THE ACOUSTIC EFFECT OF CRYOGENICALLY TREATING TRUMPETS

JESSE N. JONES IV & CHRIS B. ROGERS I

Abstract. The acoustic effect of cryogenically treating trumpets is investigated. Ten Vincent Bach Stradivarious $B\flat$ trumpets are studied, half of which have been cryogenically treated. The trumpets were played by 6 players of varying proficiency, with sound samples being recorded direct to disc at a sampling rate of 44.1 kHz. Both the steady-state and initial transient portions of the audio samples are analyzed. In some cases, a slight shift of power in the harmonic spectrum toward the higher frequencies is observed in the treated trumpets. However, no statistically independent results are seen, and the most pronounced results were not repeatable. Differences observed in player-to-player and trumpet-to-trumpet comparisons overshadow any differences that may have been brought on due to the cryogenic treatment. All data was collected in a double blind fashion. The treatment itself is a three step process, involving an 8 hour linear cool down period, a 10 hour period of sustained exposure to -195 °C (-300 °F), and a 20-25 hour period of warming back to room temperature.

1. Introduction

A controversy has developed within the musician community regarding the effectiveness of cryogenically treating brass wind instruments. Proponents claim that treated instruments sound better, brighter, and more distinct. Further, they say that the treated horns have a higher level of playability, in that notes are easier to hit, and performance fatigue is diminished. Suppliers of cryogenic treatment say that these improvements in sound and performance are due a variety of changes in material properties brought on by the treatment, including stress relief, a minimization of dislocations and voids in the crystalline structure, and a change in material property referred to as "densification [1, 2]." On the other hand, many players and established trumpet manufacturers believe that any improvements seen in the instruments is simply due to a placebo effect [3].

Much research has been conducted regarding the sound generating mechanism of the trumpet and other brass instruments [4, 5, 6, 7, 8, 9], as has the effect of wall materials and plating techniques on the tone of these instruments [10, 12, 13, 14]. Because of this research, the sound generating mechanism of brass instruments is well understood. Further, it has been shown that, in general, a brass instrument constructed from a material with a greater modulus of elasticity will produce a tone that has a spectral content with the power shifted to the higher frequencies [11, 15]. However, little formal research has been done on the acoustic effects related directly to cryogenic treatment. What has been done utilized a small sample size of

Key words and phrases. cryogenic treatment, brass instrument, trumpet.
This work was completed with the support of Steinway & Sons and Selmer Musical Instruments.

instruments, and employed a limited group of player participants [16, 17]. Finally, these examples of research were not conducted in a truly double blind fashion.

Research for this study generated a sizable database of results. Because of this, only the most pertinent data from the three most proficient players will be presented in the body of this report.

2. Experimentation

2.1. **Experimental Set-Up.** All data for this research was collected in a small sound dampening quiet room. Inside dimensions measure $7'10" d \times 7'10" w \times 7'2" h$. The walls are sound-proofed such that the average noise attenuation is $38dB$ over the audible frequency range. The interior walls are covered with Sonex$_{TM}$ acoustical foam panels, and the floor is carpeted. All sound samples for this study were recorded using Brüel & Kjær audio research equipment (microphone, microphone preamplifier, and conditioning amplifier). The line level voltage from the conditioning amp is converted to a 16 bit digital signal sampled at 44.1 kHz. The frequency response of the microphone is flat to within 2 dB over the audible range, and the signal to noise ratio ranges from 75 dB to 95 dB over the test range. In all cases, measurement levels are above this noise floor.

The ten trumpets used in this study are lacquered Vincent Bach Stradivarious $B\flat$ trumpets, model 180, 37 bell, manufactured by Selmer Musical Instruments in 1998. These trumpets are constructed of gold brass, composed of 85% copper and 15% zinc. They are assumed identical except for the fact that half have been cryogenically treated. This process involves cooling the trumpets down to $-300°F(80K)$ over a period of about 8 hours, held at that temperature for another 10 hours, then brought back to room temperature over a period of 20 hours. All temperature changes occur linearly with respect to time. The process is dry, in that the cooling process occurs in a liquid nitrogen cooled evacuated dewar chamber, and no cooling fluid comes in contact with the samples.

2.2. **Experimental Procedure.** All data was collected in a double-blind fashion; neither the players nor the researchers were aware of whether the trumpet being tested at any given time had been treated or not. The players were instructed to first warm up each trumpet to standard playing conditions, which gave them the opportunity to develop an opinion regarding the tone and playability. During the warm up period they were allowed to play the instrument any way they wished. Their opinions of playability and tone rated on a scale from 1 to 10 were recorded. Any additional comments they had regarding their impressions of the instruments were also recorded.

For the audio data samples, the performers played only the open notes of the trumpets, that is, those that can be played without use of the valves. On a scale transposed for a $B\flat$ trumpet, the notes and their respective frequencies and wavelengths are presented in Table 1.

3. Steady-State Analysis

The sound produced by many musical instruments can be broken into two segments as a function of time. The first portion heard is the attack, or the start-up period of the tone. During this period, frequency content changes very rapidly. The second segment is the steady-state tone, where the frequency content is essentially

Note (transposed)	Fundamental Frequency (Hz)	Wavelength (m)
C4	233	1.50
G4	349	0.97
C5	466	0.73
E5	587	0.58
G5	698	0.49
C6	932	0.36

TABLE 1. Examined Notes, Frequencies, & Wavelengths

constant over time. These two periods of sound work together in providing aural information to the listener regarding the nature, position, and acoustic environment of the musical instrument. For this study, the middle 50% of the note played is considered the steady-state portion.

Power spectra is calculated via the Fast Fourier Transform (FFT) after the audio sample has been windowed via a Hanning Window. Power spectra are normalized by the total power found in the sample. In order to compare the steady-state spectra of the two groups of trumpets (i.e. cryogenically treated vs. untreated), all of the normalized spectra for individual notes as played by each player for the two groups of trumpets are averaged together. When presenting these spectra, error bars are also included. These error bars represent the 70% of those values within the sample set that are closest to the mean.

3.1. **Results.** Data collection for this research began with Player #2, an advanced amateur player and upper-classman at the New England Conservatory. Over the course of three recording sessions data was collected in different combinations of the following player-to-microphone orientations; on axis in the far-field, on axis in the near-field, and off axis in the near-field. The most noteworthy data from his playing is the $E5$ ($f_0 = 587\ Hz$) on axis in the near-field. Figure 1 shows the comparison of the untreated trumpets to the treated ones for the data recorded during the first session with this player. Note that 33% of the filtered data range bars do not intersect. More specifically, there is no overlap of data in the 11 - 13^{th} and 18 -21^{st} harmonics. The maximum deviation of the data range bars is about 2 dB, found at the 19^{th} harmonic. Although no other notes from this data collecting session yield data range bars that are independent of one another, many cases show mean values from one set lying outside the range bars of the other. This deviation appears to be a function of the note played, that is, the deviation is negligible at $C4$ (the lowest note investigated), increases to a maximum at $E5$ (nearly the middle of the range of the trumpet), then diminishes back to a negligible level at $C6$ (the highest note studied). Finally, when this player played the $E5$ on-axis in the far-field and off-axis in the near-field, this deviation between the two sets of trumpets all but disappears. These power spectra are presented in Figures 2 and 3. Note that the mean values for the upper harmonics are elevated for the treated trumpets, but the data range bars overlap significantly. Because the elevation of upper harmonics in the treated trumpets is most predominant for the $E5$ note in the near field, this case will be the focus for the remainder of our discussions.

Player #3, a part-time jazz performer and Tufts University music school graduate, was examined in both the near-field on axis and in the far-field. The power

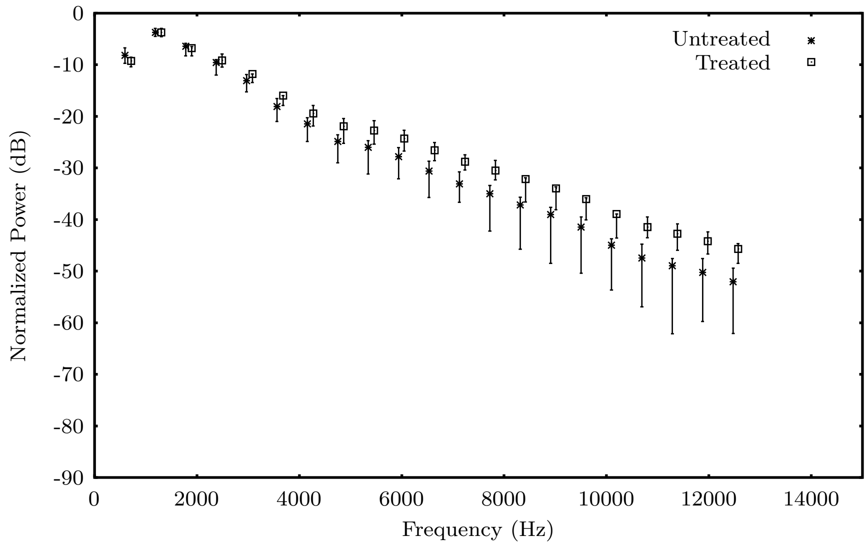

FIGURE 1. Player #2, On-Axis, Near-Field, E5, First Data Collection Session

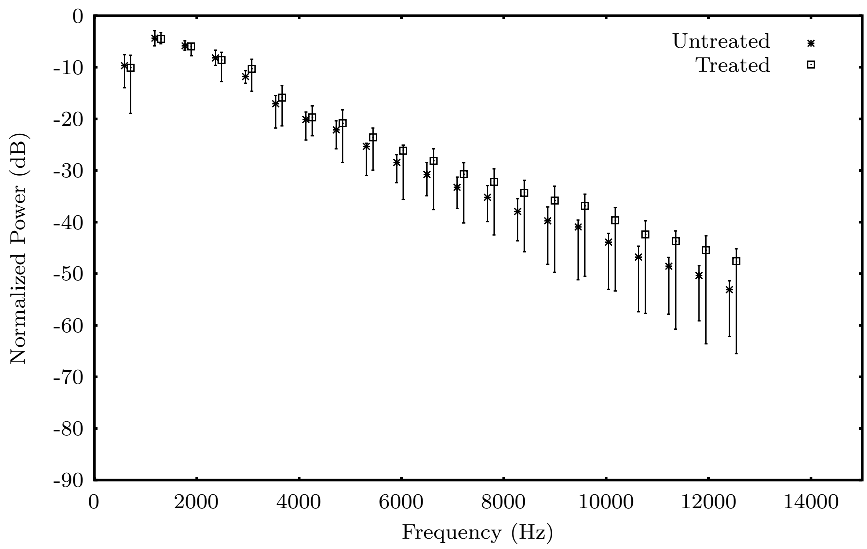

FIGURE 2. Player #2, On-Axis, Far-Field, E5

spectra from the $E5$ note in the near-field is presented in Figure 4. In this case, the mean values for the six highest harmonics of the untreated trumpets lay above the corresponding data ranges of the treated trumpets, yet the data ranges of the two groups of trumpets overlap considerably. As in the data of Player #2, the data

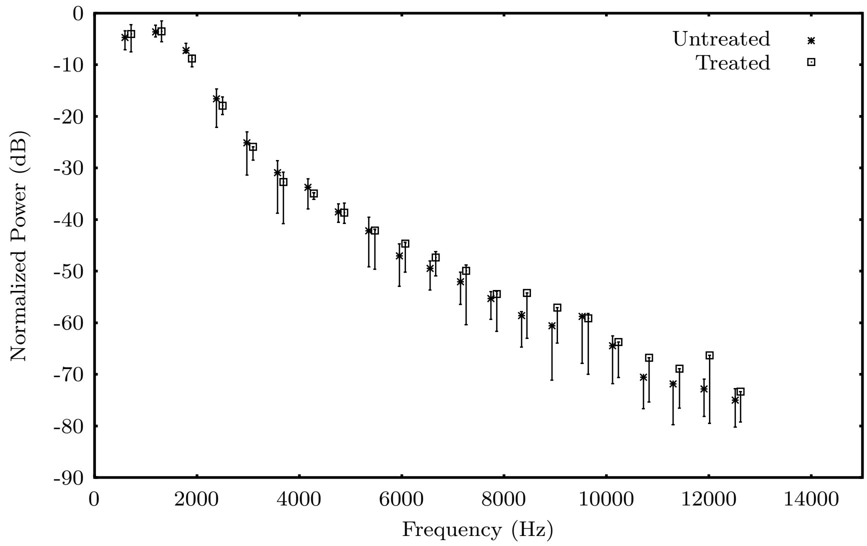

FIGURE 3. Player #2, Off-Axis, Near-Field, E5

from this note and player/microphone orientation produced the most significant deviation of the two groups. However, in the case of Player #3, it is the *untreated* trumpets that produce elevated upper harmonics on average.

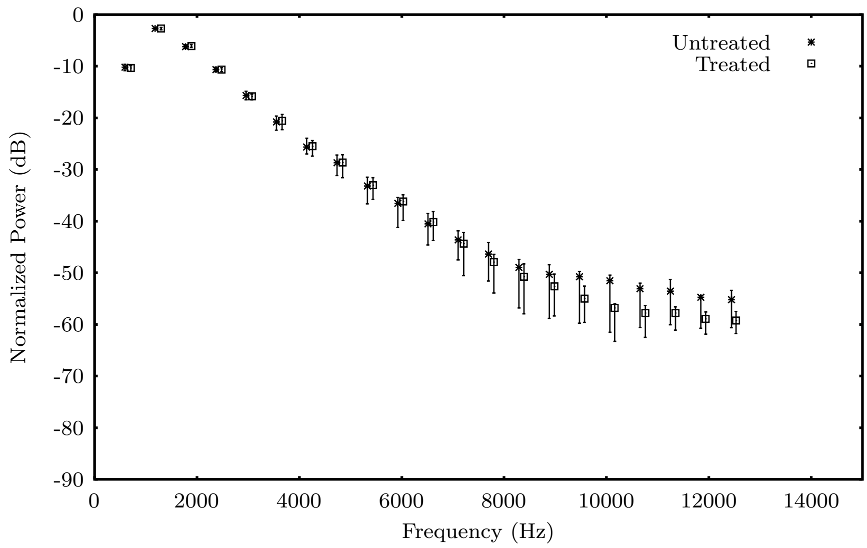

FIGURE 4. Player #3, On Axis, Near-Field, E5

Player #1, a professional classical performer, was examined on-axis in the near-field only. However, two discrete sets of data were collected. One recording involved him playing at a standard volume (*forte* or *f*), while the second session was devoted to him playing at an elevated volume (*fortissimo* or *ff*). Examination of Figures 5 and 6 reveals a slight elevation of the average values in the upper harmonics in the treated trumpets. Although the deviation is more pronounced in the *fortissimo* data set, the error bars overlap significantly in both cases.

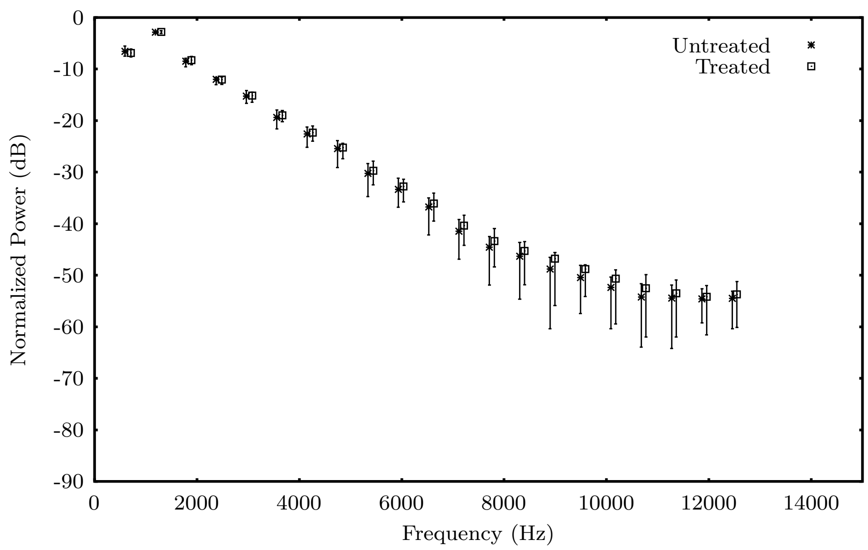

FIGURE 5. Player #1, On Axis, Near-Field, *forte*, E5

Data from the three less proficient players (not presented here) yielded similar results, in that no significant deviation between the two sets of trumpets was observed. Because only one set of data, that of Player #2 in the near-field, yielded significant deviation between the two groups of trumpets, the acquisition of that data was repeated. The comparative power spectra for $E5$ from this repeated data set is presented in Figure 7. As seen in this data, which was taken 8 months after the original set, little deviation exists between the two sets of trumpets, and the error bars overlap significantly.

Figure 8 compares the original data of Player #1 to the repeated data taken eight months later. These graphs represent the average power spectra of all the trumpets as played in the near-field, on-axis, for the note $E5$. It should be noted that the original data was taken during the summer, while this player was on break from his conservatory course work. The repeated data was taken near the end of the spring semester, when the player was in the midst of playing up to eight hours a day in classes and concerts. Although the difference between these spectra is not overly dramatic, the 12^{th} and 13^{th} harmonics do display statistic independence.

Finally, Figure 9 compares the averages of the three players playing all trumpets, $E5 forte$, on-axis in the near-field. Clearly, Player #2 produces much more power

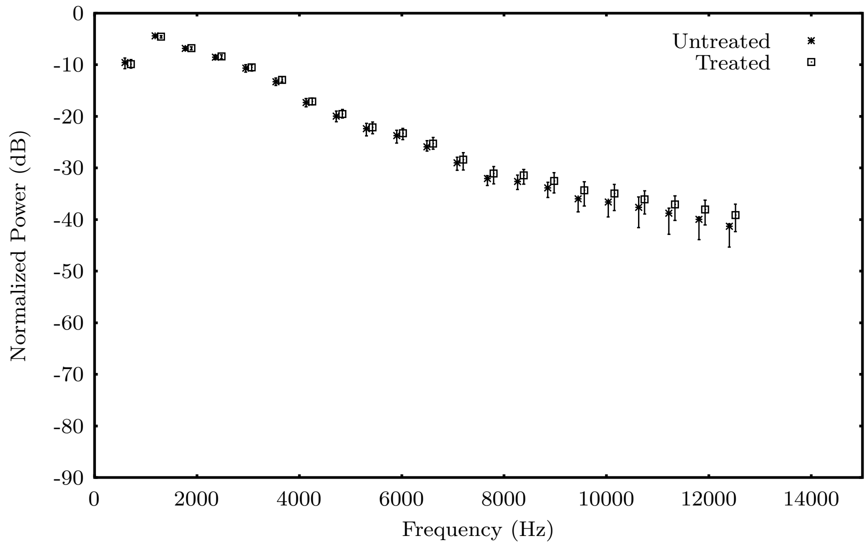

FIGURE 6. Player #1, On Axis, Near-Field, *fortissimo*, E5

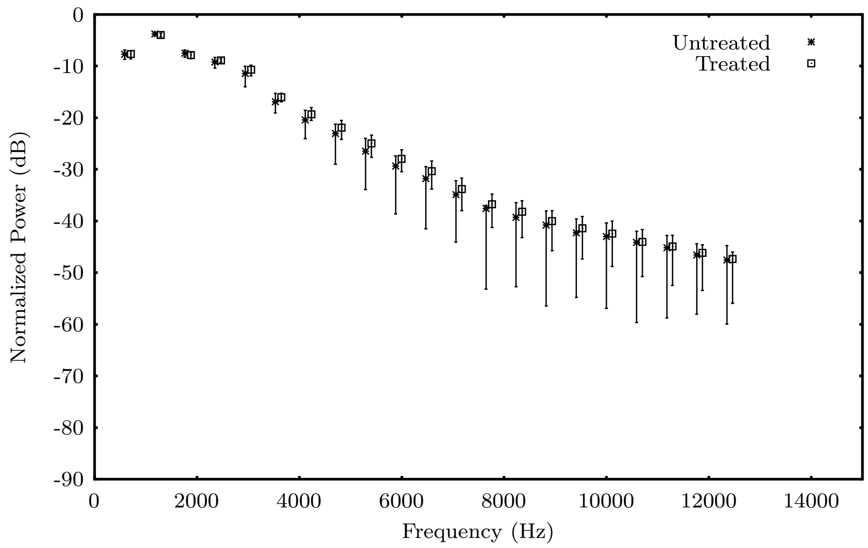

FIGURE 7. Player #2, On Axis, Near-Field, E5, Repeated Data

in the mid to upper overtones than the other two players, as the error bars for the 10th-16th harmonics show no overlap with either of the other players.

3.2. **Discussion.** In order to conclusively state that a difference exists between the cryogenically treated trumpets and their untreated counterparts (or any two sets

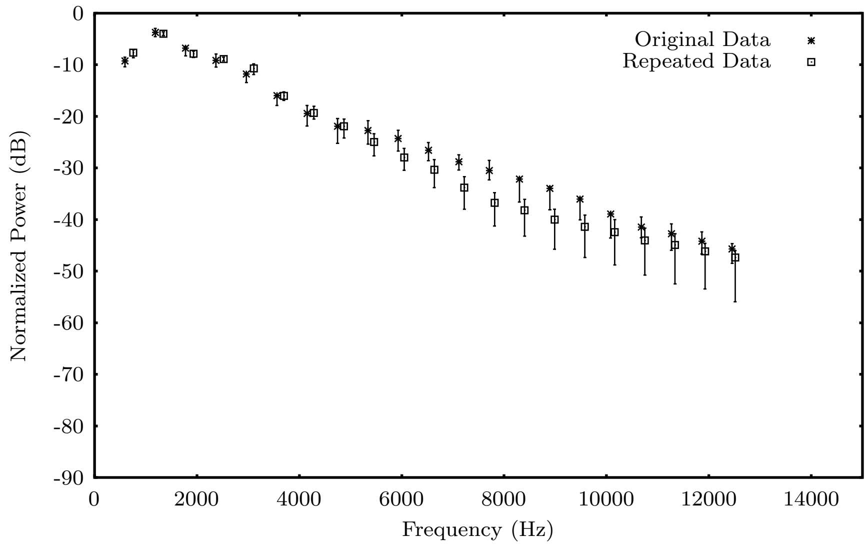

Figure 8. Players #2, Original vs. Repeated Data, On Axis, Near-Field, E5

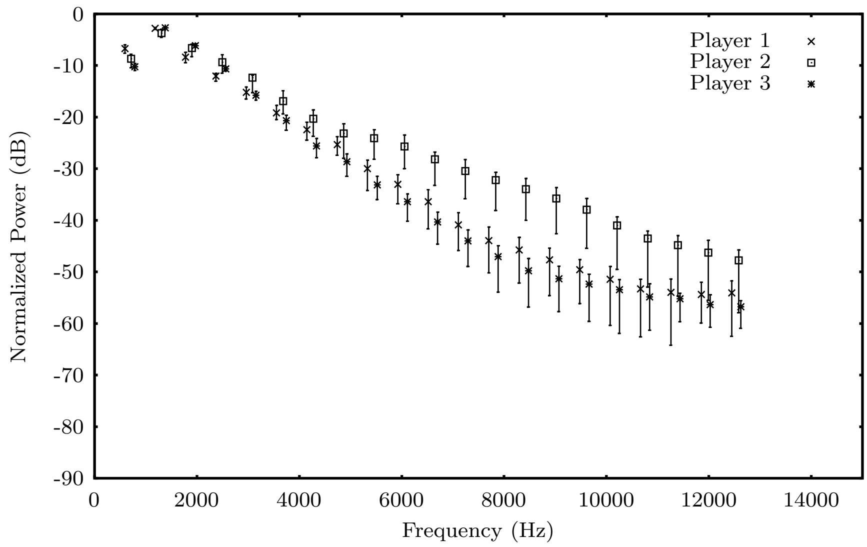

Figure 9. Players #1, #2, & #3, On Axis, Near-Field, E5

of data), the data must be statistically independent from one another. Specifically, we would need to observe power spectra comparing the two sets of trumpets with no overlapping error bars. With six players playing 6 notes in as many as three different player/microphone orientations, we have a total of 66 comparative power spectra to refer to. In fact, when comparing the cryogenically treated trumpets to the untreated trumpets, significant deviation is observed in only one case, that of Player #2 playing $E5$ on-axis in the near-field. Upon acquiring this data a second time eight months after the first session, this deviation proved to be unrepeatable. Further, if we were to disregard the error bars and simply judge the data by the mean values of the power spectra, the data contradicts itself. In the cases of Players #1 and #2, the treated trumpets have upper harmonics with greater powers. However, Player #3 produces a tone with decreased power in the upper harmonics when playing the treated trumpets. However, it can be concluded that differences in tone as seen in player-to-player comparisons can far outweigh any differences seen between the treated and untreated trumpets. This is shown in Figure 9, where Player #2 clearly has more power in the mid to upper harmonics than the other two players.

Perhaps more significantly, differences in harmonic content are apparent when comparing the repeated data of a single player, as seen in Figure 8. Presumably the only difference between the first and second sets of data for Player #2 is his level of preparedness. There is no doubt that he is a talented trumpet player, but in the second set of data he was much better rehearsed. This implies that simply practicing an instrument has more effect on tone than does the effect brought on by cryogenic treatment.

4. Transient Analysis

Much of the information the human ear uses to determine the source of a sound is found not only in the steady-state portion of that sound, but also (and perhaps more significantly) in how that sound develops as the tone transitions from start-up to steady-state. This initial portion of the sound is often referred to as the "attack". In order to quantify the attack of the sound samples examined in this study, the Short Time Fourier Transform (STFA) version of Joint Time Frequency Analysis (JTFA) was implemented. This analysis gives us insight into how the individual harmonics develop from the beginning of the note to steady-state. This is done by simply dividing the sample into small pieces in the time domain, taking the Fourier Transform of each of these pieces, then displaying the results of the Fourier Transforms sequentially, back in the time domain. Thus, we can see how the Fourier Transform evolves with respect to time. Because the case of the $E5$ note in the near field yielded the most significant results in the steady-state regime, this case will be the focus of this section. For the graphs in this section, the power for each harmonic at any given point in time is normalized by the mean power found in the steady state portion of that particular sample. When comparing two sets of trumpets, the values are expressed in decibels, with the untreated trumpets used as the reference. Thus, the untreated trumpets are considered the control group.

4.1. **Results.** Revisiting Player #2 playing $E5$ on-axis in the near-field, Figure 10 shows the development of the fundamental frequency (i.e. first harmonic) of all ten trumpets averaged together. This graph also includes the data range boundaries, which include the 70% of data points closest to the mean value, similar to the error bars in the steady-state analysis.

To more fully describe development of timbre over time in the attack period, the fundamental and four overtones in one octave steps is plotted. Figure 11 shows the

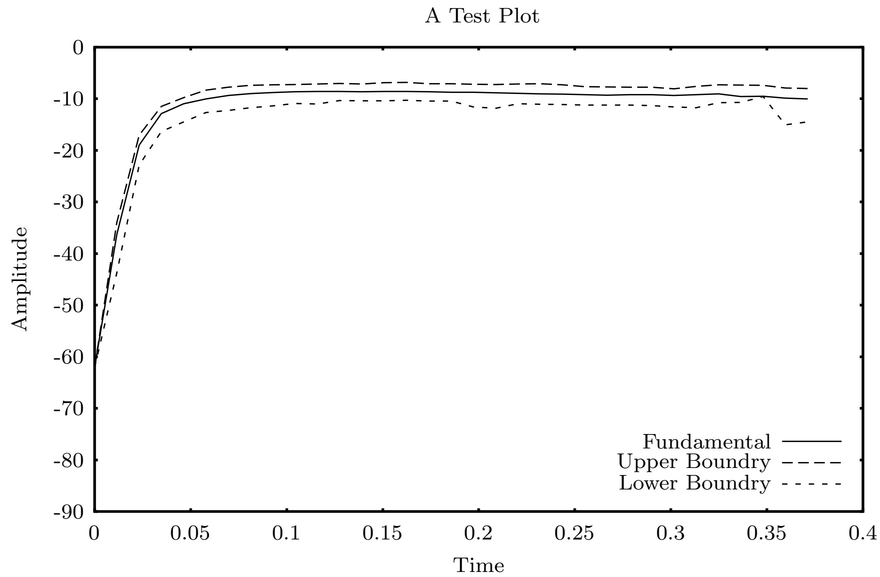

FIGURE 10. JTFA of Fundamental Frequency, Player #2 E5

development of the mean for each of these harmonics for all ten trumpets averaged together.

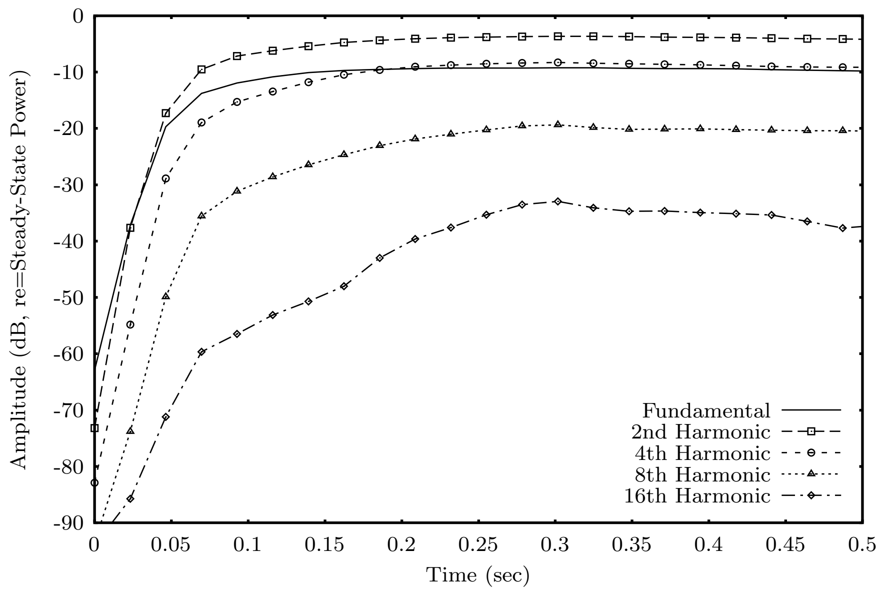

FIGURE 11. JTFA of Fundamental Frequency and Overtones in 1 Octave Steps, All 10 Trumpets

In order to compare the JTFA data for the two sets of trumpets, we can calculate the difference between the average power of each set in decibels for each point in time, using the mean power of the untreated trumpets as the reference value. Figure 12 shows this deviation for Player #2.

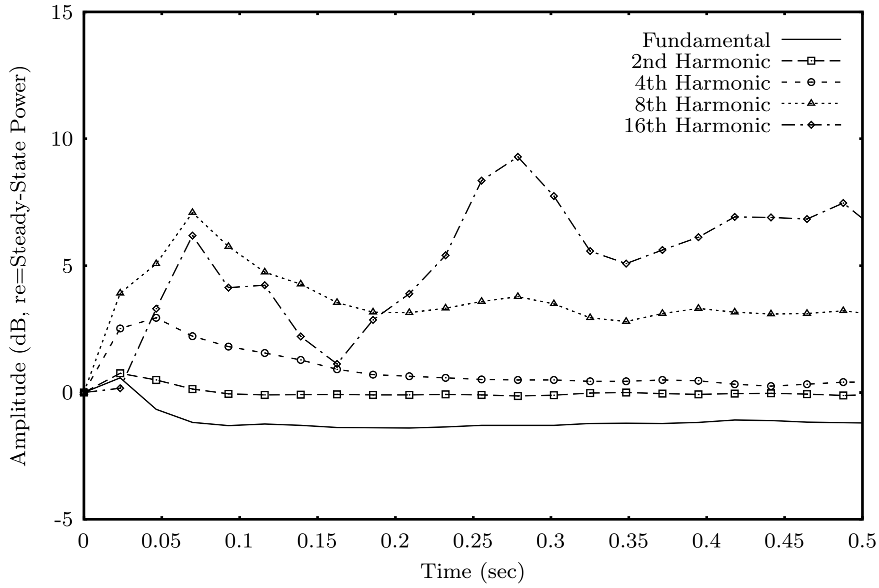

FIGURE 12. JTFA of Fundamental Frequency and Overtones in 1 Octave Steps, Treated vs. Untreated Trumpets

Note that this data correlates well with the steady-state data, in that the upper harmonics of the treated trumpets are elevated in the steady-state portion of the JTFA data for this player (i.e. after 0.3 seconds), with the fundamental being of slightly less power and the 2^{nd} harmonic having essentially equal power.

As was discussed in the steady-state section, deviations in harmonic power are not considered statistically independent unless the data range bars do not intersect. Similarly, the deviation between the error bands associated with the data from the two sets of data is calculated and expressed in decibels. More specifically, this is the deviation between the lower data range boundary of the harmonic with greater power versus the upper data range boundary of the same harmonic with lesser power. This comparison is presented in Figure 13. This analysis was executed for each set of data. As in the steady-state analysis, this set of parameters (Player #2, E5, on-axis in the near field) yielded the most significant results.

As is evident in Figure 13, the data range bands for the 16^{th} harmonic deviate from one another at only one point in time, with a magnitude of 1 dB. For the rest of the entire data sets (all other notes, players, player-microphone orientations, etc.), no deviation between the data range bands between the 2 sets of trumpets was found.

To illustrate that significant differences in attack can be observed between data sets displaying similarities in steady-state tone, Players #1 and #3 are compared in the same manner as Figure 13 in Figure 14, where the data of Player #1 is used as the reference. Reviewing Figure 9 shows that these players have very similar frequency spectra in the steady-state. However, much deviation exists in

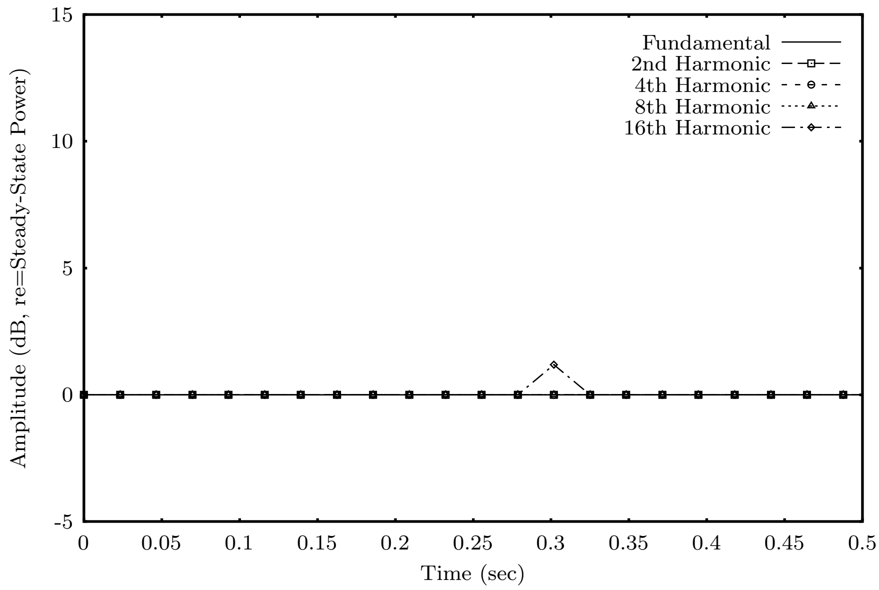

FIGURE 13. Ratio of Deviation of Data Bands for JTFA, Treated vs. Untreated Trumpets

the attack portion of their data. Specifically, data bands of the 8^{th} harmonic in the data of Player #3 deviate by as much as $7.5dB$ at $t = 0.08seconds$ while there is no deviation in the steady-state portion of the samples.

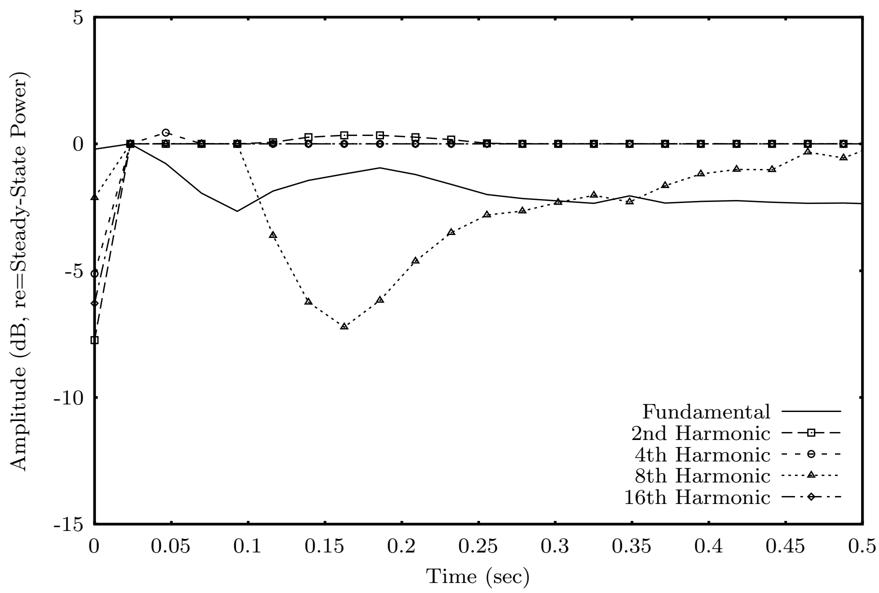

FIGURE 14. Ratio of Deviation of Data Bands for JTFA, Player #1 vs. Player #3

4.2. **Discussion.** When comparing treated and untreated trumpets from the same player, data collection session, and player-microphone orientation, no statistically independent results are seen (except for a single data point at one instant in time in a single case). Conversely, significant deviations are seen when different players are compared, and even when different data sets from the same person are compared. Although differences in the mean values of power in the temporal regime are clearly seen in many cases, these variations are overwhelmed by the scatter associated with the data.

A few conclusions can be drawn from this data. First, it may be possible that the cryogenic treatment does have an effect on the timbre and attack of the trumpets, as the large differences in the mean values of frequency content is seen in the time domain. However, the deviation of frequency content from trumpet-to-trumpet overwhelms any effect seen between the two sets of trumpets. Further, the deviation from player-to-player and even session-to-session for the same player also overshadows any effect seen due to the cryogenic treatment. Thus, it is the individual player, and even the current preparedness of the player, that has a greater effect than the cryogenic treatment on the timbre of the trumpets.

5. Conclusion

In many cases, the cryogenically treated trumpets display elevated upper harmonics when compared to their untreated counterparts. This deviation can be seen in both the steady-state and transient regions of the notes played. This could be correlated with the claims that the treatment results in a trumpet with a brighter tone. However, in the case of Player#3, the opposite is seen, with the untreated trumpets displaying stronger upper harmonics (and, presumably, a "darker" tone). In addition to this contradiction found in the data, virtually none of the data is conclusively statically independent. The scatter of data (i.e. variation from trumpet-to-trumpet) overshadows any difference seen between the treated and untreated trumpets. Further, variations seen between players and between sessions for the same player are also much greater than the variations found between the treated and untreated trumpets. Although it is possible that the cryogenic treatment does have an effect on the timbre of an instrument, the effect is subtle at best when compared to other determining factors.

References

[1] CryoPro, Inc. Cryogenic processing for brass musical instruments. Web Site, *http : //www.cryopro.com/cn_quote.htm*, quotes from Mark Curry and Ken Anstrum, 2000.

[2] Wayne Tanabe. The Brass Bow: Cryogenic resonance restoration. Web Site, *http : //www.thebrassbow.com/brassbw1.htm*, quotes from Brian Perry and Wolfgang Basch, 1998.

[3] Jeffery Krasner. In the name of science, Tufts students abuse musical instruments. *Wall Street Journal*, page NE 1, October 13, 1999.

[4] S. Adachi and M. Sato. Trumpet sound simulation using a two-dimentional lip model. *J. Acoust. Soc. Am.*, 99(2):1200–1209, 1996.

[5] R. D. Ayres. Two complex effective lengths for musical wind instrumets. *J. Acoust. Soc. Am.*, 98(1):81–87, 1995.

[6] F. C. Chen and G. Weinreich. Nature of the lip reed. *J. Acoust. Soc. Am.*, 99(2):1227–1233, 1996.

[7] D. C. Copley and W. J. Strong. A stroboscopic study of lip vibrations in a trombone. *J. Acoust. Soc. Am.*, 99(2):1219–1223, 1996.

[8] N. H. Fletcher and A. Tarnopolsky. Blowing pressure, power, and spectrum in trumpet playing. *J. Acoust. Soc. Am.*, 105(2):874–881, 1999.

[9] J. Gilbert and S. Ponthus. Artificial buzzing lips and brass instruments: Experimental results. *J. Acoust. Soc. Am.*, 104(3):1627–1632, 1998.

[10] A. Cocchi and L. Tronchin. Material and obsolescence on flute tone quality. *J. Acoust. Soc. Am.*, 103(5):2835, 1998.

[11] B. Lawson and W. Lawson. Acoustical characteristics of annealed French horn bell flares. *J. Acoust. Soc. Am.*, 77(5):1913–1916, 1985.

[12] R. W. Pyle Jr. Effective lengths of horns. *J. Acoust. Soc. Am.*, 57(6):1309–1317, 1975.

[13] R. W. Pyle Jr. The effect of lacquer and silver plating in horn tone. *Horn Call*, 57(2), 1981.

[14] R. W. Pyle Jr. How brass instruments are built: Art, craft, perhaps even science. *J. Acoust. Soc. Am.*, 1997. Conference Proceedings, 133rd ASA Meeting.

[15] R. W. Pyle Jr. The effect of wall materials on the timbre of brass instruments. *J. Acoust. Soc. Am.*, 1998. Conference Proceedings, 137th ASA Meeting,Revised version received through personal communication from the author.

[16] J. T. Lynch and J Blough. Cryogenic treatment of trumpets. Web Site, *http : //www.whc.net/rjones/jlynch/cryo/*, 2000.

[17] G. Hilliard and M. Kokaly. An investigation into the cryogenic treatment of brass trumpets. College of Engineering, University of Illinois, Urbana-Champaign, 1994.

Musical Instrument Engineering Program, Department of Mechanical Engineering, Tufts University, Somerville, Massachusetts, 02145, USA

E-mail address: `chip.jones@tufts.edu`