistling, human hums, and hum-whistles and qualitatively analyzed the source and production of human hums and whistles in order to more fully understand the human hum-whistle.

The human whistle can be produced by forming a human mouth into a Helmholtz resonating chamber which resonate air at a frequency proportional to the volume of the cavity involved - a whistler changing tones alters their embouchure to adjust the cavity volume and opening. We discovered that, like a Helmholtz resonator, human whistles display a dominant frequency, but different from a Helmholtz resonator, human whistles have its weaker overtone harmonics.

The human hum involves the vibration of vocal chords which is fundamentally different from human whistles. Human hum also has a dominant frequency associated with it, nevertheless, it does not pick up overtone harmonics as the human whistle does.

The Hum-whistle, although not as popular in the real world, has very interesting results: The simple addition of whistle and hum does not promise a plain superposition of the harmonics plot. Qualitatively, we have discovered that when the humming and whistling come from the same source (in our case, from the same person at the same time), humming and whistling tend to couple together thus creating a wide range of sidebands around the prominent harmonics. However, when we put hum and whistle from two different persons together, our analysis showed little sidebands. Therefore, it is safe to say that making sure that humming and whistling from different sources guarantees uncoupled behavior of the hum and whistle and consequently reduces the sideband effect significantly.