Comparative Analysis of the Two-hole Draw and the Three-hole Blow on Harmonica

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1. Introduction

The modern harmonica refers to a class of reed-based instruments that has been around for hundreds of years. Due to being extremely portable, relatively easy to learn and play, and affordable, the instrument sees wide usage amongst musicians and hobbyists, and has worked itself into a wide variety of musical genres.

The class of harmonicas under investigation in this analysis is knows as *Diatonic Harmonicas*. Diatonic harmonicas consist of 10 holes from which players can blow or draw air through. Each hole has two reeds which each produce a different note. One reed is excited when blown and the other is excited when drawn. The notes are arranged as in fig-1. The notes are arranged such that Major-chords of the key the harmonica is tuned to can be played by blowing simultaneously through adjacent holes, and minor-chords can be played by drawing simultaneously through adjacent holes.

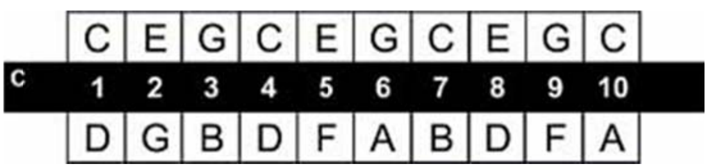


Figure 1: The common reed layout of a Diatonic Harmonica tuned to C

The principle way a harmonica makes sound is through a metal reed that is fastened above an open slot that is just large enough to allow the reed to vibrate freely. When air flows over the reed, it becomes excited and vibrates close to its fundamental frequency. This vibration throttles the flow of air through the slot, causing periodic vibrations in pressure and velocity of the air flow, thus creating sound (Will, 2014).

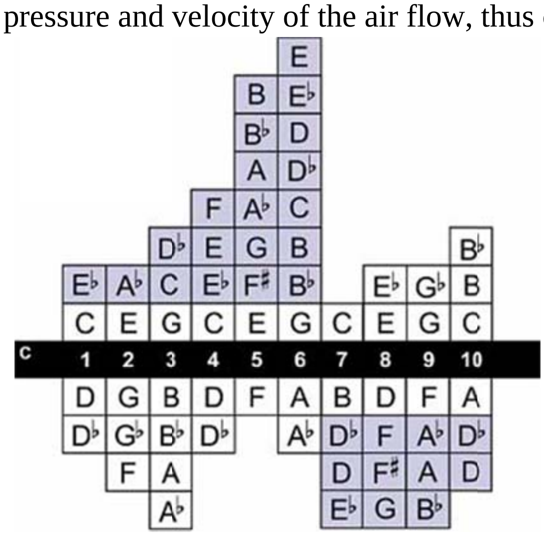


Figure 2: Extra white labels denote possible bends from a reed. Extra gray lables denote possible overblows.

Of particular interest to me is the playing technique known as *Cross-Harp*, commonly invoked by blues musicians taking advantage of the unique layout of the diatonic harmonica. The reeds of a harmonica vibrate close to their fundamental frequency, but can be manipulated through modifying the air pressures within the mouth and throat. This allows a player to play notes lower than the fundamental in a technique known as *Bending* and notes that are higher through a technique known as *Overblowing*. Fig 2. Demonstrates the possible range through these techniques. Blues Harmonica players take advantage of these extra notes by closely mimicking what is known as the *Blues Scale*. By using the 2-hole draw as the first position rather than the 1-hole blow, blues harmonica players can progress up the blues scale through a relatively easy series of blows, draws, and bends, ending on the 6-hole blow. So a harmonica that is otherwise tuned to the key of C would be used to play music written to the key of G (Gussow, 2014).

A common opinion amongst blues harmonica players is an overwhelming preference for the 2-hole draw(2D) over the 3-hole blow(3B) amongst cross-harp players, two reeds with identical fundamental frequencies. Several practical reason exist such as the fact that the 2D can be bent and it can be combined seamlessly with a bent 3-hole draw, the next note on the blues scale. But many harmonica players also claim the 2D to sound "richer" and "less wimpy" than the 3B. What these words might mean and what characteristic of the physical sound they are describing is the purpose of this investigation.

2. Hypothesis

While difficult to interpret the precise characteristics of the differences described by experienced musicians, my own experiences playing blues harp in the past would lead me to interpret their description as saying the 3B has a brighter, sharper sound, while the 2D has a mellower sound. This leads me to hypothesize that, when the harmonic content of each reed's sound is analyzed, the 3B will feature stronger, higher frequencies relative to its fundamental one, than the 2D. In order for the opinion to be so widespread, it is likely a mechanical difference between the reeds and their slots which causes this difference, and would be present amongst most harmonicas, independent of most playing techniques.

3. Equipment and Method

The instruments studied were three brand new *Hohner No. 1896 Marine Band* harmonicas tuned to the keys of C, A, and B-flat. Each was played to ensure all the reeds were functional before recording, but were not used recreationally. Recordings were made using a *Marantz PMD671 stereo 24-bit recorder* as .WAV files and uploaded to lab computers for analysis through the *WAV_Analysis* program developed for the class.

Recordings were made on each harmonica under 4 different categories:

- 2D with Small Embouchure
- 2D with Large Embouchure
- 3B with Small Embouchure
- 3D with Large Embouchure

Comparisons were made between recordings of 2D and 3B of similar instrument and similar embouchure. The two embouchure classes were included to discern if results were independent of playing style. Inconsistent differences between the two different embouchures would create uncertainty in mechanical differences between the two reeds being the cause of the acoustic differences.

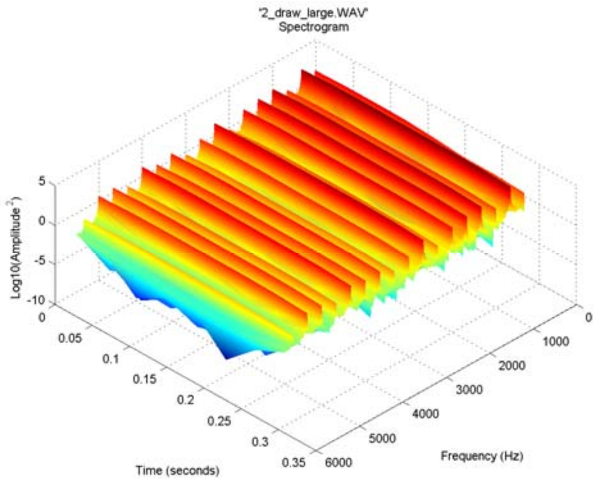


Figure 3: Example of Waterfall Plot generated by the WAV_Analysis program.

The WAV_Analysis program is capable of decomposing .WAV files and calculating measurements of several quantities based on the data, but I focused on the harmonic content of each recording. Each recording had its amplitude analyzed on a time-frequency dependent plot (referred to as a waterfall plot, domain of 0-6000 Hz) and its time-averaged amplitude analyzed on a frequency dependent plot (domain of 0-3000 Hz). This could be considered the raw data from which my own analysis took place from.

4. Analysis

I compared the frequency graphs for each case

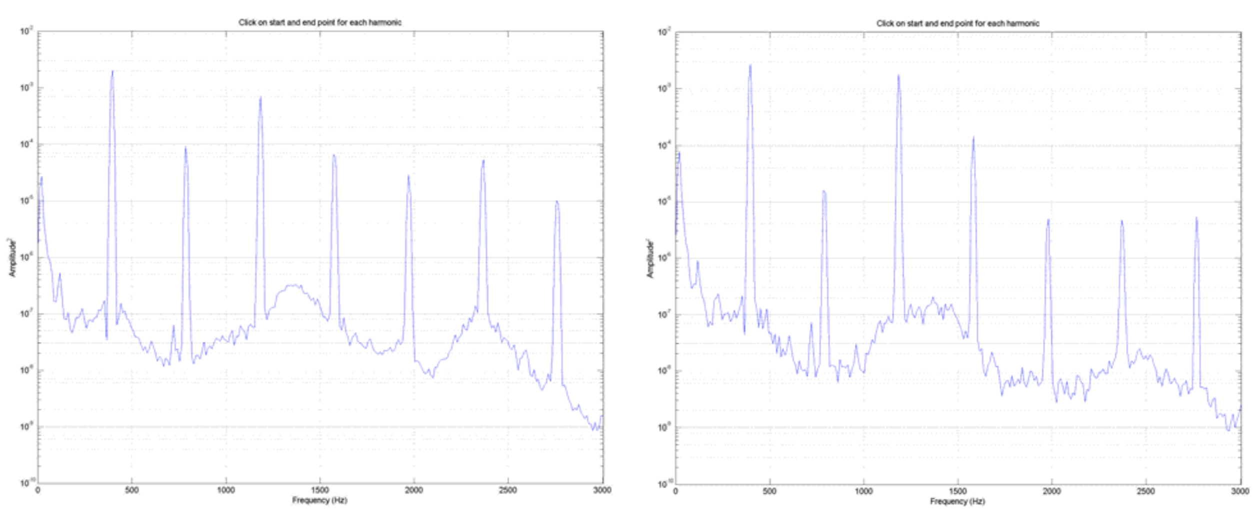
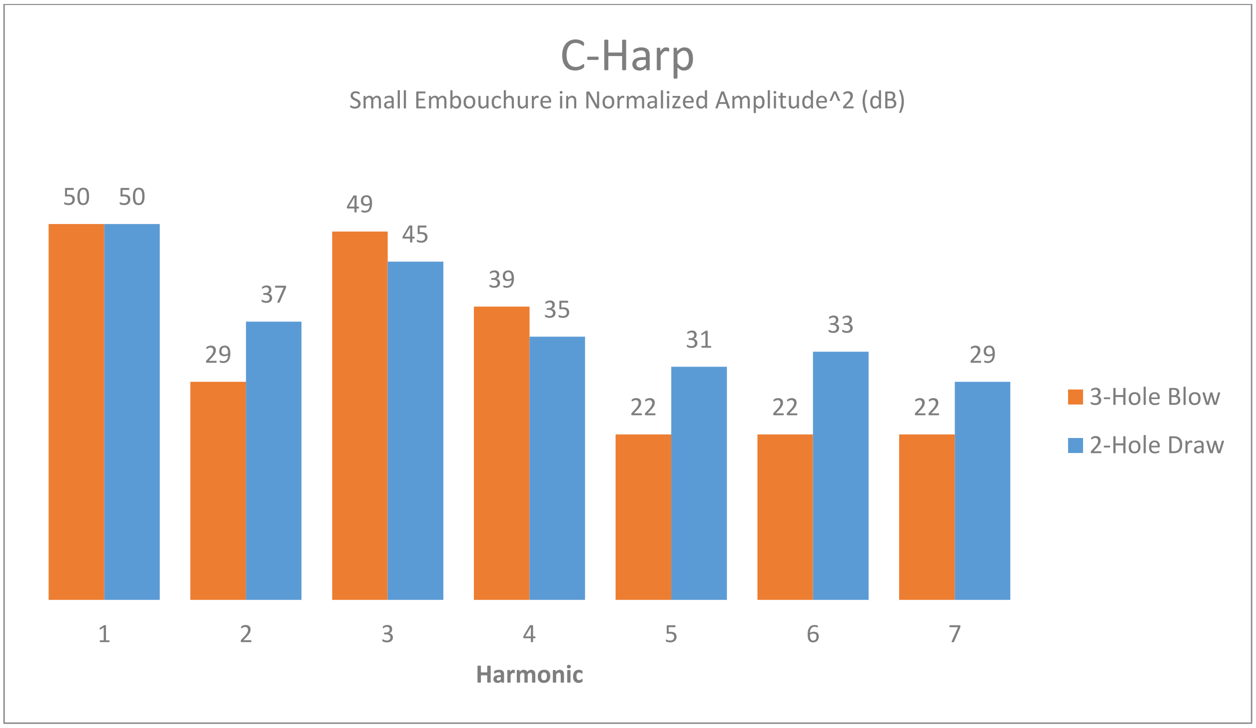
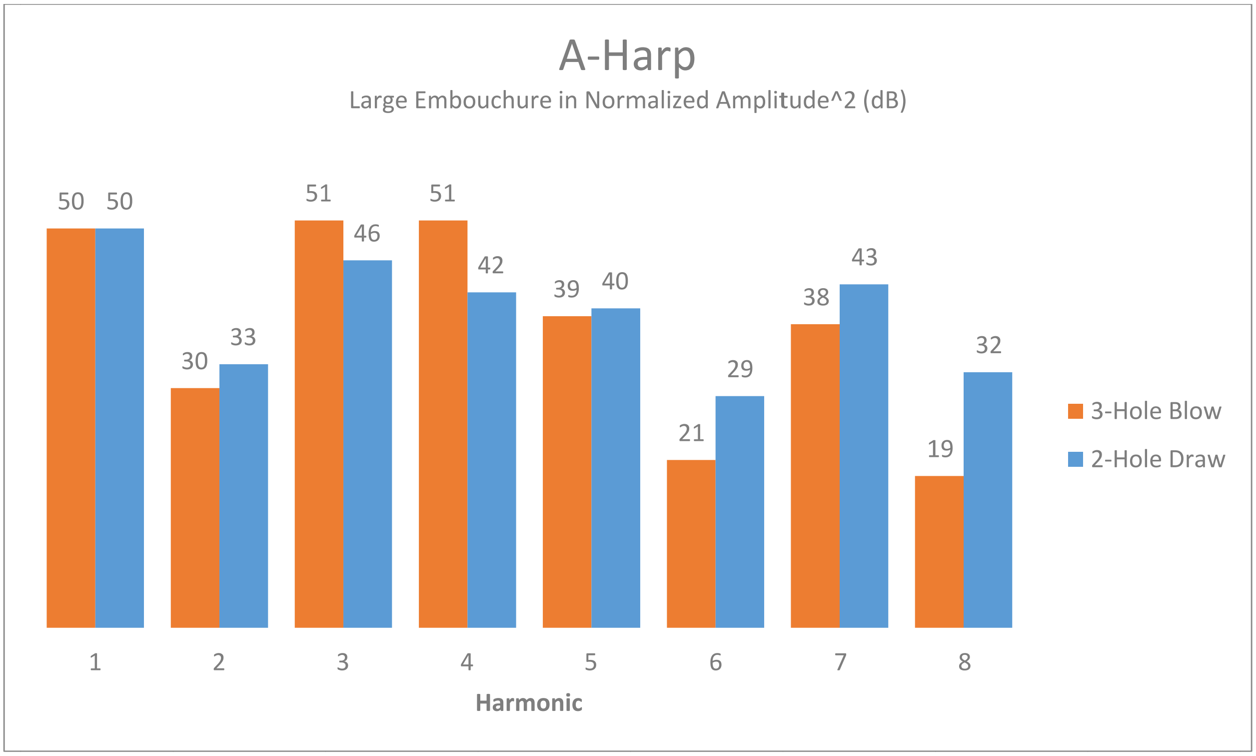


Figure 4: An example of the frequency plots I compared, in this case C-harp with small embouchure. The 2D (left) consistently showed lower 2nd and 3rd overtones than the 3B (right) across all trials.

to try and discern a noticeable pattern.

A pattern consistent amongst the first 4 harmonics appeared, that was quite striking. The 3B displayed stronger 2nd and 3rd overtones, relative to the fundamental, than the 2D did in all trials. In half the trials trials, the 2D displayed a stronger 1st overtone than the 3B, but in all trials, the 1st overtone appeared quite weak, at least a full power of ten lower than the fundamental, in amplitude^2. This became quite evident when I calculated the decibel value of each overtone and graphed the values alongside one another, normalized with the fundamental.





It was tempting to call this a success, as the higher overtones seemed to decay to insignificance compare to the first three, but I projected my results onto an equal loudness curve.

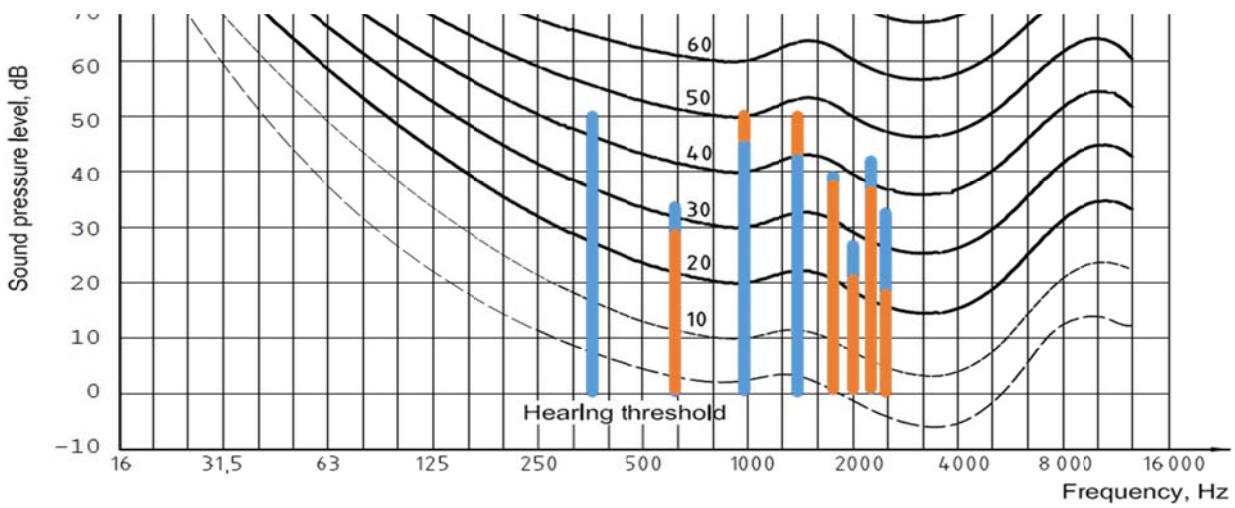


Figure 5: The results from the A-harp Large Embouchure projected onto an equal loudness curve.

From the equal loudness curves, it appears that the higher overtones are not significantly quieter than the fundamental. Indeed, even the 1st overtone does not sit especially lower than the fundamental. In fact, the 2D shows significantly higher overtones than the 3B past the 3rd overtone, sometimes by a whole 10 phons and within the audible range. This would be contrary to my hypothesis, and it was a pattern consistent among the other cases.

The original plots only had a domain of 0-3000 Hz, a domain significantly smaller than the human range of hearing. Comparing the waterfall plots proves even more illustrative.

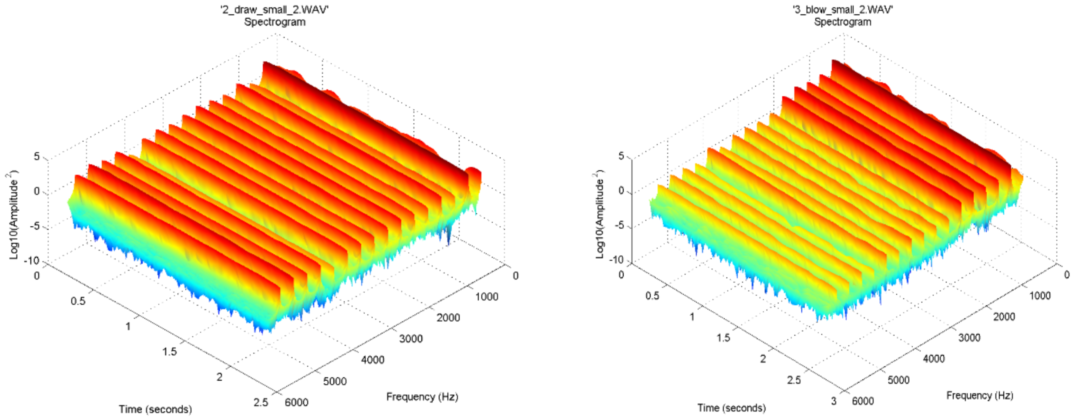


Figure 6: Waterfall Plots of the Bb-Harp. Note the much stronger overtones in the 2D (left) past the 4th overtone.

While more difficult to quantify, the Waterfall Plot makes clear through coloration how much stronger the overtones of the 2D are. It is an observation consistent with 5 out of the 6 cases, with the outlier having overtones that are comparable, as viewed from the waterfall graph. This thoroughly contradicts my hypothesis. While my original hypothesis was off, it was reassuring to see the consistency of the findings between different harps and embouchures, along with the clear differences between the data. There is consistent difference between the two reeds, 2D and 3B, and the data collected here was the first steps to describing it.

5. Conclusions

Amongst all the trials, several characteristics were consistently observed. With all descriptions relative the fundamental harmonic, the 2D consistently showed lower amplitudes in the 2^{nd} and 3^{rd} overtones than the 3B. These were often the louder overtones, sometimes superseding the fundamental in amplitude. The 2D also consistently showed higher amplitudes in the 1^{st} overtone and those higher than the 3^{rd} overtone. While the amplitudes originally seemed too small to be deemed significant compared to the fundamental, 2^{nd}, and 3^{rd}, this was seen to not be the case, and that these harmonics contribute significantly to the quality of the produced sound. The consistency of the findings suggest that there are physical differences between the sound of the 2D and 3B that are not dependent on playing technique. While data does not lend credence to one reed sounding better than the other, the differences seem to be enough for strong opinions to form

6. Acknowledgements and References

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