# Spectral Analysis of Melodic and Percussive Auditory Stimuli in Comparison to the Medel Cochlear Implant Frequency Ranges

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## Abstract

Cochlear implants are capable of improving speech recognition for people with severe hearing impairment. However, due to the implant's decreased range of stimulated auditory frequencies compared to a healthy human cochlea, music perception remains an obstacle for most cochlear implantees. By analyzing the power spectral density of a twelve-tone music composition in four melodic instruments and a drum pattern in four percussive instruments, it was determined that instruments that produce highly compressed waveforms fit best into the range of frequencies produced by the Medel cochlear implant. This is because these instruments closely mimic human vocalization. These findings indicate that music written with instruments such as the Yamaha P-515 Electric Piano's Sine Lead will allow for a better listening experience for people who have undergone cochlear implant surgery.

## Introduction

Since the introduction of the first FDA approved commercial cochlear implants in the mid 1980s, speech understanding and recognition for severely hearing impaired adults has drastically increased; further advancements and developments in cochlear implant technology in recent years have increased the frequency ranges of cochlear implants and have allowed for children as young as 12 months to receive cochlear implants (Drennan, 2008). However, the vast majority of cochlear implant users still struggle with substandard music perception when compared to their non-hearing impaired peers (Dritsakis, 2017). This problematic music perception and recognition for implantees - according to current literature - can be attributed to limited spectral channels and a diminished range of frequencies in comparison to a healthy human ear (Galvin, 2009).

In his textbook *Neuroscience. 2nd Edition.*, Dr. Dale Purves - a Geller Professor of Neurobiology Emeritus at the Duke Institute for Brain Sciences - and his Co-Authors write, “Humans can detect sounds in a frequency range from about 20 Hz to 20 kHz,” (Purves, 2001). Purves goes on to explain that human infants are capable of hearing frequencies above 20 kHz, but as they mature into adulthood the upper limit of hearing becomes 15-17 kHz (Purves, 2001). Unlike the human ear, the frequency range for the Medel cochlear implant “can be set from 70-350 Hz up to 3500-8500 Hz,” (Petrov, 2017). While this frequency range is best for human speech recognition, it fails to account for the necessities of complex music; music perception requires the ability to hear harmonics, undertones, and overtones that may exceed both the low and high end of the frequency range of the Medel cochlear implant (Petrov, 2017). Such evaluation brings up the question: what melodic and percussive instruments fit best into the frequency range of the Medel cochlear implant? Overall, an analysis utilizing computational modeling to graph the power spectral density of a twelve tone melodic line reproduced in four melodic instruments as well as a percussive pattern reproduced in four percussive instruments best reveal which qualities of instrumentation would fit into the limited range of the Medel cochlear Implant.

## Method

To carry out this procedure, a 16 second 12 tone jazz melodic line featuring chordal harmony and a separate main melody was composed and utilized. To ensure that the composition produced a full range of possible frequencies and harmonics, twelve-tone jazz was utilized. This atonal composing technique makes use of each of the 12 semitones in the chromatic scale resulting in more harmonic frequencies being reached than if only one key center was selected. To control the dynamics and tempo of each audio file, the CD quality audio recording function on the Yamaha P-515 digital piano was utilized. This feature allows for the dynamics and tempo of the composition to remain constant, while simultaneously allowing for the synthesized instrument to be changed.

The melodic line was first recorded using the CFX Grand Piano (figure 1), followed by the Harpsichord 8' (figure 2), Trumpet (figure 3), and finally, the Sine Lead (figure 4). It is important to note that the P-515 digital piano treats sustained notes on the Trumpet and the Sine Lead differently than that on the piano or harpsichord; instead of slowly decrescendoing the note is left fully at full volume until the input is canceled. Following the recording on the P-515 Yamaha Electric Piano, each recording was exported to Garageband. The audio files for this experiment were recorded electronically. As a result, the ambient noise was controlled, thus eliminating any potential, unwanted, white noise.

Thereafter, the synthesized drum rhythms were recorded. However, unlike the melodic synthesized instruments, using the the CD quality audio recording function on the Yamaha P-515 digital piano for percussive instruments did not change the drum or cymbal being synthesized. As a result, the recordings for the synthesized rhythmic instruments had to be recorded directly on Garageband. To ensure that the amplitude of the frequencies were constant, a function on the piano that controlled the weight of the hit was utilized. Each pattern of drum or cymbal lines were recorded with a 120 bpm 4/4 metronome resulting in controlled time intervals between each beat. The percussive pattern first recorded was the kick drum (figure 5), followed by the snare drum (figure 6), closed Hi-Hat (figure 7), and finally the crash cymbal (figure 8).

The melodic and percussive audio files were then downloaded as a wav file using GarageBand Version 10.2.0 On MacBookPro (Retina, 13-inch, Mid 2014) Running OS X El Capitan Ver 10.11.6 OS Exported to WAVE file, Quality: Uncompressed 16-bit (CD Quality).

After being downloaded, the audio files were uploaded into Academo's Online Spectrum Analyzer to gather results. To allow for simpler data collection, "Logarithmic Frequency Scale" was selected to analyze the recordings. Finally, screen grabs of the spectral analysis of each voice were taken and spliced together in microsoft paint.

## Results

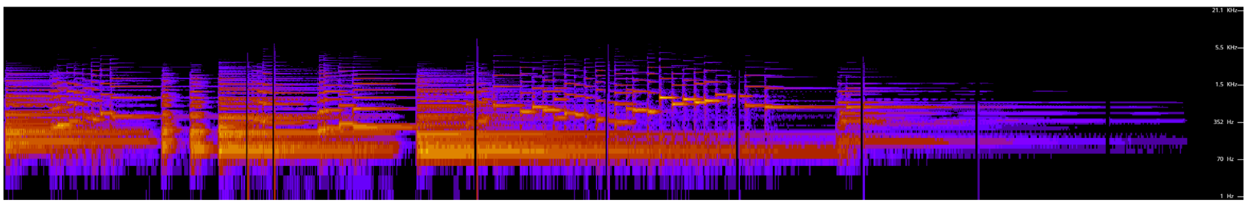


**Figure 1:** CFX Grand synthesized instrument spectral analysis. The x axis in this graph represents time in seconds, and the y axis represents a logarithmic frequency scale in Hertz. The change in colors indicate the amplitude of the wave.

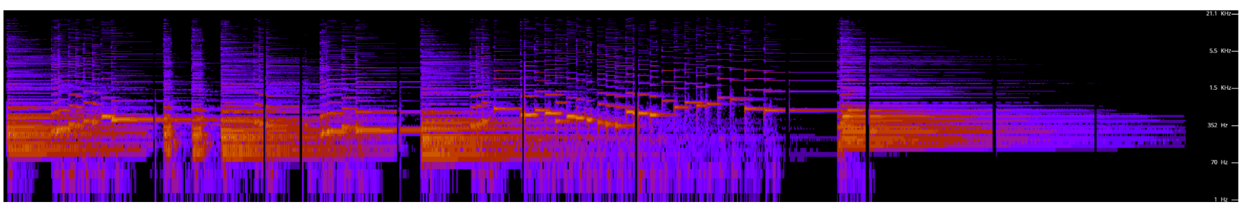


**Figure 2:** Harpsichord 8' synthesized instrument spectral analysis.

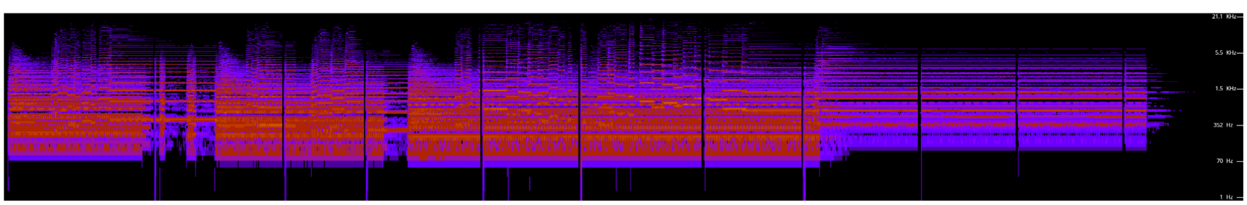


**Figure 3:** Trumpet synthesized instrument spectral analysis.

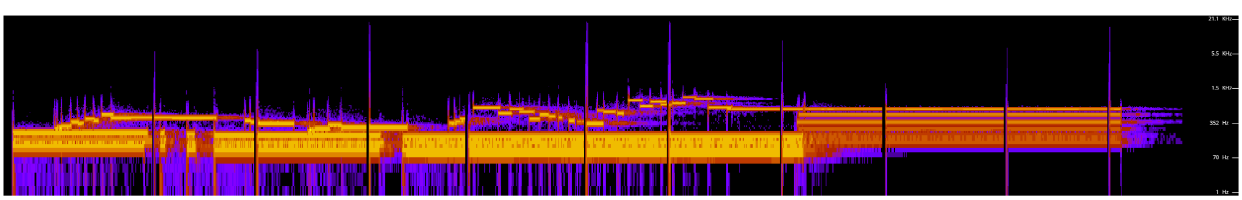

**Figure 4:** Sine Lead synthesized instrument spectral analysis.

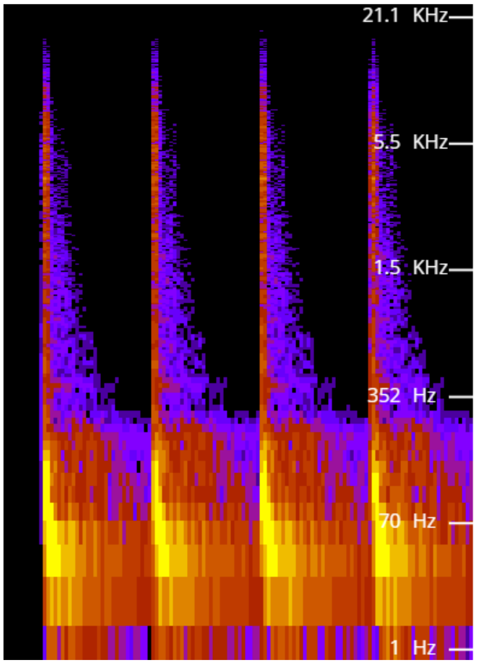


**Figure 5:** Kick Drum synthesized instrument spectral analysis.

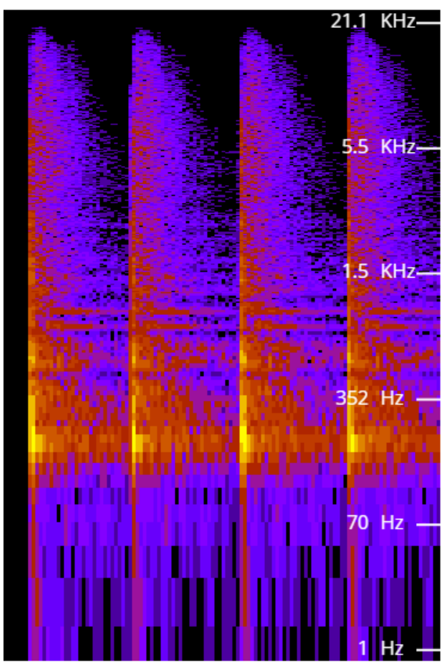


**Figure 6:** Snare Drum synthesized instrument spectral analysis.

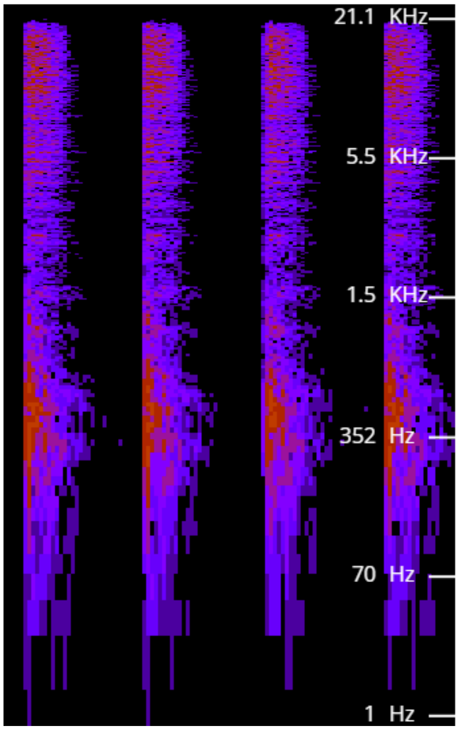


**Figure 7:** Closed Hi Hat synthesized instrument spectral analysis.

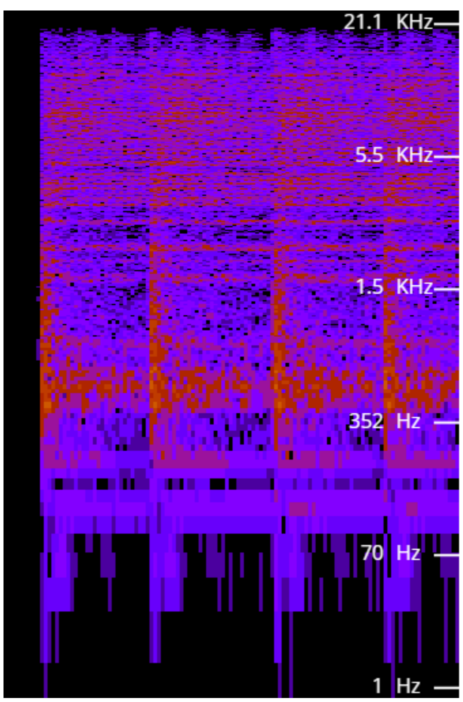


**Figure 8:** Crash Cymbal synthesized instrument spectral analysis.

## Discussion

In regards to the frequency range of the Medel cochlear implant, the Sine Lead instrument fits best within the range of frequencies generated by a Medel cochlear implant. This is because the voice is highly compressed. This is visible with the lack of upper register harmonics. The lack of overtones also impacted the amplitude of the tones and made them more concise. The melodic voice that fits the least within the frequency range of the Medel cochlear implant is the trumpet sound. This sound generated upper register harmonics that spread well above 5.5 kHz and into the 10 kHz range. The synthesized instrument's audio was not compressed which resulted in the amplitude along the harmonics and on the fundamental frequency to be diluted. The analysis illustrated that all of the percussive elements were far out of the range of the Medel cochlear implant generated frequencies. However, out of the four analyzed sounds, the snare drum fits the closest within the frequency range. The kick drum had concentrated amplitude much lower than what the cochlear implant is capable of producing, and the closed hi-hat and crash cymbal produced tones too high for the cochlear implant to reproduce.

This research can help improve the quality of music for people with cochlear implants by informing composers on which instruments to use in order to give a better and more inclusive listening experience. Furthermore, by writing music for people with cochlear implants that use instruments and synthesized voices such as the Sine Lead, composers can help improve the quality of life for people who were born hearing impaired and were never able to experience music, and help improve life for people who developed hearing impairment and miss the ability to listen to music. In future research, the polling human test subjects with cochlear implants on the clarity of different voices would allow for more accurate results. This experiment was limited in its findings by comparing the spectral analysis to the range of only one brand of commercially available cochlear implants. Additionally, this experiment may have been limited by the uncontrolled dynamics of the Sine Lead (figure 4) and the Trumpet (figure 3) as they continued to sustain the notes at full volume. Finally, this experiment may have been limited in its results due to the intermittent black vertical lines along the spectrogram that indicate previous points where the spectrogram was paused; this may have obstructed valuable data.

## Conclusion

The results of the computational model and analysis are clear: instruments and voices that closely mimic the range of human speech fit best into the frequency range of the Medel cochlear implant. Thus, to improve music perception for people with cochlear implants, it is important that composers utilize instruments that produce compressed sound waves, imitate human speech, and have few harmonics.

## Acknowledgments

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## References

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