

Wolf Tones and Humidity in Violins—An Attempt of Quantitative Observation

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ABSTRACT

This paper attempts to, perhaps for the first time in this type of studies, quantitatively evaluate the severeness (as defined in this paper) of the undesired wolf tones on a violin as the surrounding humidity changes. The severity of the wolf tones was evaluated by a skilled violinist under various humidity conditions. It was found that a total duration and frequency of occurrence of wolf tones during a set period time are largest around 50% humidity, a humidity at which violins are recommended to be maintained for optimizing the projection across the entire register of the instrument, whereas other characteristics of the wolf tones, such as modulation index and the period, did not exhibit significant changes over the humidity change. When the humidity deviates from 50%, the total durations and the occurrence frequency of the wolf tones both diminishes. On the other hand, the amplitude (i.e. volume) of the wolf tones are larger on the lower humidity and the higher humidity ends, and was smallest around 50% humidity. These findings may shed new light on the traditional theories and analysis of wolf tones as well as on evaluations of various wolf tones elimination methodologies. It was also found that although the evaluation method involved some subjectivity, this way of evaluating the wolf tones had consistency and a good degree of reliability, paving a new way to quantify the wolf tones.

Introduction

Wolf tones are an uncontrollable wobbling sound that occurs on many bowed string instruments at a particular note and have tormented string players for centuries. The unpleasant and dissonant characteristics of the wolf tones not only destroy the otherwise beautiful musical phrases, but also give the performer unwanted anxiety when passages that involve them approach during a performance. As discussed below, there have been many scientific and pseudoscientific approaches to analyze the cause of the wolf tones and there are many empirical ways to eliminate the wolf tones. The cause of wolf tones has been investigated by impulse response type frequency response analysis as well as numerical simulations on the resonance frequencies of the instruments. Also, various devices and instrumental adjustments have been experimented to eliminate the wolf tones. Yet, there appears to be inconsistent ways of evaluating the degree or amount of wolf tones in both analyzing the cause of the wolf tones and evaluating the results of the wolf tone elimination devices. Sounds of string instruments, such as violins, in particular the quality, tone, and volume of sounds largely depend on skills of the performer, and so does the degree and severeness of the wolf tones. This paper first briefly reviews the existing significant publications and then moves onto explaining how the author came to believe evaluations of wolf tones in various humidity levels may be worth undertaking. The experimental procedures employed are then explained and the results are presented and analyzed.

Literature Review

The past studies on the nature of wolf tones have typically relied on methods that avoided the involvement of actual instrumentalists in an attempt to eliminate subjectivity, and had mostly aimed to provide a dynamic explanation of the phenomenon based on physics, with no mention of humidity as a potential factor.

Two of the earliest significant contributors to the study of wolf tones were G. W. White and C. V. Raman. White observed the motion of the front plate of the violin to conclude that the pulsing quality of wolf tones and the periodic fluctuation in intensity are caused by beatings of two close frequencies produced when the frequency of the vibration impressed on the instrument body approaches the body's resonance frequency (White 1915, cited in Raman 1916). Raman disagreed with White, pointing out that such beatings would be too brief and insignificant to account for the persistent fluctuation of intensity seen in wolf tones. After recording the motion of both the front plate and the string, Raman instead theorized that wolf tones occur when a string alternates between the fundamental pitch and its octave overtone due to the over-resonance of the instrument body (Raman 1916). J. C. Schelleng took the investigation to the field of electrical engineering by modeling the components of the cello as "resonant transmission line (the string) coupled through a transformer (the bridge) to a series resonant circuit (the body)", as described by Ian Firth and J. Michael Buchanan (Schelleng 1963, cited in Firth et al. 1973). According to Jeffery Showell, German scientist Walter Vollmer has done a similar study using coupled vacuum tube circuits as well as the actual instruments (Showell 2004), and remarkably, Schelleng and Vollmer had individually come to a conclusion that the wolf tone is a result of the over-resonance of the instrument body, causing the fundamental to split into two close frequencies that creates a beating. This view has also been confirmed by Firth and Buchanan, by means of holographic studies (Firth 1974) and frequency analysis both by scientific methods as well as by ear. Today, it appears that this theory on the cause of the wolf tones has been widely accepted. That is, when the player tries to play a note with a frequency f , the pitch splits into two frequencies, f_1 and f_2 , deviating from the original pitch in different directions. The presence of these two frequencies causes a beat note with a frequency of $(|f_1 - f_2|)$; this beat note is the undesirable wolf tone.

On the other hand, with respect to possible means for eliminating wolf tones, the investigation on the cause of wolf tones naturally allows researchers and luthiers to suggest or discover various ways to mitigate wolf tones. For example, Jeffery Showell and Carolyn Wilson Field had both discussed the idea of putting a weight between the bridge and the tail piece to dampen the vibration coupled to the instrument body, thereby mitigating if not preventing the wolf tone. This approach seems plausible in theory since damping the vibration in the instrument body would alleviate the over-resonance and the consequent split of the fundamental pitch. In fact, most modern wolf-tone eliminators use similar mechanisms to alleviate the wolf (McKean 2009). However, there is a caveat discussed by both Showell and Field: the damping of the instrument body naturally dampens the instrument sound throughout its entire register, diminishing its sound quality and potentially even its playability. This is a serious issue for musicians; as a cellist herself, Field predicts that most string players would be unwilling to sacrifice their sound quality for the elimination of wolf, and that they would rather use other empirical techniques on their unadjusted instruments to mitigate the effect of wolf tones. In recent years engineers have tried to improve the wolf eliminators into effectively suppressing the wolf tone while maintaining the sound quality of the instrument, but they may be far from being the ideal solution to wolf tones.

The search for the ideal way to handle wolf tones is not a journey exclusive to scientists. String players and luthiers have empirically found ways to mitigate wolf tones. Renowned violinmaker James McKean points out that using strings with lower tension could help alleviate the wolf tone (McKean 2009). Instability of wolf tones, their spontaneous appearance and disappearance, was also documented by Carolyn Hagler, a professional cellist (Hagler 2022). However, these papers did not appreciate or recognize the quantitative impact of humidity on instrument sound and ultimately the severeness of wolf tones. Elizabeth Marshall, a professional cellist that has performed in international venues, notes that the condition and placement of the bridge and soundpost could

also have an impact (Marshall 2020, October 26). Elizabeth Marshall, in another article, states that the ideal humidity range for string instruments are near 50%, ranging from 40-60%. She acknowledges humidity as a very important aspect of getting good sound quality (Marshall 2020, October 19); however, Marshall and the others mentioned above fell short of considering humidity as a potential factor affecting wolf tones. Over a century has passed since the preliminary studies done by White and Raman, and it seems that there has not been a single scientific study made on the correlation between the severity of wolf tones and the ambient humidity level.

Experiment

Setup and Procedure

The author lives in Northern California where the humidity is quite constantly near 50%. When the author traveled to Westport, NY to attend Meadowmount School of Music, a summer camp for young string instrument players, in the summer of 2023, the violin that had pronounced wolf tones near a high B tone on the G string stopped producing the wolf tones a few days after the arrival. The humidity in Westport, NY when the author was there was constantly about 65% to 80% due to unusually frequent rainfalls in that summer. This experience prompted the author to design experiments, after coming back to California from New York, that can determine the effects of the humidity on the wolf tones on the violin.

To understand the impact of humidity on wolf tones, various characteristics of wolf tones were measured as the surrounding humidity was changed. In order to set the surrounding humidity, one or two humidifiers (Humidifier 6L Ease Allergy: Breathe Free® by Everlasting Comfort) were placed inside a room of a size: 8.5'W x 10'L x 8'H to increase and stabilize the humidity of the room beyond the ambient humidity, which was typically 50% in Cupertino, CA. The humidifiers were set at a specific intensity level and the door of the room was closed or opened to a certain degree so as to create an environment with a target humidity level. Two home-use humidity monitoring devices (which was AcuRite Indoor Temperature and Humidity Monitor® by AcuRite) were used in recording the humidity inside the room. The violin used for the experiment was obtained at a local violin shop where the author tried several tens of violins to see which one of the violins produced wolf tones relatively easily. The subject violin was placed inside the room for approximately 24 hours to get acclimated to the humidity set in the room. The monitoring devices were checked approximately every two hours to ensure that the humidity in the room remained fairly consistent while the violin underwent acclimation. Then, after about 24 hours of the acclimation, the author, who is a violinist with over ten years of experience, played the violin and made his best effort to produce a wolf tone from instrument while recording the sound for a two-minute interval on Logic Pro X via the internal microphone on MacBook Pro. The microphone was positioned two feet from the violin. This procedure was repeated every 24 hours with the humidity level being varied by changing the intensity of the humidifier device as well as the extent to which the door to the room was opened. For each measurement, the respective positions of the microphone and the player in the room were kept constant.

The experimental setup described above only allowed humidity levels greater than or equal to the natural humidity level in the author's home in Cupertino CA, which was typically just below 50%. In order to create conditions drier than 50%, the violin was put inside a transparent garbage bag together with an appropriate amount of a drying agent (DampRid® by W.M. Barr) to absorb excess moisture so that the violin was acclimated to a drier environment. As before, the violin was allowed 24 hours to adjust to the humidity level inside the bag. The same humidity monitor described above was also put in the bag to monitor the hu-

midity level. Then in order to measure the wolf tones, the violin was taken out from the bag and quickly transferred to the same room used in the above-described experimental setup, and the same process of recording the wolf tones was performed within approximately five minutes after the violin was removed from the bag.

Method of Qualitative Observations

In order to establish what parts of the recordings were considered wolf tones, the waveforms were digitally sampled on Logic Pro X. The waveforms of wolf tones had a rapid and cyclic intensity fluctuation as compared to other parts of the waveform (Figure 1). The wolf tones typically occurred around B-flat or B on the G string for the violin used in the experiment.

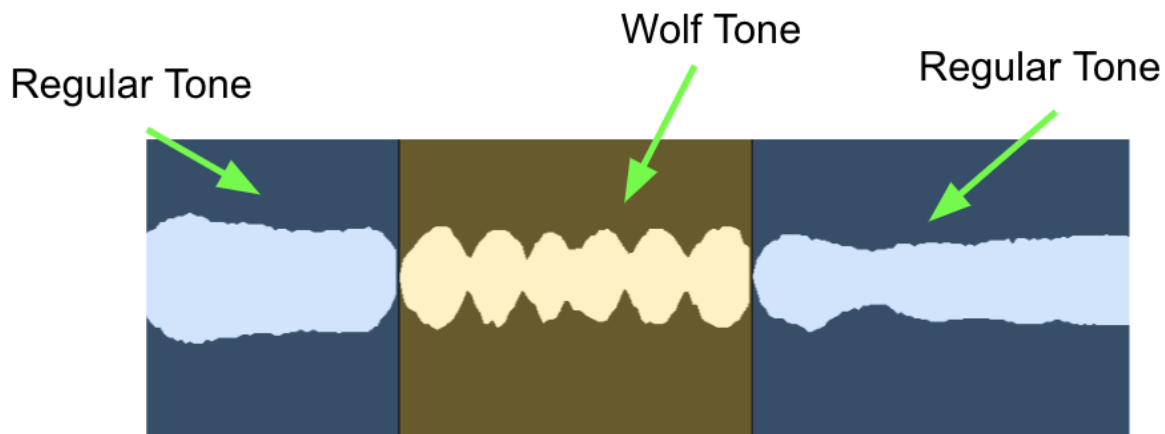


Figure 1. Portions of the amplitude output waveform of the violin sound recorded on Logic Pro X illustrating wolf tones and regular tones.

Each recording in its entirety were visibly and auditorily judged by the author upon identifying which portions were to be considered wolf tones. Portions were classified as wolf tones if they satisfied two criteria:

1. The captured waveform displayed three or more periods of consistent and rapid intensity fluctuation on the waveform
2. The recording was audibly classified as a consistent wolf tone by the author. A typical wolf tone segment sounds like this.

Audio segments which satisfied the criteria above were isolated for qualitative observations. Portions of the recordings that lacked any of these qualities were not included in the collection of qualitative data. Many portions (roughly about a third of the recognized candidates for wolf tones) had a waveform that looked like a wolf tone but lacked consistency or wolf-tone-like quality in the sound, or were audibly classified as a wolf tone by the author but did not have enough consistency in the waveform for it to be used in the qualitative observation. See Figure 2 for examples.

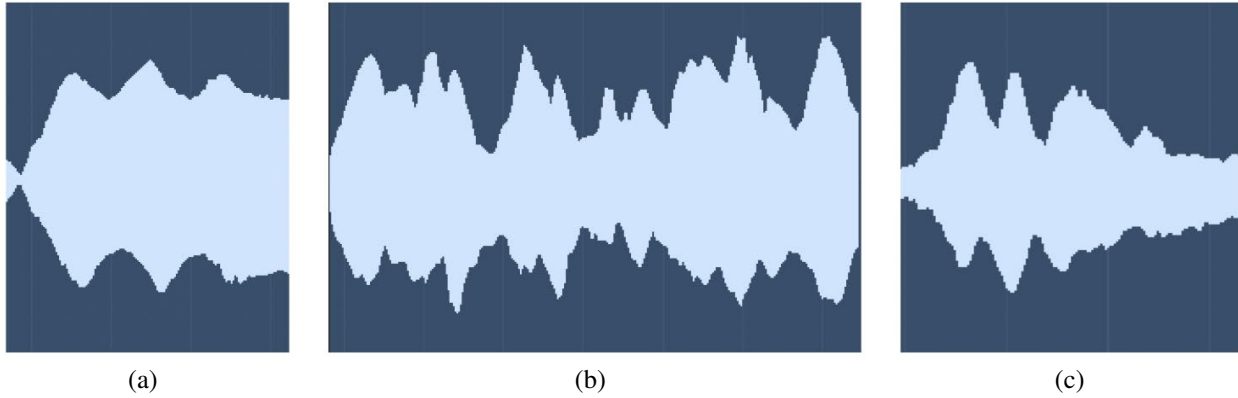


Figure 2. Examples of portions of the anomalies that failed to classify as wolf tones. (a) The waveform displayed characteristics of a wolf tone but it was not auditorily classified as a wolf tone. (b) It sounded like a wolf tone but the waveform did not show any consistency or cyclic nature. (c) It sounded like a wolf tone at the start but the sound cracked near the end of the portion. In the waveform, the third cycle of intensity fluctuation was not consistent with the first two cycles.

In other words, in this paper, wolf tones are defined as uncontrollable consistent periodic oscillations. These determinations obviously required some degree of subjective judgements on the part of the author; however, the author made his best effort to classify them as consistently as possible throughout the data points obtained at the different humidity levels.

Method of Quantitative Observations

The severity of wolf tones were assessed based on the degree by which the pitch and the amplitude deviated from the intended dynamics and intonation, as well as how easy it was to produce wolf tones. Specifically, as a means to measure the “severity”, the period of wolf tones, the ratio between the maximum and average amplitudes of the intensity fluctuation, and the number of occurrences and duration of wolf tones in a set two-minute period were measured from the recorded audio samples. Since wolf tones are beatings produced by vibrations of two close frequencies, the frequency of the beating note and the intensity fluctuation of a wolf tone are the difference of the two frequencies produced upon playing. This means that the higher the frequency of the beat note, the more separate the two frequencies are, indicating larger pitch drift. In turn, the smaller the period (the inverse of frequency) of the intensity fluctuation in wolf tones, the more severe a wolf tone is thought to be. The ratio between the maximum amplitude and the average amplitude can be thought as a quantity analogous to the modulation index, which is a numerical value that evaluates the degree to which the intensity fluctuates with respect to the unmodulated carrier in the radio wave amplitude modulation (AM), and is referred to as “Modulation Index” in this paper.

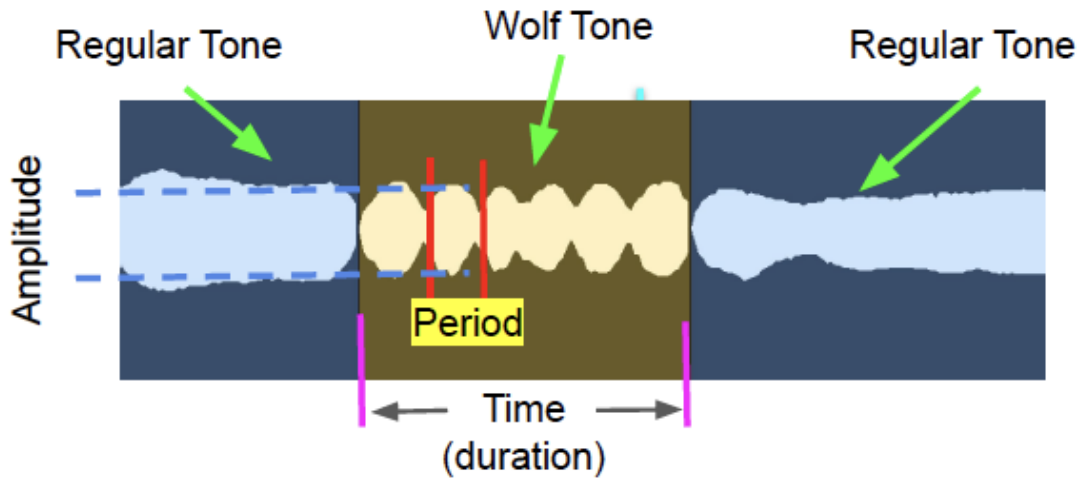


Figure 3. Portions of the amplitude output waveform of the played violin sound on Logic Pro X illustrating wolf tones and regular tones. The center shows a wolf tone. The figures also indicate various parameters that were evaluated: averaged period, time(duration), and amplitude are shown.

Results and Discussions

For each of the two-minute measurement of wolf tones at various humidity levels, which ranged from 16% to 87%, the averaged period of wolf tones, the total duration (time) of wolf tones, the occurrence (number) of wolf tones, the averaged amplitudes of wolf tones, and modulation index as defined as maximum amplitude divided by average amplitude were evaluated. The results are shown in Figures 4-6 below.

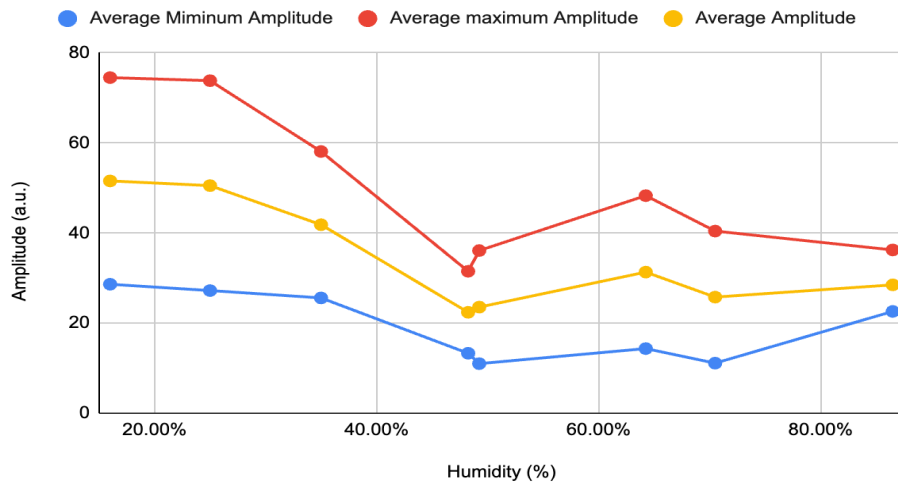


Figure 4. Wolf tone amplitudes versus Humidity. For each of the two-minute measurements, each wolf tone's maximum and minimum amplitudes were measured from the Logic Pro X's amplitude output, and averaged over the wolf tones in the two-minute period, to produce the plotted averaged maximum, minimum and average amplitudes.

As shown in Figure 4, the average amplitudes showed peculiar structures as a function of humidity. Interestingly, the amplitudes of the wolf tones (loudness) were smallest near 50% humidity, and the drier the environments were, the louder the wolf tones were. The amplitudes also increased as the humidity increased above 50%, but the change was marginal compared to the increase observed as the humidity decreased below 50%.

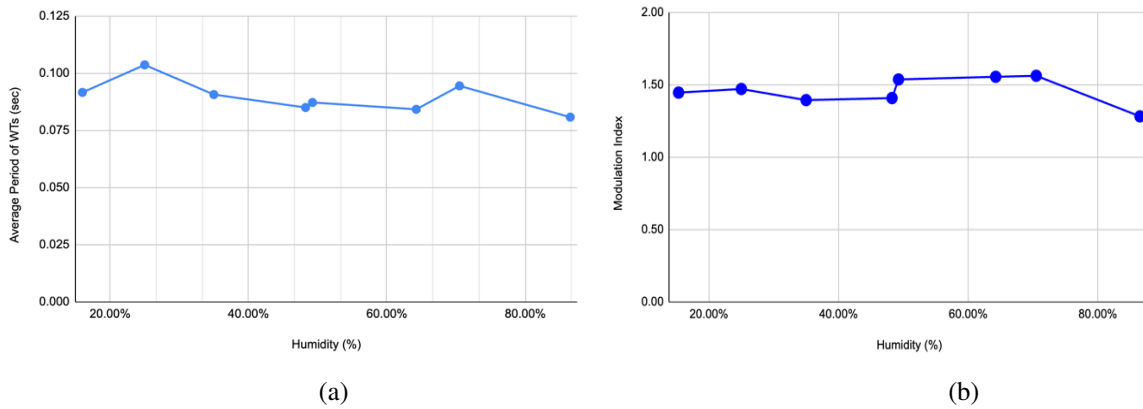


Figure 5. (a) Average period of the wolf tones versus humidity. (b) Average modulation index, which was defined in this paper as maximum amplitude divided by the average amplitude of each wolf tone segment averaged over the two-minute measurement window. See Figure 6 for the graph of maximum, minimum, and average amplitudes versus humidity.

As indicated in Figure 5, both average period of the wolf tones and the modulation index were found to be fairly constant as humidity was varied. This indicates that the deviation in both the split pitches in the wolf tone as well as the intensity fluctuations relative to the unmodulated carrier were unaffected by change in humidity.

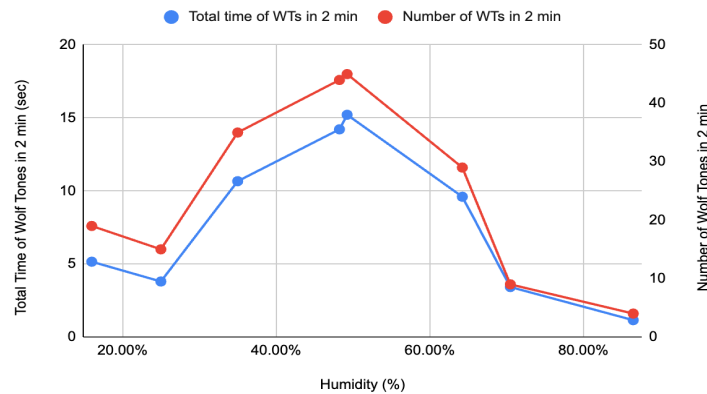


Figure 6. Total time of wolf tones and number of wolf tones in respective two-minute measurement windows, with respect to humidity.

Conversely, as shown in Figure 6, the total time of wolf tones and the numbers of wolf tones showed clear structures as a function of humidity, with both quantities peaking at around 50% humidity and disappearing at high humidity. Considering the fact that 40-60% is the optimum humidity for string instruments, this

means that, at the humidity level where the instruments have the best sound quality (Marshall 2020, October 19), the instruments are also most susceptible to wolf tones, encountering longer wolf tones more frequently.

Ultimately, the quantitative data collected indicates that ambient humidity is a huge factor affecting the presence of wolf tones. Near 50% humidity, the wolf tone would be fairly soft but the most persistent, and this will change as humidity increases or decreases away from 50%. In a dryer environment, the wolf tone would be less persistent but louder in volume, while in a more humid environment, the wolf tone would rarely appear, and when it does, would have a relatively soft volume.

Knowing that humidity can significantly impact wolf tones, future studies on the nature of wolf tones may incorporate humidity into their experiments to see what findings it may lead to. For example, a study may compare the effectiveness of different types of wolf eliminators at different humidities.

However, the experimental results do not allow for a definitive conclusion on how humidity could be used to mitigate wolf tones in the future. One may conclude that the ideal humidity for best mitigating wolf tones is 80% or above, since the total duration and the occurrences of wolf tones would be close to zero and the average amplitudes would be relatively low, but such a high ambient humidity would ruin the sound quality of the instrument as a whole, rendering it an unfavorable solution. Ultimately, when attempting to use humidity to mitigate wolf tones, musicians must find a compromise between having low susceptibility to wolf tones and having a good sound quality, as the two qualities is predicted to be incompatible throughout all range of humidities.

Also note that all the graphs above had two measurement points near 50% humidity, each taken on a separate day, and that their response variable values were fairly similar. Despite some subjective procedures of this experiment which partially relied on the judgment and skills of the player, the consistency in these pairs of measurement points and the clear structure seen in each graph shows that the data collected are adequately reliable, and that this way of evaluating wolf tones based on individual judgment could be expanded upon in future investigations. For example, a future study may gather several professional string players and have them follow the same procedures in parallel as part of their experimental method.

Conclusions

The period of wolf tones, the ratio between the maximum and average amplitudes of the intensity fluctuation, and the number of occurrences and duration of wolf tones in a set two-minute period were measured from the recorded audio samples to assess the severity of the wolf tones. The wolf tone was both generated and classified with reasonable consistency. It was found that a total duration and frequency of occurrence of wolf tones during a set period time are largest around 50% humidity, a humidity at which violins are recommended to be maintained. When the humidity deviates from 50%, the total durations and the occurrence frequency of the wolf tones both diminishes. On the other hand, the amplitude (i.e. volume) of the wolf tones are larger on the lower humidity and the higher humidity ends, and was relatively smallest around 50% humidity. These findings shed new light on the traditional theories and analysis of wolf tones as well as on evaluations of various wolf tone elimination methodologies.

Limitations

As described above, there were some limitations to this experiment such as manually determining the presence of a wolf tone. In future work, more rigorous methods of wolf tone classification could be contemplated. For example:

- Perform FFT (fast Fourier transform) of the recorded waveform data. This would show not only the beat note ($|f_1 - f_2|$), but also the two high frequencies (f_1 and f_2) which may be further analyzed.

- Wolf tone classification was done manually which inherently has human error. It may be interesting to see how equally experienced violinists will evaluate the presence or absence of wolf tones. For example, such violinists can be asked to perform the same violin playing and recording sessions and identify wolf tones from the recorded waveforms, and the respective results can be compared. This would further evaluate the reliability and reproducibility of the procedures utilized in this paper and reduce bias.
- Wolf tone generation was done manually by the author's best effort. But in a sense, this procedure more accurately reflects reality as violins are played by humans, not robots or machines. Also, the author experienced that a tiny change in the pressure of the left hand finger pressing the G string and bowing speed and pressure as well as the position of the bow's contact point (close to the bridge or father away) can significantly affect the wolf tone's sound and volume. This in turn means that subjective elements are large, but also mechanical setups, such as robot fingers and robot bowing arm may not be adequate or even realistic either. As described above, having multiple professional violinists perform the above procedures and evaluating the variations in the results would be an interesting next step.
- Control variables, such as the amount of rosin on the bow, may have changed over the course of eight days in which the experiment was conducted. This is another element difficult to control. Yet, the reality is that normal violinists would not know exactly how much rosin is on their bows. They usually go with their feel and how the violin reacts. So, again having multiple violinists make the same effort under the same conditions as much as possible at their best effort, and evaluating the variations on their results would provide useful information.
- As described above, the lower humidity data points were taken in a room with an approximate humidity of 50% because the author could not create lower constant humidity levels in a controlled manner. Further, the humidity was controlled by the rather crude way, using domestic-use humidifiers and adjusting the degree of the opening of the door to the room. More controlled experimental lab setup would certainly increase the experimental accuracy with regard to the humidity control.

Acknowledgments

The author would like to thank Henry Love for his mentorship throughout the research and writing process and Masao Yoshimura for assisting the monitoring of humidity levels, collection of data, and revision process.

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