Comparing Overtone Intensity Between Electric and Acoustic Guitars

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1: Abstract

Despite similarities in their overall structure, electric and acoustic guitars produce markedly different sounds due to the distinct mechanisms through which each instrument generates and projects sound. These sonic differences are immediately apparent to listeners and arise primarily from variations in the instruments' overtone profiles. Overtones shape the character of a sound beyond its fundamental frequency, making both their relative magnitudes and the specific frequencies at which they occur critical for distinguishing between instruments. Because of this, determining which instrument—electric guitar or acoustic guitar—produces the most diverse and intense overtones was the aim of this experiment. To investigate these overtone patterns, the same two notes—A440 and E330—were played on both instruments, with careful control over playing technique and room environments to minimize variability unrelated to instrument type. The resulting sound waves were analyzed using the Fast Fourier Transform (FFT) to produce power spectra, allowing for the identification and quantification of overtone components. To account for differences in overall volume, overtone magnitudes were normalized by expressing them as ratios relative to the fundamental frequency. The analysis revealed that electric guitars exhibit a richer and more complex overtone structure than acoustic guitars, contributing to their distinctive and layered timbre.

2: Introduction

The acoustic and electric guitar have become cornerstones of modern music, each offering distinct tonal characteristics due to their differences in sound production and physical construction. While the acoustic guitar projects sound through its hollow body, the electric guitar relies on electromagnetic pickups and amplification. This distinction raises questions about the underlying physical and perceptual mechanisms that contribute to each instrument's unique timbre. We chose to investigate this topic not only out of personal curiosity as musicians, but also due to the lack of conclusive research quantifying how constructional and material differences affect perceived sound. Understanding these differences is useful for luthiers, manufacturers, and audio engineers aiming to design instruments with tailored sonic properties.

Recent research has shown that the top plate and brace construction of an acoustic guitar have a profound influence on its vibrational modes and resonant behavior (Rau and Hoover). These structural factors directly impact how energy is transferred from the strings to the body, thereby shaping the overtone spectrum and overall tonal quality. Similarly, although electric guitars lack a resonant soundbox, their tone is not entirely independent of body material. A study by Jasiński et al. demonstrated that different tonewoods produce distinguishable differences in the spectral envelope and energy output of electric guitars, even when using the same hardware and pickups (JASIŃSKI et al.). This challenges the common belief that electric guitars are immune to the acoustic effects of construction materials.

Moreover, the harmonic content of guitar signals plays a key role in the perception of brightness and other timbral features. Tsumoto et al. explored how harmonic overtones interact with a psychoacoustic metric known as "sharpness" to influence perceived brightness in distorted electric guitar timbres (Tsumoto et al.). Their findings reveal a suppression effect, where excessive overtones paradoxically reduce the listener's perception of brightness. These results align with the work of Gualandri, who analyzed harmonic distributions in an acoustic guitar and confirmed that plucking position and body resonance influence overtone distribution—a finding we extend by standardizing plucking and listening conditions across both guitar types (Gualandri).

Complementing these structural and psychoacoustic studies, Alm and Walker emphasize the role of time-frequency analysis in distinguishing instrument sounds. Their work highlights how tools like Fourier transforms, spectrograms, and scalograms provide powerful visualizations—time-frequency portraits—that closely align with our auditory perception of musical timbre (Alm and Walker). While Fourier analysis has long been used to identify overtones and fundamentals, Alm and Walker show that spectrograms and scalograms add further insight by capturing the evolution of these features over time and distinguishing nuanced characteristics like attack and decay. These portraits not only reinforce the importance of harmonic structure but also underscore the richness of detail that overtone analysis can reveal.

Taken together, the existing literature lays a solid foundation for understanding the acoustics of guitar sound production, yet a direct, empirical comparison of overtone structures between acoustic and electric guitars remains underexplored. Our work builds on these studies by applying high-resolution spectral analysis techniques—rooted in the time-frequency framework described by Alm and Walker—to capture and compare the overtone profiles of both instruments under controlled conditions. By doing so, we aim to provide a clear, quantitative basis for understanding the sonic distinctions between these two iconic instruments.

3: Experimental Methods and Calibration

3.1 Calibration of Microphone

The data acquisition sensor, a Dayton Audio iMM6 microphone, required calibration to yield accurate measurements. Using sensor-specific information available on the Dayton Audio Calibration Website, the microphone was calibrated through the following process:

$$x = 39.4 \qquad \text{Find Microphone-Specific Calibration Parameter } \left(\frac{V}{Pa}\right) \tag{1}$$

$$\text{sens} = 10^{\frac{39.4}{20}} \qquad \text{Find Microphone Sensitivity in Reference to } \log_{10} \tag{2}$$

$$\text{pres} = \frac{V}{\text{sens}} \qquad \text{Find Pressure from Voltage Data Using Sensitivity} \tag{3}$$

This process converts the voltage signal acquired from the microphone into pressure data, which is more suitable for reporting acoustical measurements. From pressure, sound levels can be expressed in decibels using:

$$\text{dB}_{\text{SPL}} = 20 \cdot \log_{10}\left(\frac{\text{pres}}{20 \cdot 10^{-6}\ Pa}\right)$$

Alternatively, power spectra of the sound waves can be reported in appropriate units of Pa^2. The latter method is used in this analysis to report and compare the intensity of overtones.

3.2 Experimental Procedure

To begin the experiment, a MATLAB script was written to facilitate data acquisition. The script was designed to sample at a rate of 51.2 kHz, a frequency high enough to capture the harmonic content of guitar notes and that is also usable by the data acquisition system. Each trial recorded three seconds of audio to ensure a sufficient capture window for analyzing both the attack and decay of the note—crucial phases for evaluating overtone content. The data acquisition system used was a National Instruments 9234 cDAQ block that itself was attached to a National Instruments 9174 cDAQ chassis and power source. The NI9234 acquired an analog voltage reading from the microphone, and using the calibration method described earlier, was converted to a pressure reading.

Before running formal tests, a baseline validation of the setup was conducted. A casual speaking voice was recorded from one meter away from the microphone. This sample was then played back to verify that the recorded dB levels were in the expected range of 60–70 dB, confirming the microphone's calibration and ambient recording conditions. In addition, background noise levels were quantitatively assessed prior to each trial to ensure that ambient noise remained negligible. Decibel levels of the room were consistently measured to be below 35 dB, much lower than that of the guitar.

The physical experimental setup was then constructed. A distance of one foot from the microphone was carefully measured and marked with tape. This location served as the consistent sound source position across all tests. For the acoustic guitar, the body of the guitar was placed at the mark, as it functions as the resonant source. For the electric guitar, the amplifier was positioned at the marked spot, since the speaker is the primary emitter of sound.

In accordance with the findings of Gualandri, many physical controls were put into place to mitigate any potential disturbances to the pure tone of the note being studied. This included muting all other strings by taping them, staying consistent with the location of the fretting hand and how the strings were plucked, as well as staying consistent with when the string was plucked in reference to the timing of data collection. Additionally, certain measures had to be taken to make the data collected as comparable as possible between the two instruments. This included using the pickup located close to the neck, as it produces the cleanest sound, and ensuring that the amplifier did not add any distortion to the tone of the note. Failure to comply with these constraints would lead to data that is not directly comparable.

The test matrix found below was then executed with close attention to the order in which each run is executed. For each experimental run, data were recorded according to the matrix plan. Finally, before each recording, the room was allowed to return to silence to reduce background noise.

3.3 Testing Scheme

3.3.1 Run Definition

Run 1: Acoustic Guitar Playing A4 (440 Hz)	Run 2: Acoustic Guitar Playing E4 (330 Hz)
Run 3: Electric Guitar Playing A4 (440 Hz)	Run 4: Electric Guitar Playing E4 (330 Hz)

3.3.2 Test Matrix

Experiment	Run	Replicate	Instrument	Note
1	3	1	Electric	A4 (440 Hz)
2	4	1	Electric	E4 (330 Hz)
3	2	1	Acoustic	E4 (330 Hz)
4	3	2	Electric	A4 (440 Hz)
5	2	2	Acoustic	E4 (330 Hz)
6	1	1	Acoustic	A4 (440 Hz)
7	4	2	Electric	E4 (330 Hz)
8	1	2	Acoustic	A4 (440 Hz)

3.4 Experimental Setup

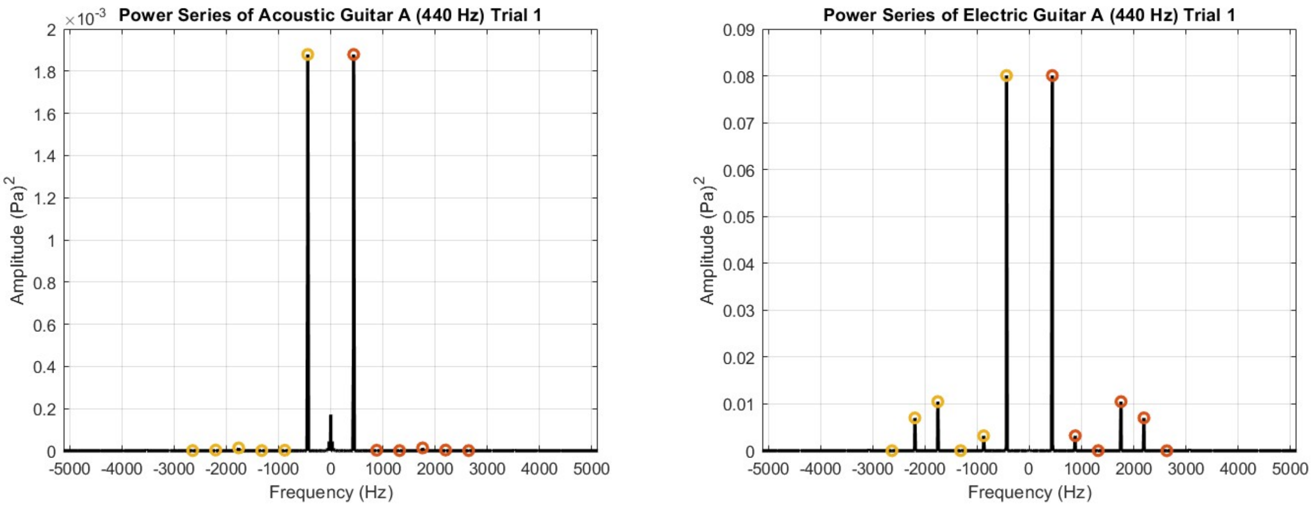
Photo showcasing experimental set-up with taped strings, location of instrument and microphone

4: Results and Analysis

4.1 Graphical Data

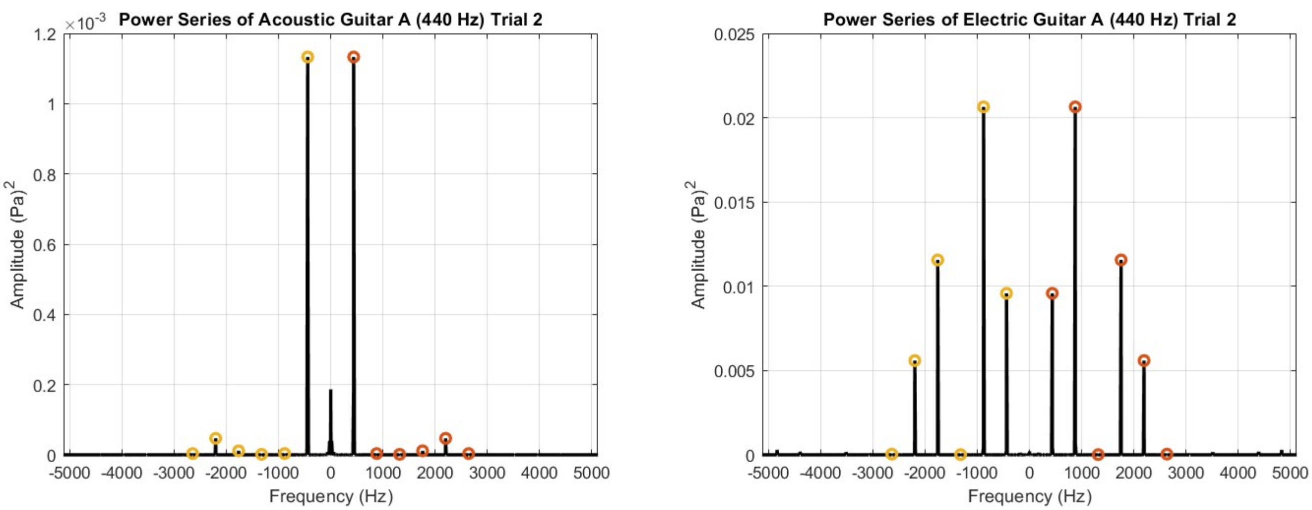
For the graphs below, both the fundamental frequency and the subsequent overtones are circled for clarity. Note that the entire Nyquist frequency range is not shown, as the focus of this experiment is limited to the first five overtones. The frequency axis has been appropriately scaled to enhance visibility in the region of interest.

Shown below are the power spectra for the first sample of Note A440 played on both the acoustic and electric guitars. In these samples, it is evident that the overtones occur at the same frequencies—multiples of 440 Hz—in both cases. However, the electric guitar exhibits more prominent overtones relative to its fundamental frequency, as indicated by the significantly higher amplitudes of its overtone peaks compared to those of the acoustic guitar.



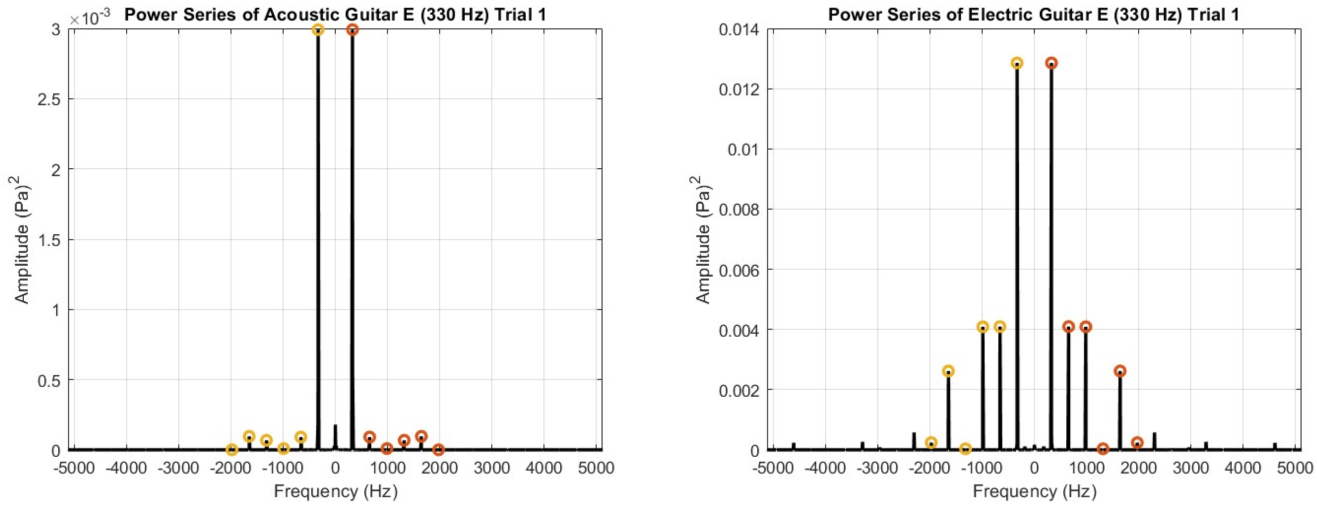
Power Spectrum of the First Trial of Acoustic and Electric A440 Notes Respectively

Shown below are the power spectra for the second sample of Note A440 played on both the acoustic and electric guitars. Interestingly, in the electric guitar sample, some of the overtones—specifically those at 880 Hz and 1760 Hz—have larger amplitudes than the fundamental frequency. Additionally, in the acoustic guitar sample, the fourth overtone appears more pronounced compared to the previous trial.



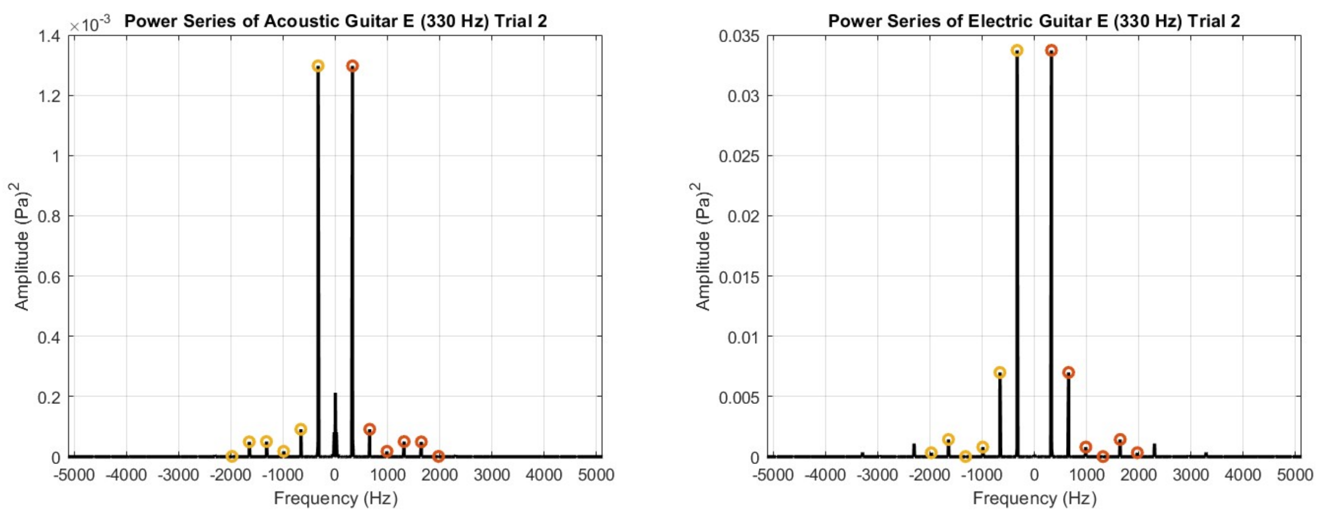
Power Spectrum of the Second Trial Acoustic and Electric A440 Notes Respectively

Shown below are the power spectra for the first sample of Note E330 played on both the acoustic and electric guitars. Notably, the overtone sequence for E330 is more pronounced in the acoustic guitar compared to the overtone sequence for A440 on the same instrument. However, consistent with previous results, the electric guitar's overtones still dominate in amplitude relative to the acoustic guitar. Additionally, the electric guitar exhibits prominent peaks at much higher frequencies beyond the first five overtones.



Power Spectrum of the First Trial of Acoustic and Electric E330 Notes Respectively

Also shown are the power spectra for the second sample of Note E330 for both instruments. Among all samples, this particular trial features the most prominent overtones for the acoustic guitar, with some even surpassing those of the electric guitar. Similar to the other E330 trial, the electric guitar continues to display strong overtones beyond the region of primary interest and has a notably dominant first overtone in this sample.



Power Spectrum of the Second Trial Acoustic and Electric E (330 Hz) Notes Respectively

4.2 Standardizing of Overtone Magnitudes

4.2.1 Method

To enable direct comparison of overtone intensity between samples, all overtone magnitudes must be standardized relative to the volume of the note played. This is particularly important because the intensity of the electric guitar's fundamental frequency far exceeds that of its acoustic counterpart.

To achieve this standardization, each overtone intensity was divided by the intensity of its corresponding fundamental frequency, allowing the relative strength of the overtones to be meaningfully compared across instruments and trials.

For the first two overtones of the second trial of Note E (330Hz) played on the acoustic guitar, this process is as follows:

First Overtone:

$$\begin{aligned} \text{Overtone Intensity} &= 9.14 \cdot 10^{-5} \text{ Pa}^2 \\ \text{Fundamental Intensity} &= 1.29 \cdot 10^{-3} \text{ Pa}^2 \\ \text{Relative Intensity} &= \frac{\text{Overtone Intensity}}{\text{Fundamental Intensity}} \\ &= \frac{9.14 \cdot 10^{-5} \text{ Pa}^2}{1.29 \cdot 10^{-3} \text{ Pa}^2} \\ &= 0.070456 \end{aligned}$$

Second Overtone:

$$\begin{aligned} \text{Overtone Intensity} &= 1.82 \cdot 10^{-5} \text{ Pa}^2 \\ \text{Fundamental Intensity} &= 1.29 \cdot 10^{-3} \text{ Pa}^2 \\ \text{Relative Intensity} &= \frac{\text{Overtone Intensity}}{\text{Fundamental Intensity}} \\ &= \frac{1.82 \cdot 10^{-5} \text{ Pa}^2}{1.29 \cdot 10^{-3} \text{ Pa}^2} \\ &= 0.014070 \end{aligned}$$

4.2.2 Tabular Results

Uncertainty in power spectra arising from microphone sensitivity was estimated by propagating the manufacturer-specified signal-to-noise ratio (70 dB), leading to a pressure uncertainty of approximately 0.03%. Squaring to obtain power spectra doubles the relative uncertainty, resulting in an instrumental uncertainty of approximately 0.06% in power measurements. As this value is negligible relative to experimental variability, it was not included in the table below.

Overtone	**Acoustic**				**Electric**			
	A440		E330		A440		E330	
	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2
1	0.001500	0.003243	0.030505	0.070456	0.040196	2.153961	0.318660	0.207561
2	0.000581	0.001332	0.003137	0.014070	0.000472	0.001591	0.318193	0.024026
3	0.007380	0.010123	0.022787	0.039091	0.131153	1.206438	0.002812	0.000674
4	0.001924	0.041598	0.032224	0.038303	0.087783	0.583850	0.203786	0.042696
5	0.000594	0.003236	0.000224	0.001123	0.000263	0.004571	0.018787	0.010076

Table 1: Relative overtone intensities for Notes A440 and E330 played on acoustic and electric guitars across two trials.

4.3 Statistical Analysis of Overtone Intensity

To quantitatively compare the overtone structures produced by acoustic and electric guitars, two-sample t-tests were conducted on the normalized overtone intensity data. Each sample set consisted of twenty overtone measurements (five overtones across two notes and two trials) per instrument. The objective was to determine whether either instrument boasts significantly more intense overtone profiles.

Because the population standard deviations were unknown and the sample sizes were moderate, a t-test was employed. This variant of the two-sample t-test does not assume equal variances between groups. Additionally, a significance level of $\alpha = 0.05$ was selected, corresponding to a 95% confidence level for all hypothesis tests. Separate t-tests were also conducted for each note (A440 and E330) independently to determine whether overtone differences were consistent across musical pitches. For each note-specific comparison, the same procedure was followed: grouping overtones across both trials for each instrument and performing a t-test at a 95% confidence level.

Because no specific directional hypothesis was established regarding which instrument would produce stronger overtones, a two-tailed t-test was used. This approach tests for any statistically significant difference, regardless of whether the electric or acoustic guitar exhibits greater overtone intensity. Across all tests, a p-value less than 0.05 was considered statistically significant, indicating that the overtone intensities of the electric guitar were significantly greater than those of the acoustic guitar.

Comparison	**t-statistic**	**p-value**	**Significance ($p < 0.05$)**
All Overtones (Electric vs. Acoustic)	2.1263	0.04677	**Yes**
Note A (440 Hz)	1.8128	0.1033	No
Note E (330 Hz)	2.1042	0.06311	No

Table 2: Summary of *t*-tests comparing overtone intensity between electric and acoustic guitars.

5: Conclusions and Future Work

Although the overtone analysis showed slight variability between trials, the electric guitar consistently produced overtones of greater magnitude than the acoustic guitar. For the acoustic, overtone-to-fundamental ratios remained below 10^{-1}, with no significant outliers observed. In contrast, the electric guitar exhibited overtone magnitudes spanning several orders of magnitude, including extreme outliers where the overtone-to-fundamental ratio exceeded 1, indicating that in some cases, the overtones were more prominent than the fundamental.

The results for the acoustic guitar indicate that the fundamental frequency is consistently the strongest component in the frequency spectrum when a note is plucked. This outcome aligns with the nature of acoustic guitars, which are designed to amplify the fundamental tone through their resonant body. Notably, for both trials, the open E330 note exhibited stronger overtone presence in the first three overtones compared to the fretted A440 note. This observation is consistent with the findings of Perov, who explains that guitars tend to lose harmonic richness as notes are fretted higher up the neck. Open strings, in contrast, allow for greater body resonance and stronger harmonic content (Perov et al.).

While the results for the electric guitar were generally consistent across most trials, certain values suggest possible sources of experimental error or uncertainty in the measurement process. The overall trend of stronger harmonic presence is expected, as the electric guitar produces an electrical signal that is more susceptible to noise and distortion compared to the acoustically amplified sound of an acoustic guitar. Additionally, the lack of a resonant body in electric guitars limits acoustic reinforcement of the fundamental frequency. Anomalous data were observed in Trial 2 for the A440 note, where the first and third overtones appeared stronger than the fundamental. This irregularity may be attributed to random errors, such as improper fretting, inconsistent plucking location, or potential electrical interference from the amplifier. Despite these anomalies, the relationship between the harmonic content of open versus fretted strings mirrors that observed in the acoustic guitar trials, and results for the open E330 note remained consistent across electric guitar trials.

Statistical analysis of the hypothesis using a t-test revealed that electric guitars produce a more layered overtone structure when the entire dataset is considered. This conclusion is supported by a p-value falling below the significance threshold of $\alpha = 0.05$. In contrast, individual t-tests conducted on the two notes studied (A440 and E330) did not show statistically significant differences between guitar types in terms of overtone prominence. This is likely due to the reduced sample size in the note-specific tests compared to the combined dataset. When performing a t-test, increasing the sample size improves the statistical power, making it easier to detect smaller differences in the data.

As shown in our graphical representations, the difference in overtone structure is clearly visible, particularly in the E330 trials, between the acoustic and electric guitars. Unfortunately, this observable difference was not reflected in the statistical results of the individual note tests. Given the opportunity to repeat the experiment, we would collect a larger volume of data to ensure greater reliability and statistical robustness.

Future work could take several directions to provide more detailed insights into the soundscape differences between acoustic and electric guitars. One potential approach is a more granular analysis of each string, comparing open and fretted notes on wound versus unwound strings. Additionally, examining the harmonic modes of the strings could reveal how directly exciting standing waves influences the presence and strength of overtones. Perhaps the most intriguing and practical extension would be analyzing the same note (i.e., same frequency) played on different strings. Such an experiment would illuminate how factors like string type and fret location interact to shape the harmonic content. These investigations would deepen our understanding of the physical and acoustic distinctions between electric and acoustic guitar soundscapes.

6: AI Statement

We chose to follow the criteria outlined in Level 3 of the AI assistance framework. We believe these criteria align well with our learning objectives and reflect how we envision AI integrating into our future work as engineers. Despite the growing role of AI, we still believe that strong technical writing skills will remain essential in our professional lives. The ability to clearly present ideas and objectives—potentially with the aid of external tools—is a valuable skill that will continue to be relevant in the workplace.

That said, there are certain aspects of writing, such as editing, that can be effectively expedited with AI. Importantly, this type of assistance does not alter the content or meaning of the writing but instead enhances clarity. For this reason, we believe that using AI for editing purposes is consistent with the type of professional support we will encounter in the future.

Works Cited

Alm, Jeremy F., and James S. Walker. “Time-Frequency Analysis of Musical Instruments.” *Society for Industrial and Applied Mathematics*, vol. 44, no. 3, Dec. 2002, pp. 457–76. *JSTOR*, www.jstor.org/stable/4148384.

Gualandri, Daniel. “Analysis of an Acoustic Guitar.” From a report uploaded online by the Physics Department of the University of Illinois, Urbana-Champaign.

JASIŃSKI, Jan, et al. “On the Audibility of Electric Guitar Tonewood.” *Archives of Acoustics*, vol. 46, no. 4, Oct. 2021, pp. 571–78.

Perov, Polievkt, et al. “The Physics of Guitar String Vibrations.” *The Physics of Guitar String Vibrations*, vol. 84, no. 1, Jan. 2016, pp. 38–43. https://doi.org/10.1119/1.4935088.

Rau, Mark, and Richard Hoover. MEASUREMENTS OF ACOUSTIC GUITAR TOP PLATES DURING THE VOICING PROCESS. July 2019, Keynote presentation, Montreal, Canada.

Tsumoto, Koji, et al. “The effect of harmonic overtones in relation to “sharpness” for perception of brightness of distorted guitar timbre.” *Proceedings of Meetings on Acoustics*, vol. 29, no. 3, Dec. 2016, p. 035002. https://doi.org/10.1121/2.0000380.