Analyzing the Effect of a Percussive Backbeat on Alpha, Beta, Theta, and Delta Binaural Beats

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Part 1: The Research Process

The inspiration for this project really comes from my undying love of music, and my inkling for finding scientific explanations for everything. My volunteering experiences especially inspired how I undertook this project. I've been volunteering as a music therapist in places like our local science museum as well as schools in India using my drumming. I've noticed that drums are very effective at reducing stress, improving motor skills, and focus-related tasks for children in particular, yet when it comes to professional auditory therapy, drums are neglected in favor of synthesized compositions like binaural beats. As a result, auditory therapy can be difficult for some children especially, to use effectively, as the monotony of some therapy tactics could actually be irritants and end up having adverse effects.

Thus, my research project attempts to make auditory therapy more universal and accessible for listeners of all kind, by adding elements of music and rhythm to it. I wanted to find out, however, if there is a scientific basis of adding musical percussion to a binaural beat, in order to make this method of auditory therapy more musical. This would allow me to use the same percussion that I have seen to work as music therapy, and introduce it into binaural beats to make this type of auditory therapy more accessible, appropriate, and enjoyable to listen to for many people, especially those with Autism or ADHD.

In order for me to perform this research, Music Technology Professor Daniel Walzer from UMass Lowell graciously offered his help as a mentor. He suggested numerous tweaks and changes that I made to my research plan, including the recording setup, how I transferred the audio to my computer, which kinds of spectrograms and audio analysis tools to use, and even how to record two different drums to achieve optimal recordings. Overall, however, I didn't use any labs or professional-level equipment to perform this project, and, for the most part, this project was done entirely at home.

If I had to summarize this project and my experiences during it in just a few words, it would go something like this. Binaural beats are tools used in music and auditory therapy to improve memory and sharpen focus and motor skills. They involve playing two different tones into each ear so that the brain perceives a third tone with a pulsing effect and creates its own brainwaves. Since percussion is often used in music therapy, but rarely in binaural beats, I want to find if there is a scientific conclusion to be made about adding a percussive backbeat to binaural beats.

I recorded and created percussion-based binaural beats using computer software, and I wrote a computer simulation software that takes into account frequency ranges, pitches, and pulsing effects of drumming among other factors to determine how efficient a certain binaural beat is in eliciting brainwaves. I found that whenever certain aspects of a percussion-based backbeat were optimized, they were 4% more efficient than regular binaural beats. I'd like to continue this research by performing brainwave analysis on humans in the future. This research could increase the accessibility of music therapy compared to monotonous binaural beats, as rhythmic compositions involving a binaural beat can increase therapeutic effects and appeal to more listeners in the general public, especially those with Autism or ADHD.

Of course, my inclination to think scientifically hasn't stopped since the Regeneron STS competition, and, if anything, I've just become more curious about the intersection between music and science. Lately I’ve found myself questioning computer science’s role in music therapy, especially as a replacement of live instrumentation and musical composition. In my own experience volunteering as a music therapist, I’ve used live drumming as the main method of interaction with children, and I never thought to use synthesized compositions that were made from computer programming. However, as the world shifts towards using computers more and more, will live instruments find themselves getting replaced by these computerized compositions? How can they be made and replicated to the extent that they are sonically equivalent to real instruments played in a live setting? Could they end up being even more efficient than live instrumentation for whatever reason, as through the power of audio editing, it is possible to theoretically make the most sonically efficiency musical compositions?

All of these are questions that I have had regarding the intersection of music therapy and computer science with regards to what direction music therapy is heading in. It would seem by these questions that computer science could carry music therapy in a direction that has never been explored before, but the question also needs to be asked, how would going in this technologically dependent path, resulting in a lack of human interaction, influence music therapy’s soothing effects? Part of the reason why I find my own sessions so therapeutic is not necessarily that there is an instrument being played, and may not even be anything musical at all. It is the fact that there is face-to-face interaction with another human, and that we’re bonding over this instrument we are playing together. How would continuing down the road of technological music therapy deprive us of these experiences, and is it worth it in the end?

Music therapy seems to be heading in a direction both of pros and of cons, and I’d certainly love to shape its future through computer science and math.

At the end of the day, if I had to give advice to current high schoolers on conducting research, I would simply suggest one thing: research something you love and something that you are genuinely interested in. It can be about anything. Music, for the most part, is not really thought of as a particularly scientific thing. However, there is a scientific explanation behind every single thing that exists in this world. Find something that piques your curiosity, and take a nosedive into researching it, going through every crevice and crease of it and leaving no stone unturned. Engulf yourself in something you love and let it consume you to the point where, even when you're done, you are only more curious than when you started. I know all of this sounds extremely cheesy, but when you approach scientific research with that much passion, you get a beautiful result.

Abstract

Binaural beats to stimulate brainwave entrainment are generally absent of percussion, relying on the beat frequency to generate pulsing for entrainment. This paper analyzes the effect of adding a percussive backbeat to a binaural beat on brainwave entrainment. Alpha (10 Hz), beta (20 Hz), theta (5 Hz), and delta (3 Hz) binaural beats were created. These beats were duplicated, and appropriately pitched percussion was added to one set of the beats using LTAS analysis. For the preliminary phase, these beats were analyzed through computer simulation, taking into account harmonic and timbre frequency variations, occurrences of pulses *(P_b)*, brain rate calculations *(f_b)*, and tempo-to-entrainment values, among other factors, to determine *frequency following response* rates. Through ANOVA analysis, the simulation suggests that specific frequency variations combined with other specific amplitudes, P_b values, and pitches of percussion, specified in detail in the paper, improve *frequency following response* and intensify f_b values, therefore stimulating memory and focus-related brain activity, by around 4%. Overall, however, there is still an 15% deterrence of percussion-based binaural beats. The next phase of this research will involve electroencephalography (EEG) and galvanic skin response (GSR) analysis on human subjects. These specifically pitched rhythm-based binaural beats have many implications such as creating a more accessible listening experience for all listeners, especially those with autism and ADHD, as well as increasing the efficiency of binaural beats on memory and brain power for music and auditory therapy.

1 Introduction

Binaural beats are a tool in auditory therapy used to influence the brain and make it sharper via brainwave entrainment and meditative state inducement. They have been used in therapeutically treating insomnia, dementia, Parkinson's Disease, and other conditions with their roots in psychology [4].

A beat is a concept in physics involving waves, most specifically acoustic waves, regarding their frequencies, and constructive and destructive interference of sine waves with different frequencies [14].

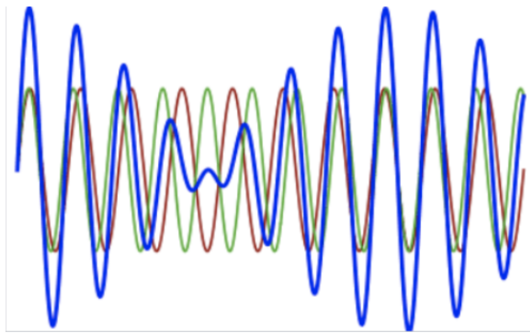

Figure 1: Representation of a Beat (blue wave) Using Constructive and Destructive Interference [6]

This cycle of constructive and destructive interference of waves with slightly different frequencies will continue until once again, the peak spots of each wave's cycle will coincide, and constructive interference will be maximized again. At this point, there are two different points in time where the constructive interference of sine waves is maximized, and so is the amplitude. With sound waves, which behave in this sine wave manner, this creates a sort of wobble effect, with the sound's volume changing between higher and lower, but being the loudest at the points of the highest constructive interference. The amount of "wobbles" that are created per second, or the amount of times constructive interference is maximized in a second is known as the beat frequency of the two waves [10].

The concept of a binaural beat as an auditory illusion that utilizes the fundamental concepts of beats and waves. When two different sounds of two slightly different frequencies are played dichotically, meaning one sound is played through each ear, the brain perceives a beat frequency that is equivalent to the difference between the two frequencies. This auditory signal is transmitted throughout the brain into the thalamus, auditory cortex, and other cortical regions [8]. A pure binaural beat is simply composed of tones with a steady and consistent frequency. Generally, other instruments are not used in binaural beats.

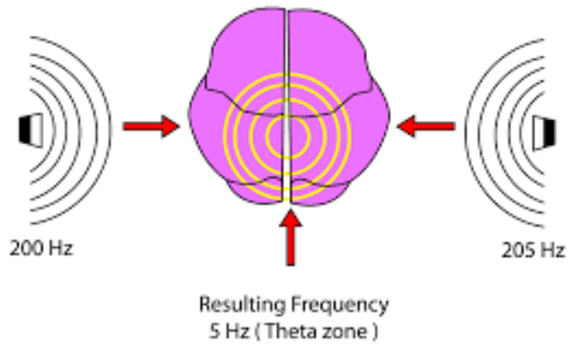

Figure 2: The Effect of a Binaural Beat on the Human Brain [7]

The brainwave entrainment process is predicated on the notion of frequency following response, where the brain adjusts its dominant frequency to match the subharmonic frequency of the beating sounds. For example, when one listens to a 10Hz binaural beat, the brain is conditioned to perceive a subharmoic frequency of 10 Hz, and thus eliciting brainwave entrainment, which can later be used to sharpen memory and other brain activity.

The concept of binaural beats has been used throughout the world in music therapy sessions to help increase attentiveness and memory retention, for example. Research has been conducted on the ability for a binaural beat to influence these aspects of psychology. [11] concludes that both alpha and gamma binaural beats (40 Hz) have had success in increasing the attentiveness of subjects and have extrapolated that binaural beat entrainment has useful applications in situations with attention deficits. Such a result seems odd however, when compared to [13], which concludes that after Electroencephalography analysis of the brain when undergoing binaural beat treatment, little change is perceived, if at all. This would indicate that the functions and processes that the brain executes are similar both before and after binaural beat treatment. Overall, the efficiency of binaural beats is a debated topic, with some scientific research explaining that on some levels, changes occur, while other research counters that on other levels, changes do not occur.

The composition of a binaural beat often involves two underlying tones of alike, but not identical, frequencies, which helps the brain to create the third perceived frequency. Oftentimes, these tones are structured in amplitude in such a way to create an unnoticeable yet present pulsing feeling, bringing the mind even deeper into a trance state. Many binaural beats are simply composed of the two underlying tones without any extra layered instruments or musical components.

The addition of a percussive backbeat to a binaural beat has many implications, some of which are yet to be discovered. Adding musical effects to an auditory therapy concept like binaural beats has the potential to make the therapy method much more accessible and appropriate to use for a wider range of people, such as for listeners with Autism Spectrum Disorder or ADHD.

Little research has been done on the effect of using percussion in the efficacy of a binaural beat. Research has been done on the effect of Shamanic Drumming on its tendency to induce trance, but there has been no direct comparison of the efficacy of auditory therapy when percussion is present versus when it is not [1].

Without percussion, binaural beats are a monotonous hum, but with percussion, binaural beats have the possibility of becoming more sonically accessible and structured rhythmic patterns that are easier to focus on, thus potentially making the brain even more sharper after exposure. While a percussive backbeat has the ability to intensify entrainment, it also has the same possibility of disrupting the frequencies created by the tones of a binaural beat. A percussive section with different frequencies than the underlying tone of a binaural beat could cause the entire frequency of the sound to change, thus negating any possibility of the brain perceiving two very similar frequencies and processing them to create its own frequency.

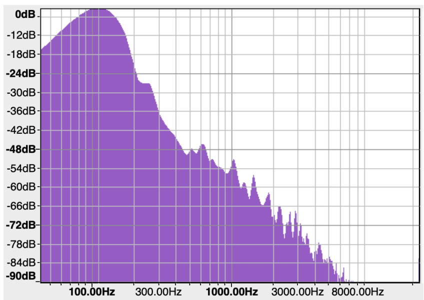

Figure 3: Plot Spectrum analysis of Shamanic Drumming

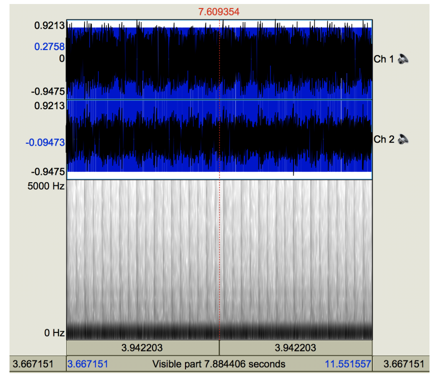

Figure 4: Spectrogram Analysis of Shamanic Drumming

An important aspect of adding a percussion backbeat is deciding which drums to use in the binaural beat. Of the limited occurrences when percussion has been used in a binaural beat, the drum used has been analogous to a Shamanic drum, a single drum beat that repeats to create a pulsing rhythmic effect that is intended to entrance the listener. However, an instrument like the tabla, which is composed of two different drums, one low-pitched and one high-pitched, almost like a bass and treble drum [5], has not been researched in the context of binaural beats. Having two drums working in tandem may still create that same pulsating effect, but sonically the frequencies may not necessarily match up to allow the brain to perceive that third frequency. The uncertainty in determining the effectiveness of a percussive backbeat in general, and especially with a drum like the tabla in binaural beats is the subject of the research.

2 Method of Binaural Beat Creation

This experiment revolves around the concept of introducing a rhythmic backbeat to a binaural beat. The frequency analysis on the bass drum, which instrument that was used to create the rhythmic backbeat was a traditional Indian percussion instrument known as the tabla. The tabla is composed of two different drums, one that serves as the bass drum and another that creates a treble-like sound.

This instrument is significantly different than the occasionally used shamanic drum. The reason for this is that the shamanic drum only consists of one drum and thus one range of frequency, whereas the tabla consists of two drums which cover different ranges in the frequency and pitch spectrum for sound [3]. This could either enhance or detract the effect of the rhythmic binaural beat on frequency following response and memory and brain activity stimulation, depending on a variety of factors.

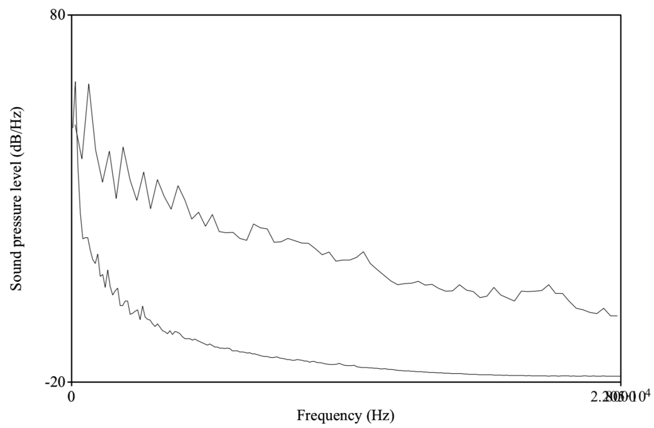

Figure 5: Long-Term Average Spectrum Analysis of Tabla vs Shamanic Drum

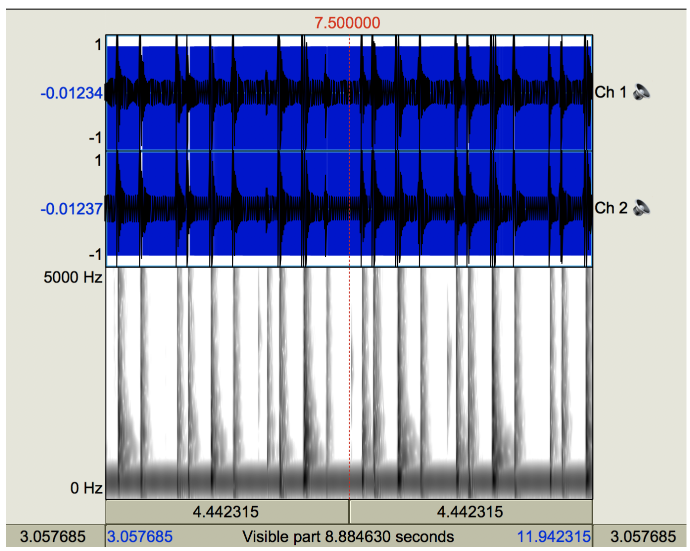

Figure 6: Spectrogram Analysis of a Binaural Beat with Percussive Backbeat

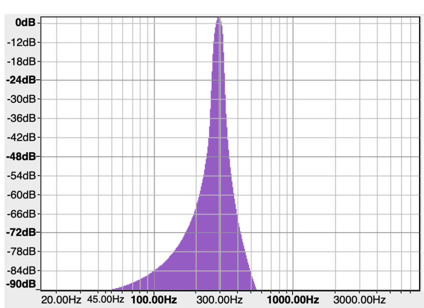

Figure 7: Alpha Binaural Beat Plot Spectrum

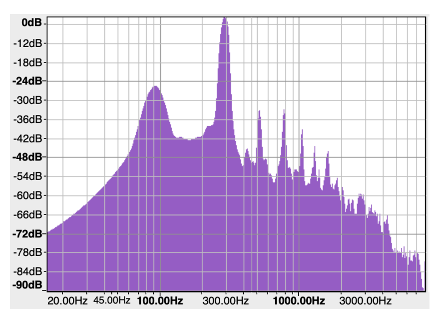

Figure 8: Plot Spectrum of Alpha Binaural Beat with Percussive Backbeat

Creating the percussion based binaural beat first requires the creation of a regular binaural beat, which is composed of two underlying tones of slightly different frequencies. The frequency of the binaural beat was

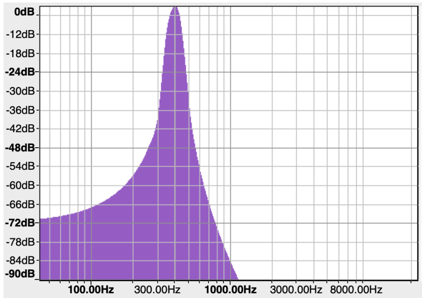

Figure 9: Beta Binaural Beat Plot Spectrum

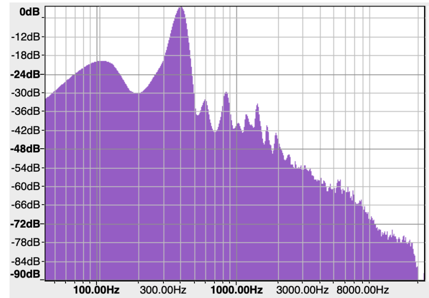

Figure 10: Plot Spectrum of Beta Binaural Beat with Percussive Backbeat

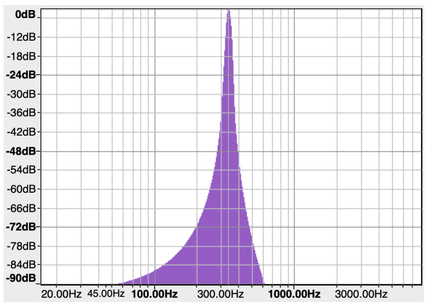

Figure 11: Theta Binaural Beat Plot Spectrum

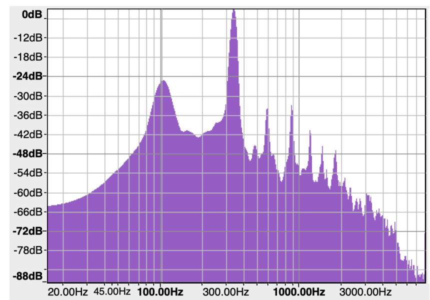

Figure 12: Plot Spectrum of Theta Binaural Beat with Percussive Backbeat

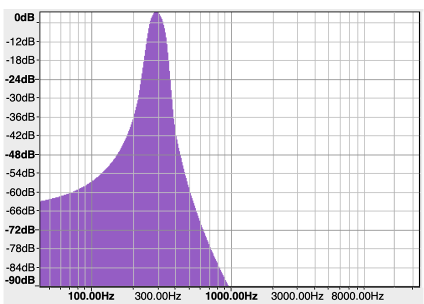

Figure 13: Delta Binaural Beat Plot Spectrum

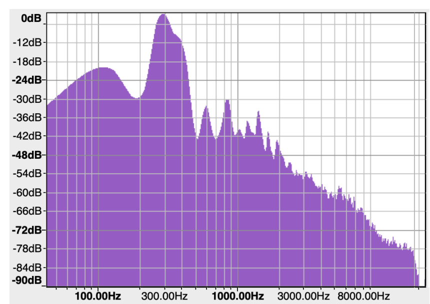

Figure 14: Plot Spectrum of Delta Binaural Beat with Percussive Backbeat

defined to be the beat frequency of the two tones, or in other words, the mathematical difference of the two tones' frequencies.

For the purpose of this project, four different types of binaural beats were created. These were alpha, beta, delta, and theta binaural beats. Each of these binaural beats is intended to create a frequency that causes a certain type of brainwave to become more prominent. A difference of 10 Hz created an alpha binaural beat. Similarly, 20 Hz corresponded to beta, 5 Hz to theta, and 3 Hz to delta.

The creation the binaural beats involved generating two tones of these frequencies and adjusting them so that one tone was assigned to only one ear, making them two individual monaural tones to create the binaural beat. This tone generation occurred in the computer program Audacity, and was duplicated and pitched appropriately for a duration of 5 minutes. Multiple versions of these binaural beats corresponding to specific pitches of sound were also created.

Percussion was recorded via a dual-microphone setup over each drum over the percussion instrument, allowing for frequency analysis to be performed on each head. The rhythms were recorded in 30 second intervals and then looped for a duration of 5 minutes over the generated binaural beats.

Multiple versions of percussion were created and recorded to correspond to different pitch and amplitude values, as well as different tempos of rhythm which corresponded to differentiating pulsing values.

The percussion was then analyzed through Long-Term Average Spectrum (LTAS), and appropriately panned, pitched, and layered before adding it to the binaural beat.

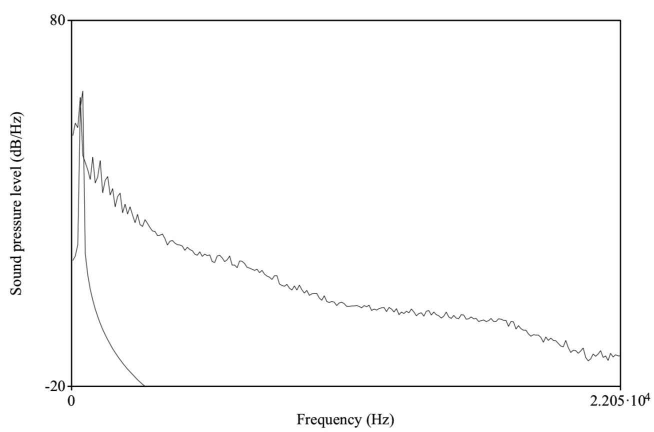

Figure 15: Long-Term Average Spectrum Analysis of Percussion-Based Binaural Beat vs. Regular Binaural Beat

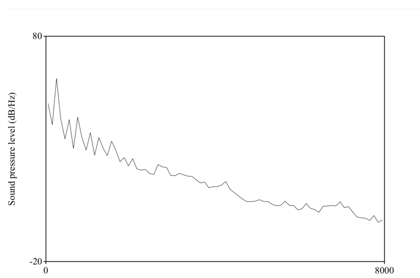

Figure 16: Long-Term Average Spectrum Analysis of Alpha Binaural Beat with Percussion

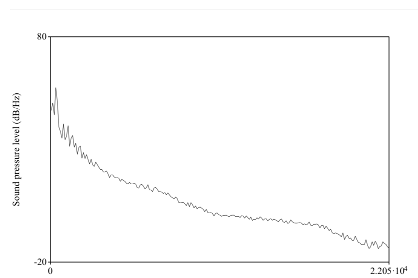

Figure 17: Long-Term Average Spectrum Analysis of Beta Binaural Beat with Percussion

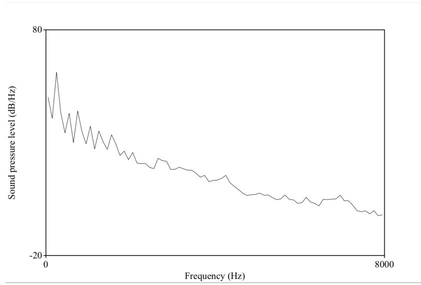

Figure 18: Long-Term Average Spectrum Analysis of Theta Binaural Beat with Percussion

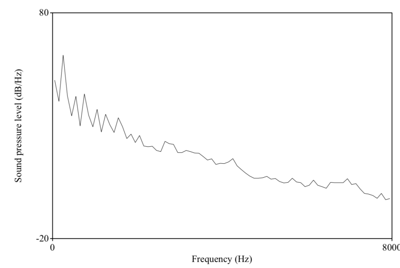

Figure 19: Long-Term Average Spectrum Analysis of Delta Binaural Beat with Percussion

3 Method of Data Collection

3.1 Amplitude and Pitch (Frequency)

The first phase of this project was to use both the rhythmic and non-rhythmic binaural beats in a Java simulation. The purpose of this simulation was to take in inputs of potential scenarios, such as frequency of the beat, duration of listening, and current mental state, among many other variables, to determine the significance of the effect of the binaural beat. The addition of a percussive rhythm would be the main difference in the simulation between a binaural beat with a rhythmic backbeat and one without it.

The main independent variable in this paper is the presence of a percussive backbeat, which will be modeled by the tabla. Many other factors are derived from the presence of a tabla rhythmic backbeat.

Regardless of the presence of a rhythmic backbeat, the binaural beat would always have a value for specific frequencies and amplitudes. The input for the two different frequencies would determine the eventual beat frequency, which was calculated by taking the difference of the two initial frequencies. This beat frequency would then cause certain brainwaves to be produced in the simulation. Amplitude also had an effect on how the sounds produced or prevented brainwaves, as depending on the amplitude, it could get easier or harder for a person to focus. Certain brainwaves are also designated with certain amplitudes, so if the amplitude of the beat matched up with these values, the beat became more effective. A coefficient was determined using these values with regards to amplitude to partially determine efficacy of frequency following response.

Table 1: Amplitude Values for Corresponding Brainwave Types [12]

Brainwave Type	**Frequency (Hz)**	**Amplitude (μV)**
Alpha	8.0-13.0	20-200
Beta	13.0-30.0	5-10
Theta	1.0-5.0	20-200
Delta	4.0-8.0	5-10

Moreover, the frequencies of the percussive rhythm and the binaural beat can either coincide or not coincide with one another. Since frequencies correspond to pitch, this simulation takes into account the frequency values of both the binaural beat and the percussive backbeat, and assigns a pitch value to them. If these pitch values sonically coincide or harmonize with one another, such as both the percussion and binaural beat being at a pitch of A, or the percussive rhythm being at a pitch of C and the binaural beat being at a pitch of G (a V chord), the efficacy of the binaural beat increases, because the pitches and tones sonically harmonize and contribute to each other's effects. Thus, the frequency and pitch analysis of both the percussion and the binaural beat plays a pivotal role in determining the effects of their combination. When the frequencies line up in such a way, the simulation has a mathematically reduced chance of creating any sort of disturbance in the binaural beat that would disrupt its intended effect.

Using the LTAS and Spectrogram analysis conducted above, frequency ranges were created for both binaural beats with percussive backbeats and the control backbeats. These frequency ranges were also analyzed for intensity and duration of frequency in the simulation software. Thus, the LTAS and Spectrogram analysis provided the key data input for the frequencies and amplitudes of the created binaural beats.

For the purpose of the simulation, when the frequency and amplitudes of both the binaural beat and percussive backbeat coincided in such a manner, the frequency and amplitude coefficients were said to be ”maximized.”

3.2 Rhythm, Tempo, and Pulse to Brainwave Entrainment Analysis

Through an analysis of drumming with regards to brainwave production, [2] concluded that rhythms of certain beats per second were most effective at producing certain types of brainwaves. The following was concluded: rhythms from 4 to 4.5 beats per second were most effective at producing theta waves, and were also effective at producing alpha and beta waves. Rhythms with 3 to 4 beats per second were somewhat effective in producing theta waves, as were rhythms with 4.5 to 5.5 beats per second. These values from the Maxfield analysis are of particular interest with regards to the percussive backbeat, as the beats per second, which is determined by the frequency of the sounds and the tempo of the rhythm, will be a key factor in either producing more or less of a certain wave. The values from this analysis were used in the simulation program in this way.

Table 2: The Tempo/Pulse Values with Regards to the Type of Brainwave Elicited [2]

Type of Brainwave Elicited	**Tempo/Pulse of Percussion (bps)**
Alpha	4.0-4.5
Beta	4.5-4.75
Theta	3.0-5.5
Delta	4.0-5.0

The method of calculating the pulse of the binaural beats was using tempo analysis on the percussion whenever a percussive backbeat was present, or using the formula to calculate the beat frequency of two waves with different frequencies. The pulse values calculated based on these two scenarios were then entered in the simulation and appropriately matched with the type of brainwave elicited according to the study.

Whenever the associated pulse value corresponded with the wave type that was intended to be elicited by the binaural beat, then the tempo/pulse coefficient was said to be ”maximized.” For example, for a binaural beat with a frequency range from 300 Hz to 310 Hz, and a corresponding beat frequency of 10 Hz, making it an alpha-wave eliciting binaural beat, the pulse and tempo coefficient would be maximized for the values between 4.0 and 4.5 bps.

3.3 Brain Rate Calculation

A mathematical formula has been created to predict overall mental state based on brainwave changes [9]. This formula was incorporated into the simulation based on perceived changes in brainwaves based on the binaural beat. Using the changes in different regions of the brain, and determining the extent of brainwave change

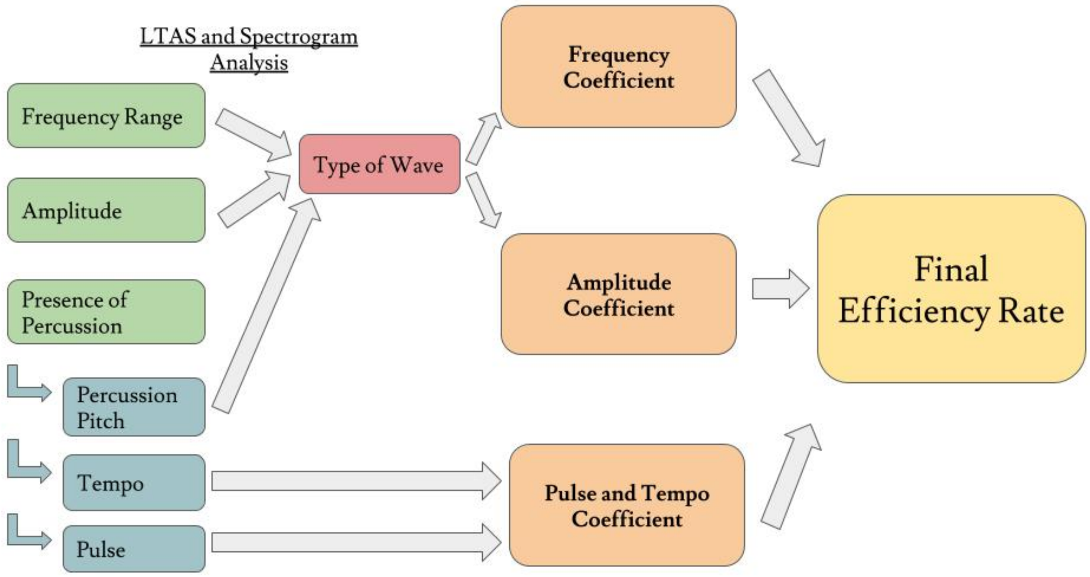

Figure 20: Flowchart Diagram of Efficiency Rate Calculation

in that region, the total mental state of a person can be predicted. This formula has varied coefficients and values depending on what part of the brain is being affected, which types of brainwaves are being produced, as well as other factors like consciousness and age of the person listening. The purpose for including this formula would be to provide a strictly mathematical basis for determining how effective binaural beats were in creating a certain mental state.

$$f_b = \sum f_i P_i = \sum f_i \frac{V_i}{V} (1)$$

This equation calculates the total brain rate, f_b, for a given brain as a function of the sum of individual values for brainwave bands. The individual brainwave bands are calculated by multiplying the frequency of the brainwave band, f_i by the fraction of the total amplitude that the specific band creates, V_i/V.

This equation is true for when:

$$V = \sum V_i \tag{2}$$

This means that the total amplitude V is the sum of individual amplitudes of different frequency bands, labeled as V_i.

$$f_b = \frac{1}{V} \int f V(f)\, df \tag{3}$$

The above equation represents the most precise version of the calculation of brain rate given individual changes in specific brainwave production for infinitely many frequency bands.

$$V = \int V(f)\, df \tag{4}$$

Equation 3 is true when V is equal to the sum of every single function of amplitude, $V(f)$, for each frequency band.

Using the efficiency coefficient calculated from the formula from [2], and a combination of frequency, amplitude, and other pulse analyses, an overall efficiency coefficient was determined based on these and other factors, and this *efficiency coefficient* was in turn used to calculate the brain rate using the above formulas.

Table 3: Sample Calculations for Brain Rate Formula

Band	f_i **[Hz]**	V_i (μV)	$f_i V_i/\mathbf{V}$ **[Hz]**
Alpha (α)	10	7.76	2.27
Beta (β)	18	8.93	4.71
Theta (θ)	6	10.18	1.79
Delta (δ)	2	7.29	0.43

In this case, $\sum \mathrm{V}_i = 34.16\ \mu V$, and the brain rate, f_b, $= \sum f_i V_i/\mathbf{V}\ = 9.20$.

4 Results

4.1 Simulation Results

Table 4: Example of Simulation Results for 20 Alpha Binaural Beats with Percussive Backbeat

Frequency Range (Hz)	**Amplitude (μV)**	**Percussion Tempo (bpm)**	**Percussion Pitch**	**Wave Elicited**	**Efficiency Rate**	**Brain Rate (Hz)**
324.291-333.555	102.3	201.251	C	α	0.709	9.441
323.218-337.512	93.72	201.962	E	α	0.784	8.175
328.090-337.704	127.39	197.164	F#	α	0.725	8.207
329.586-336.124	84.32	201.607	G	α	0.928	8.512
324.148-333.455	144.01	192.629	G	α	0.758	9.119
326.509-331.027	77.44	196.854	A#	α	0.765	7.263
328.025-335.032	122.31	195.941	B	α	0.744	9.064
323.571-334.111	189.12	196.696	C#	α	0.801	8.251
325.896-335.498	190.77	194.434	G	α	0.765	8.146
322.535-330.645	100.98	197.617	E	α	0.826	9.233
324.532-331.917	69.31	194.554	F#	α	0.886	9.184
322.172-340.161	170.32	198.537	D	α	0.833	8.067
326.925-332.012	89.88	183.31	G	α	0.811	9.217
328.416-337.024	87.32	198.133	C#	α	0.722	7.321
321.466-339.712	120.01	200.882	D	α	0.965	7.35
329.567-334.462	53.78	195.392	B	α	0.807	9.181
326.620-335.763	130.22	191.438	A#	α	0.889	9.474
327.489-339.842	114.35	195.784	A#	α	0.831	8.126
322.188-334.055	172.35	198.99	B	α	0.77	9.005
328.681-333.164	132.2	202.007	C	α	0.744	7.182

Table 5: Example of Simulation Results for 20 Delta Binaural Beats with Percussive Backbeat

Frequency Range (Hz)	**Amplitude (μV)**	**Percussion Tempo (bpm)**	**Percussion Pitch**	**Wave Elicited**	**Efficiency Rate**	**Brain Rate (Hz)**
240.405-261.715	10	104.535	D#	δ	0.78	5
247.601-260.770	9.72	105.332	C	δ	0.651	4.565
248.762-259.209	10.39	107.174	F#	δ	0.675	4.558
244.680-255.065	8.32	103.183	E	δ	0.799	4.686
245.487-259.387	10.01	111.397	F#	δ	0.593	4.419
237.981-255.587	9.44	102.391	A#	δ	0.668	4.483
243.645-252.729	12.31	107.552	A#	δ	0.747	4.645
248.250-251.709	11.12	110.48	E	δ	0.645	4.644
249.0129-259.657	10.77	101.634	G	δ	0.712	4.429
237.965-252.199	10.98	110.331	D#	δ	0.683	4.127
251.215-258.041	9.31	111.516	F#	δ	0.814	4.648
246.492-260.962	10.32	111.455	D	δ	0.809	4.553
245.253-262.088	8.88	110.988	F#	δ	0.656	4.621
250.730-261.404	7.32	109.234	G	δ	0.603	4.68
244.651-258.930	10.01	109.461	D	δ	0.843	4.701
239.730-263.956	5.78	111.932	B	δ	0.854	4.83
240.280-254.527	10.22	109.739	A#	δ	0.596	4.613
249.069-256.610	14.35	109.303	D	δ	0.86	4.699
240.505-256.767	12.35	105.16	G	δ	0.784	4.906
245.144-262.855	12.2	103.185	E	δ	0.724	4.407

4.2 ANOVA Statistical Analysis

Table 6: ANOVA Analysis of Alpha Binaural Beat with Percussive Backbeat when Individual Coefficients are Maximized

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Binaural Beat with Percussive Backbeat	50	36.92094	0.738419	0.006441
Control Binaural Beat	50	35.51628	0.710326	0.005172

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	***P-value***	*F crit*
Between Groups	0.019731	1	0.019731	3.398166	0.068291	3.938111
Within Groups	0.569019	98	0.005806			
Total	0.58875	99				

The efficiency rate for Alpha Binaural Beats with a percussive backbeat is, on average, 3.94% more efficient than a control alpha binaural beat without percussion.

Table 7: ANOVA Analysis of Beta Binaural Beat with Percussive Backbeat when Individual Coefficients are Maximized

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Binaural Beat with Percussive Backbeat	50	43.00518	0.860104	0.009523
Control Binaural Beat	50	41.61737	0.832347	0.006663
1-5				

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	***P-value***	*F crit*
Between Groups	0.01926	1	0.01926	2.379876	0.12613	3.938111
Within Groups	0.793106	98	0.008093			
Total	0.812367	99				

The efficiency rate for Beta Binaural Beats with a percussive backbeat is, on average, 3.36% more efficient than a control alpha binaural beat without percussion.

Table 8: ANOVA Analysis of Theta Binaural Beat with Percussive Backbeat when Individual Coefficients are Maximized

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Binaural Beat with Percussive Backbeat	50	34.87478	0.697496	0.002236
Control Binaural Beat	50	33.83984	0.676797	0.000475

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	***P-value***	*F crit*
Between Groups	0.010711	1	0.010711	7.899528	0.005972	3.938111
Within Groups	0.132877	98	0.001356			
Total	0.143588	99				

The efficiency rate for Theta Binaural Beats with a percussive backbeat is, on average, 3.11% more efficient than a control alpha binaural beat without percussion.

On average, when the individual coefficients of a percussion-based binaural beat are maximized, the binaural beat is **3.90%** more efficient than a binaural beat without percussion.

Table 9: ANOVA Analysis of Delta Binaural Beat with Percussive Backbeat when Individual Coefficients are Maximized

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Binaural Beat with Percussive Backbeat	50	37.44331	0.748866	0.00509
Control Binaural Beat	50	35.53678	0.710736	0.005446

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	***P-value***	*F crit*
Between Groups	0.036349	1	0.036349	6.900313	0.010002	3.938111
Within Groups	0.516233	98	0.005268			
Total	0.552582	99				

The efficiency rate for Delta Binaural Beats with a percussive backbeat is, on average, 5.20% more efficient than a control alpha binaural beat without percussion.

Table 10: ANOVA Analysis of All Binaural Beats with a Percussive Backbeat

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
All	200	128.2577	0.641289	0.00589
Overall without perc	200	148.6915	0.743457	0.006905

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	***P-value***	*F crit*
Between Groups	1.043848	1	1.043848	163.1627	1.5E-31	3.864929
Within Groups	2.54624	398	0.006398			
Total	3.590089	399				

On average, for all binaural beats with percussion, the calculated efficiency rating is **14.6%** less efficient than a binaural beat without percussion.

5 Discussion

When the coefficients for each individual factor, amplitude, frequency, and pulse and tempo were maximized, the mean of the efficiency rate of the percussion-based binaural beat was, on average, 4% more than the sample control binaural beats without percussion, indicating that binaural beats with percussive backbeats that were optimized would result in more efficient brainwave entrainment with regards to memory, focus-related tasks, and inducing meditative states. That is to say when the calculated pulse value of the beat was around 4.0 beats per second, which would correspond to an alpha brainwave according to the formula for tempo-to-entrainment, and when the binaural beat itself was an alpha beat, the pulse and tempo coefficient was said to be ”maximized” and the efficiency value would increase. In the same way, if the amplitude of both the binaural beat and the percussion corresponded to the specific values of the amplitude of an alpha binaural beat, 20-200 μV, the amplitude coefficient was said to be ”maximized”. Finally, when the percussion pitch, of a given frequency value, was sonically identical to the frequency range of the binaural beat, then the frequency coefficient for a percussion-based binaural beat was said to be ”maximized.”

Generally, the coefficient of efficiency has no drastic effect on the values of brain rate, however there is a slight indication that when the efficiency of a binaural beat was perceived to be higher, there was an overall decrease in the variation of the f_b values calculated by the formula.

The ANOVA analyses of the mean efficiency coefficients of both regular binaural beats and percussion-based binaural beats indicates that overall, percussion-based binaural beats are, on average, 15% more inefficient than regular binaural beats in eliciting frequency following response. This would indicate that the brainwave synchronization that is attempted by a percussion-based binaural beat is, on average, more disruptive than beneficial for brainwave entrainment in general and frequency following response, indicating that all percussion-based binaural beats, on average, would detract from stimulating memory and focus-related activity.

However, the analyses of note are the ones where the individual coefficients for a percussion-based binaural beat are ”maximized.” In this particular situation, percussion-based binaural beats are, on average, 4% more efficient than regular binaural beats in eliciting frequency following response, indicating that for these types of binaural beats, the synchronization effect of percussion intensifies the effect that it has on brainwave entrainment and frequency following response.

These conclusions align with [2] and [1] in suggesting that percussion has a strong influence over brainwave entrainment and the inducement of a trance-like state, and when the specific properties and characteristics of these percussive rhythms were optimized to match and coincide with the property of its binaural beat, then the efficiency rate was maximized overall.

There were a few limitations regarding this study that one should be aware of when replicating the experiment. The production of the binaural beat was created from audio directly recorded from a microphone to a computer instead of a third party interface. This caused the quality of the sound to be manipulated in a less efficient manner, and for some of the quality of sound to be lost in the audio transfer.

Moreover, the simulation did not account for aspects of human involvement such as mood, state of mind, or age. Thus, because the efficiency of a binaural beat was solely determined based off of sound analysis and simulation, irrespective of human conditions, one should note that replicating this experiment with potentially more accurate results will involve human involvement. This will be able to account for individual factors that influence a brain’s psychological susceptibility to auditory therapy, and overall will provide a more holistic approach on brainwave entrainment in different scenarios with regards to percussion.

For this reason, the next phase of this project will involve performing EEG and GSR analysis on humans using binaural beats with a percussive backbeat, which will allow to directly analyze the effects of frequency following response on brainwave entrainment and the subsequent effects on other psychological factors.

The general consensus from this research would be that the effect of percussion, for the most part, is disruptive when combined with other auditory therapy effects. However, it is notable that when certain aspects of a percussive rhythm are optimized to fit certain characteristics, the efficiency of an auditory or music therapy method could be enhanced significantly. These changes are much more easily observable when performing experiments on human subjects, which is the future plan of this research project.

There is an indication through this research that the backbone of auditory therapy can be improved to fit the demands of the lowest-common-denominator listener. This means that by adding more soothing musical elements to auditory therapy like binaural beats, auditory therapy becomes more accessible and more listenable to the general public, while also having even stronger results to improve brain-related activities such as memory and focus tasks.

6 Conclusion

This research analyzed the effect of a percussive backbeat on alpha, beta, theta, and delta binaural beats. Using computer software and percussion instruments, percussion-based binaural beats were recorded and shaped. These binaural beats were analyzed through Long-Term Average Spectrum (LTAS) and Spectrogram analysis, and the data values obtained from these analyses were used in a computer simulation. The computer simulation accounted for frequency, amplitude, pulse of percussive rhythm, and other factors, to create an efficiency rating and corresponding brain rate for a part ocular binaural beat. ANOVA analysis of the simulation results indicate that overall, percussion-based binaural beats have a net negative effect on the efficacy of binaural beats, making them 15% less efficient. However, when the percussive characteristics of a binaural beat were "maximized," they enhanced brainwave entrainment and frequency following response by 4%.

The future plans for this study involve testing the same percussion-based binaural beats on humans, using EEG and GSR analysis to track brainwave responses to the binaural beats. This will allow for the most comprehensive understanding of how percussion affects auditory therapy for a human subject directly.

Overall, this research indicates that there are more accessible avenues to be taken in terms of auditory therapy. For autistic and ADHD children especially, monotonous auditory therapy like binaural beats have been inefficient at providing profound effects. Adding musical components to auditory therapy will allow it's effects to be experienced and appreciated by the lowest-common-denominator listener, and appeal to the widest range of people. By adding soothing elements to auditory therapy, a more fruitful and accessible listening experience can be achieved, and in turn, memory, brain power, motor and social skills, as well as other deficiencies, can be vastly improved.

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