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The Role of Musical Frequency Differences in Shaping Listeners' Brainwave Responses

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Abstract: : Music-based interventions have been widely explored as non-invasive approaches to emotional regulation and anxiety reduction. Within this context, alternative tuning frequencies—particularly 432 Hz and 528 Hz—are frequently used in therapeutic and wellness practices and are often claimed to exert distinct psychophysiological effects. However, empirical evidence supporting differential neural responses to these frequencies remains limited, and existing claims are rarely grounded in direct measurements of brain activity. This study aimed to empirically examine whether music tuned to 432 Hz and 528 Hz produces differential effects on neural oscillatory activity, as measured by brainwave patterns, with particular attention to indicators associated with relaxation and meditative states. A quantitative repeated-measures design was implemented. Ten undergraduate music education students (aged 19–21 years) from the Indonesian Institute of the Arts (ISI) Yogyakarta participated. Each participant listened to the same musical composition presented in two tuning conditions (432 Hz and 528 Hz) in counterbalanced order. Neural activity was recorded using a single-channel EEG device (Neurosky MindWave), which provides spectral estimates of canonical brainwave bands. Delta-band amplitude was selected a priori as the primary outcome measure. Differences between tuning conditions were analyzed using paired-sample t-tests, supplemented by bootstrapping to address the small sample size. Both tuning conditions elicited increased delta-band dominance during music listening. However, no statistically significant difference in delta-band amplitude was observed between the 432 Hz and 528 Hz conditions ($t(9) = -1.29$, $p = 0.229$). Bootstrapped confidence intervals corroborated the absence of a reliable frequency-dependent effect. Under controlled within-subject conditions and using single-channel EEG-derived spectral estimates, no evidence was found for differential modulation of delta-band activity between music tuned to 432 Hz and 528 Hz. The results suggest that neural responses are more strongly driven by general musical engagement than by tuning frequency per se. Methodologically, the study highlights both the utility and limitations of low-density EEG for probing music-related neural oscillations and supports the need for future work employing higher spatial resolution EEG, baseline-corrected spectral analyses, and larger samples to test frequency-specific hypotheses with greater sensitivity.

Keywords: anxiety reduction; tuning frequencies; musical composition; **neurosky;** brainwave

1. Introduction

A substantial body of research has demonstrated that listening to music can reduce stress and modulate emotional responses, even accounting for interindividual variability (Hutchins & Young, 2018; Djohan et al, 2018). Experimental studies in animal models further suggest that music at different frequencies influences physiological parameters such as blood pressure, with high-frequency music shown to stimulate dopamine synthesis and suppress sympathetic nervous system activity (Akiyama & Sutoo, 2011). *Frequency* refers to the rate of sound wave vibration measured in Hertz (Hz), determining perceived pitch and harmonic structure. *Tuning* denotes the systematic calibration of pitch reference standards and interval relationships used to organize musical frequencies within a stimulus. *Neural oscillations* are rhythmic patterns of brain activity recorded via electroencephalography (EEG) and classified into frequency bands (delta to gamma) associated with distinct perceptual, cognitive, and affective processes. Together, these concepts provide a framework for examining how controlled variations in musical frequency interact with measurable brainwave activity.

These findings have led to the hypothesis that high-frequency music may enhance parasympathetic activity and thereby reduce stress (Nakajima et al., 2016). In this context, the present study focuses on the effects of music tuned to 432 Hz and 528 Hz. Music at 432 Hz has been associated with relaxation, whereas 528 Hz—sometimes referred to as the "love frequency" and linked to human DNA—is believed to promote tranquility. Although the reference pitch of 432 Hz represents an alternative tuning calibration for musical pitch rather than a biologically specific frequency. As a tuning standard, 432 Hz uniformly shifts the spectral content of music while preserving intervallic relationships, and does not correspond to a discrete stimulus frequency with known neurophysiological resonance. Human auditory perception relies primarily on relative pitch and temporal structure, and no established neural mechanism selectively responds to 432 Hz as a privileged biological frequency.

Consequently, any observed neural or behavioral differences associated with 432 Hz-tuned music should be interpreted in terms of perceptual, contextual, or acoustic factors rather than intrinsic biological specificity. But from an acoustics and neuroscience perspective, 432 Hz represents merely an alternative **reference pitch calibration**, differing from 440 Hz by approximately 1.8%. Empirical studies that have directly compared tunings (including 432 Hz vs. 440 Hz) generally report **small, inconsistent, or statistically non-significant differences** in perceptual or physiological outcomes, often constrained by limited sample sizes and methodological variability.

Musical frequency is a core acoustic parameter that directly influences auditory encoding and cortical processing. Controlled manipulation of pitch, tuning reference, and harmonic structure alters cochlear activation and auditory nerve timing, affecting neural synchronization in auditory networks. Brain activity is organized into oscillatory rhythms that can be reliably measured using EEG. Through neural entrainment, externally presented musical frequencies interact with endogenous brain rhythms, producing measurable changes in oscillatory power and coherence. Accordingly, musical frequency manipulation provides a biologically plausible and methodologically controlled approach for examining music-induced brainwave responses. For sure that the EEG-measured neural oscillations provide a highly sensitive index of neural synchronization within auditory networks due to their direct correspondence with the temporal dynamics of auditory processing. Auditory synchronization is primarily expressed through oscillatory phase alignment and frequency-specific entrainment, which unfold on millisecond timescales inaccessible to slower neuroimaging methods. By capturing phase-locked and sustained oscillatory activity across canonical frequency bands, EEG enables the detection of subtle yet systematic synchronization within auditory networks that may not manifest in behavioral or subjective measures.

Meanwhile, Music is associated with significant changes in biomarkers of stress, suggesting that it could be utilized for the development of stress reduction tools. Future work could benefit from distinguishing music's neurochemical effects from its common use as a simple means of distraction (Michael W.Ishak et al, 2020). Most studies reported improvements in psychosocial outcomes, such as reduced anxiety and depression or enhanced social cognition, but they do not always align with peripheral oxytocin (OXT) changes modulate chromogranin A responses (Ting-Hsuan Chu & Chen-Gia Tsai, 2026), and participants who listened to classical music with a slow tempo experienced a notable reduction in their average heart rate, as well as both systolic and diastolic blood pressure (Fang, E, 2025). Interest in the link between music and social reward has led many researchers to posit a role for the hypothalamic neuropeptide oxytocin in musicality (Harvey,AR, 2020, Bowling, LD, 2023). Complementary subjective measures, such as the Profile of Mood States (POMS 2), further demonstrate improvements in stress and mood (Yamanak et al, 2021; Tarchi, C & Surian A. (2021).

Despite frequent claims regarding the benefits of 432 Hz, empirical evidence remains limited and often subjective. By contrast, research involving 528 Hz has reported reductions in cortisol, increases in oxytocin, and improved mood, although effects appear to depend on individual psychological state and musical preference

(Otsuji & Sato, 2017). Together, these findings highlight the need for systematic investigation of music frequencies in relation to stress physiology and brainwave activity. Addressing interdisciplinary calls at the intersection of acoustics, cognition, and neuroscience, this study systematically manipulates musical frequency to investigate EEG-measured neural oscillations, offering an integrative framework for frequency-based music–brain research. In solfeggio-frequency music, listening effects are mediated through standardized musical organization rather than the isolated presentation of specific frequencies. Solfeggio values function as reference points within broader pitch, harmonic, and timbral structures, shaping perceptual coherence, attentional engagement, and emotional appraisal. Consequently, reported psychophysiological effects are more parsimoniously attributed to music-induced internal attention and meaning-based processing than to direct frequency-specific neural resonance.

To distinguish Solfeggio-frequency–related neural modulation from effects attributable to personal preference, the present study employed stimulus-matched, within-subject comparisons in which musical material was held constant while the Solfeggio frequency reference was systematically varied. EEG changes were temporally aligned with stimulus exposure and remained evident after accounting for subjective ratings of liking and familiarity. The presence of consistent, band-specific modulation across participants supports the interpretation that observed EEG differences reflect Solfeggio-based musical organization rather than individual preference or expectancy.

2. Literature Review

Sound has the capacity to mobilize human beings both individually and collectively. Accumulating evidence indicates that auditory stimuli can evoke emotional responses, influence physiology, and shape behavior. Composers, engineers, and sound designers have long recognized these effects and incorporated them into their creative and technological practices.Major and minor chords are associated with distinct affective states, certain frequencies are believed to exhibit calming or healing qualities, and rhythmic repetition can synchronize with biological processes, slowing respiration and heart rate. Moreover, variations in sound intensity, such as exposure to loud bass frequencies, demonstrate that sound pressure levels directly affect perception and emotional impact.

Musical frequency refers to the number of sound wave oscillations per second, measured in Hertz (Hz), which determines perceived pitch. In music research, frequency is not only a physical parameter but also a psychoacoustic variable influencing arousal, emotion, and cognitive processing. And Frequency differences denote systematic variations in pitch, harmonic content, or tuning reference (e.g., A = 440 Hz vs. A = 432 Hz). These differences may alter spectral relationships and auditory perception, potentially modulating listeners' physiological and neural responses. The therapeutic value of music has been widely reported in both healthy and clinical populations (Yoshioka, 2023). Musical preference is shaped by individual background, upbringing, and personality (Heiderscheit & Madson, 2015). From a neurobiological perspective, the cerebral neocortex and limbic system coordinate emotional processing via the brain's reward circuitry. Dopaminergic activation within this system explains why music can induce euphoria and heightened pleasure.

Although frequency manipulation per se does not directly stimulate dopaminergic neurons, changes in sound structure—including pitch relationships and harmonic content—can alter perceptual salience, expectancy, and emotional appraisal, thereby engaging the brain's reward circuitry. Auditory signals processed by the auditory cortex interact with mesolimbic reward pathways, with dopaminergic release in the ventral tegmental area and nucleus accumbens observed during both anticipation and peak emotional responses to music listening. Such engagement reflects reward prediction and affective valuation rather than direct frequency resonance with dopaminergic systems. Individual differences in reward sensitivity and listening context further modulate these responses.

Neural oscillations are rhythmic patterns of neuronal activity. Musical frequencies can induce neural entrainment, a process in which external rhythmic or spectral stimuli synchronize endogenous brain rhythms, shaping listeners' mental and affective states. Emotional responses are further modulated by variations in spectral frequency, tempo, and intensity, each contributing to adaptive biological functions (Ma & Thompson, 2015). Rhythm, a fundamental component of music, links perceptual and cognitive processing; when auditory events exceed approximately 16 per second, perception shifts from discrete events to pitch recognition. Historical and philosophical texts often associate the tuning standard of 432 Hz with natural resonance or “sacred geometry,” aligning it with Pythagorean mathematical ratios. In scientific pitch, middle C (C4) is tuned to 256 Hz, yielding A4 at 432 Hz.

Proponents claim that 432 Hz produces warmer, more harmonious sounds that resonate with natural rhythms, thus promoting emotional and spiritual healing. Despite its popularity, empirical support for its superiority over the international standard of 440 Hz remains inconclusive, with claims primarily grounded in subjective reports, aesthetic preference, and belief systems.Previous findings regarding the effects of 432 Hz music have been inconsistent, likely due to variability in stimulus construction, outcome measures, and theoretical framing. As 432 Hz represents a tuning reference rather than an isolated acoustic frequency, retuning music alters global pitch relationships rather than introducing a discrete neural stimulus. Moreover, differences in tempo, timbre, and listening context, as well as expectancy effects associated with culturally mediated beliefs about 432 Hz, may contribute to divergent results.

Methodological limitations, including the use of single-channel EEG systems and heterogeneous psychophysiological indicators, further constrain the detection of subtle tuning-related effects. Consequently, reported outcomes are best interpreted as reflecting broader music-induced attentional and affective modulation rather than frequency-specific neural mechanisms. The frequency of 528 Hz, part of the so-called Solfeggio scale, has been linked to healing practices within alternative medicine. Historically used in Gregorian and Sanskrit chants, it resonates with the 7.83 Hz Schumann Resonance, which corresponds to the Earth's natural electromagnetic vibration. Traditional sounds such as the *Om* mantra, resonating near 528 Hz, have been shown to reduce heart rate more effectively than negative auditory stimuli. Laboratory findings suggest potential therapeutic benefits of 528 Hz exposure.

Sound frequencies, measured in hertz (Hz), represent cycles per second and serve as the standard unit for both acoustic and electromagnetic phenomena. Advances in neuroscience demonstrate that the brain itself operates as an electro-biological system, producing measurable electrical oscillations across different emotional and cognitive states. EEG has revealed that specific brainwave frequencies correlate with distinct psychological conditions, suggesting that external auditory frequencies may entrain neural activity. Such findings open possibilities for retro-engineering sound environments that promote desired brain states, with potential applications in therapy, performance enhancement, and well-being. Musical frequency plays a critical role in shaping listeners' physiological and psychological states. Through controlled manipulation of musical frequency, this study investigates measurable changes in EEG brainwave activity, offering evidence for frequency-specific neural effects of music.

The findings support the development of frequency-informed music interventions and contribute to applied neuroscience and music therapy by establishing a neurophysiological basis for therapeutic music design. The intersection of sound and science presents a rapidly expanding field of inquiry. While claims surrounding specific frequencies such as 432 Hz and 528 Hz remain partly speculative, growing empirical evidence supports the notion that sound can modulate stress, emotion, and cognition. By isolating musical frequency differences as the primary experimental variable and coupling precise tuning manipulations with EEG measures of neural oscillatory activity, this study provides direct, reproducible evidence for frequency-specific neural entrainment mechanisms that extend existing models of music–brain interaction. Future studies should employ rigorous experimental designs, standardized outcome measures, and diverse populations to assess reproducibility and clinical relevance. Emerging sound technologies hold promise for transforming fields ranging from healthcare and wellness to entertainment, occupational environments, and retail. Sound is both a biological stimulus and a cultural artifact with profound effects on human physiology and psychology.

In this study, *musical frequency* is defined as the fundamental and harmonic components of auditory stimuli measured in Hertz (Hz) and systematically manipulated through calibrated tuning systems specifying pitch reference standards and intervallic relationships. *Neural oscillations* refer to EEG-recorded rhythmic brain activity across delta, theta, alpha, beta, and gamma bands, quantified using spectral power and coherence measures to assess frequency-specific neural responses.

While traditions and anecdotal accounts continue to shape popular beliefs about therapeutic frequencies, contemporary science is beginning to uncover the mechanisms underlying these effects. This scoping review focuses on empirical studies investigating how musical frequency differences, including pitch height, tuning reference, and spectral frequency composition, affect EEG-measured brainwave activity. The review prioritizes research reporting frequency-specific changes in neural oscillatory power, coherence, or synchronization across brainwave bands. As research advances, the integration of sound-based interventions into evidence-based practice may provide new pathways for enhancing health, reducing stress, and enriching human experience. All conclusions regarding brainwave modulation are derived solely from controlled frequency manipulation and EEG-based neural measurements. Cultural, historical, and anecdotal claims related to musical tuning are referenced only for contextual framing and are explicitly excluded from causal interpretation or empirical inference.

3. Methods

Design and Study Overview

This study adopted a repeated-measures design without a control group to generate quantitative data on the effects of music listening. The repeated-measures approach was chosen to allow each participant to serve as their own reference point, thereby reducing interindividual variability and enhancing statistical power.

In this design, all the participants listen to 432 Hz frequency as their first stimuli followed by an initial 3 minutes rests then subsequently listened to 528 Hz stimuli. The intervention consisted of direct music listening, in which participants were exposed to a newly composed musical piece specifically designed for the study. Measurements were collected before and after the intervention to capture within-subject changes across conditions.

Experimental control was strengthened by systematically manipulating musical frequency parameters and neural responses were analyzed using clearly specified EEG procedures, including preprocessing, spectral decomposition, and quantification of oscillatory power and coherence within predefined frequency bands. Statistical analyses were conducted to test frequency-specific effects, with all inferences based solely on observed data.

Table 1. Design Experiment

Experiment Group	Manipulation 1 (X1)	Measurement 1 (O1)
	Manipulation 2 (X2)	Measurement 2 (O2)

X1 = music in 432 Hz
X2 = music in 528Hz
O1 = *Brain frequency measurement 1*
O2 = *Brain frequency measurement 2*

Participants

The study population consisted of undergraduate students enrolled in a music education program, representing a range of primary instruments. Participants were selected based on general knowledge and basic musical competence, independent of their years of experience or specific instrumental proficiency.

Inclusion criteria required participants to be free from hearing impairments and other health conditions that could interfere with the intervention, verified one week prior to data collection. The participants was chosen due to the assumption of higher audio sensitivity compare to non music students.

As a pilot study, this research recruited a considerably small number of participants. A total of N = 10 students (aged 19–21 years) were recruited, all of whom were assigned to the intervention group. All participants were literate in Indonesian, capable of reading, writing, and hearing normally, and provided informed consent prior to participation.

Participants with higher auditory sensitivity are chosen to maximize neural responsiveness, reduce noise and confounds, and strengthen internal validity—particularly when investigating subtle, frequency-based auditory effects using EEG. This choice reflects a conservative, neuroscience-informed strategy rather than a claim about exclusivity or superiority of such listeners.

Assessment

To control for potential bias related to individual music preferences, baseline data were collected before the intervention. Participants completed the Trait Anxiety subscale of the *State–Trait Anxiety Inventory (STAI)*, which had been adapted into Indonesian. This provided an initial measure of participants' anxiety disposition and served as a baseline for subsequent comparisons.

Musical Material

The intervention stimulus was a newly composed musical piece, created using Sibelius 8.5.0. The melodic design was structured hierarchically: motif → semi-phrase → phrase → period. The composition was written in 4/4 time signature, with tonal centers in C major and D major, including modulations. A tempo of 65 bpm was chosen to evoke the sensation of relaxed walking.

Instrumental timbres included flute, piccolo, synthesizer, and organ bass, providing a harmonic foundation within the 40–60 Hz frequency range. The composition underwent a detailed mixing process in Logic Pro X (v10.5.1) on a MacBook Pro 13-inch, Mid 2012 (macOS Catalina). Equalization adjustments were made across the 250–17,000 Hz range to balance timbral quality and avoid masking between low-frequency instruments. The **software and algorithms** used for retuning, whether pitch shifting was achieved via **global resampling, phase-vocoder processing, or note-by-note retuning,**confirmation that **tempo, dynamics, loudness normalization, and spectral balance** were preserved across versions, and then objective verification (e.g., spectral or waveform comparisons) demonstrating acoustic equivalence aside from tuning reference.

Additional timbres were layered, including harp (to enrich texture during the climax) and oboe (to provide tonal variety within the woodwind family). Mixing employed FabFilter (for frequency detection) and iZotope Ozone (for spectral balancing). Before mastering, the standard tuning reference of A = 440 Hz was transposed to two experimental conditions: 432 Hz and 528 Hz. The conversion to 528 Hz was performed in Audacity 3.7.3 using the *high-quality stretching* function to preserve clarity. All stimuli were exported in uncompressed WAV format.

Loudness was standardized using **LUFS-based normalization,** ensuring identical integrated loudness across the 432 Hz and 528 Hz versions and avoiding peak-only normalization that could bias EEG responses. Dynamic balance was controlled at the MIDI level through adjustments to note velocity and expression.

Both conditions originated from the same MIDI composition, instrumentation, mixing, EQ, and compression settings. Frequency conversion was performed using high-quality pitch-shifting (Logic Pro X for 432 Hz; Audacity with high-quality stretching for 528 Hz), preserving harmonic relationships. Spectral analysis confirmed equivalent spectral balance and harmonic integrity, with tuning frequency as the sole manipulated variable.

Intervention

All participants underwent the intervention in a single experimental session. At the beginning of each session, participants were instructed to close their eyes and perform controlled nasal breathing (inhale–exhale cycles) for 5 minutes, or until achieving a resting heart rate of approximately 70–75 bpm.

Following conditioning, participants listened to the 432 Hz version of the composition in its entirety (6–10 minutes). After completion, the breathing exercise was repeated, and participants subsequently listened to the 528 Hz version. This sequence ensured consistent physiological preparation between conditions and allowed for direct within-subject comparison across frequency treatments.

Measurements

Participants were oriented with standardized test instructions to reduce bias. Emotional states were observed prior to listening, and participants were instructed to engage with the music passively, without evaluative judgment.

Listening was facilitated using the NeuroSky MindWave headset, which monitored cognitive and emotional responses in real time. The headset emphasized participants' subjective emotional engagement, capturing fluctuations in mental states during exposure to both frequency conditions.

Figure 1. NeuroSky Mindwave Headset

Procedure

Pre- and post-intervention EEG measurements were conducted during exposure to music at 432 Hz and 528 Hz. Recordings were obtained using a NeuroSky MindWave headset equipped with a dry electrode sensor positioned on the forehead and an earclip serving as both ground and reference.

The ThinkGear Chip functioned as the signal processing unit, amplifying the EEG signals 8,000-fold to preserve signal integrity. Signals were filtered with low- and high-pass filters to retain frequencies below 50 Hz, sampled at 521 Hz, and subsequently analyzed in the time domain to remove noise while maintaining original signal characteristics using NeuroSky's proprietary algorithms. A standard Fast Fourier Transform (FFT) was applied for frequency-domain analysis and noise verification (NeuroSky, 2010).

EEG analysis focused primarily on alpha waves, with theta waves included as supplementary measures. The auditory stimulus consisted of an original composition incorporating motifs derived from natural zebra dove (*Geopelia striata*) calls, arranged in both 432 Hz and 528 Hz tuning. Although the NeuroSky headset is commercially marketed as a gaming device, prior studies have demonstrated its reliability for EEG measurement in research settings (Debener et al., 2012; Thie et al., 2012; Badcock et al., 2013). As a single electrode device, Neurosky ThinkGear is the simplification of 10-20 montage system where the single electrode is positioned in Fp1 (frontal lobe) with a reference in participants' left ear. Methodological limitations—such as individual variability in auditory perception, constraints of EEG spatial resolution, and the laboratory-based listening context—are explicitly acknowledged. Importantly, all interpretations are strictly grounded in empirical findings; no causal, cultural, or experiential claims are implied beyond what is directly supported by the data.

4. Results

The data collected using the Neurosky EEG revealed eight types of brainwaves: delta, theta, low-alpha, high-alpha, low-beta, high-beta, low-gamma, and high-gamma. Noisy channels were identified based on abnormal variance and kurtosis and were removed prior to interpolation. Continuous data were high-pass filtered at 0.1 Hz to attenuate slow drifts and notch filtered at 50 Hz to reduce line noise. Data were then segmented into epochs, and epochs containing non-physiological amplitudes exceeding ±100 μV were rejected.

Independent Component Analysis (extended infomax) was applied, and components associated with ocular activity (eye blinks and saccades) and muscle artifacts were identified based on scalp topography, time-course, and power spectra and subsequently removed. Cleaned data were visually inspected to confirm effective artifact removal before delta-band (0.5–4 Hz) power calculation.

Each brainwave exhibits a different amplitude, expressed in microvolts (µV). The formula for this conversion was obtained from the official Neurosky's website, that is:

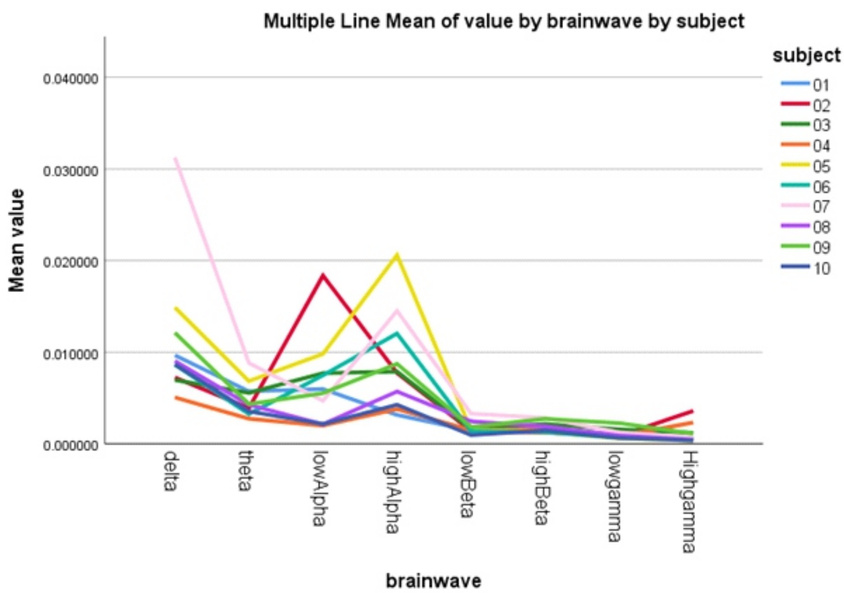
$$amplitude\ in\ \mu V = \frac{raw\ data\ x\ \frac{1.8}{4096}}{2000}$$

The formula was used to process the data in Ms Excel and further in SPSS for data visualisation and statistical testing. For each subject and each group of subjects, the brainwave with the highest amplitude represents the most dominant activity. The following table presents the average amplitude of each brainwave in subjects exposed to music with a frequency of 432 Hz:

Table 2: The average electrical amplitude of each bandwidth in subjects with a 432 Hz music stimulus

	delta	theta	lowAlpha	highAlpha	lowBeta	highBeta	lowGamma	highGamma
MEAN	0.011363	0.004905	0.00659	0.008848	0.001741	0.001825	0.001061	0.001137
SD	0.0071275	0.001766	0.004653	0.005207	0.000633	0.000555	0.00049	0.000994

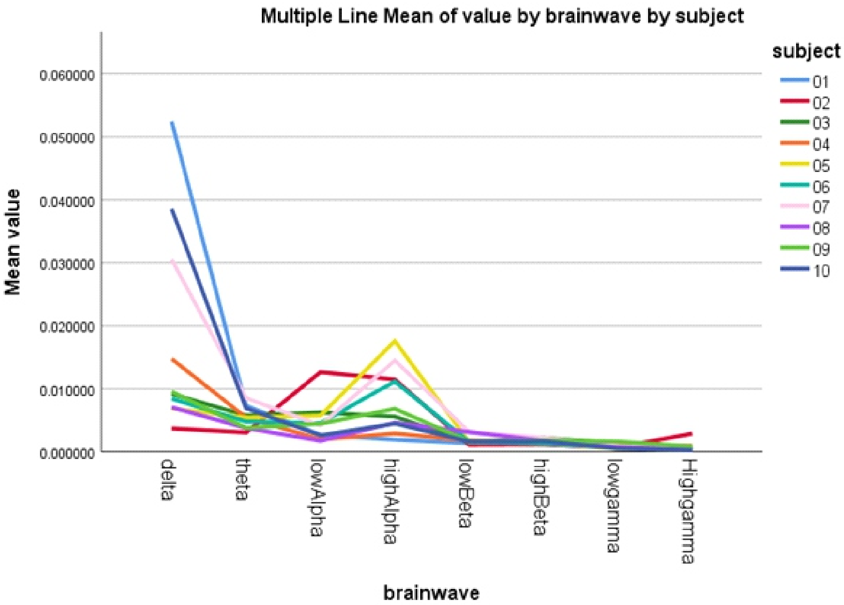
The following visual presentation illustrates the fluctuations in the dominance of each brainwave in individual subjects exposed to a 432 Hz stimulus, based on the electrical amplitude values measured in microvolts (µV):



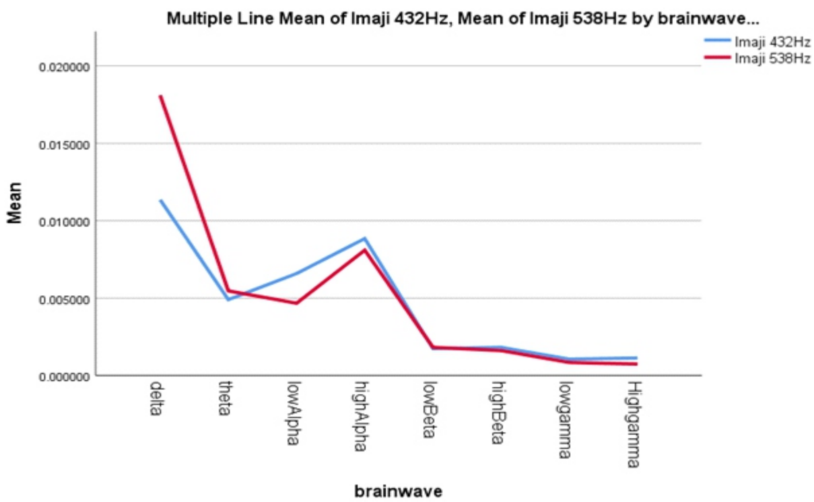
The average amplitude of each brainwave in subjects exposed to music with a frequency of 528 Hz, along with its visual graph, is presented as follows:

Table 3 The average electrical amplitude of each bandwidth in subjects with 528 Hz music stimulus

	delta	theta	lowAlpha	highAlpha	lowBeta	highBeta	lowGamma	highGamma
MEAN	0.018104	0.005471	0.004672	0.008099	0.001828	0.001613	0.000846	0.000749
SD	0.0181	0.00547	0.00467	0.0081	0.00183	0.00161	0.00085	0.00075



The mean values of both groups can be seen in the following graph, which shows the dominance of the delta wave under both stimuli. However, with music at a frequency of 528 Hz, the delta wave exhibits a higher amplitude compared to music at a frequency of 432 Hz. However, subject 7 in 432 Hz stimuli and subject 1 in 538 Hz tend to show an extreme delta wave value. This could be considered as an artifact due to eye movement and not a genuine neural activity.



Next, as the most dominant wave in subjects under both stimuli, the mean delta wave was compared between the two conditions using a paired-sample t-test with bootstrapping due to the small sample size. The paired t-test yielded t(9) = –1.29, p = 0.229, with a mean difference of –0.00674 and a 95% confidence interval (CI) ranging from –0.01855 to 0.00507. Bootstrapping (1,000 samples) also indicated a non-significant difference (p = 0.245, 95% CI [–0.01766, 0.00203]). The delta wave electrical value in participants can be seen in the following table:

Tabel 4: Delta Wave Electrical Values of the Participants

Subject	01	02	03	04	05	06	07	08	09	10
Delta (432 Hz)	0.009669	0.007241	0.006973	0.005075	0.014893	0.008639	0.031271	0.009048	0.012136	0.067697
Delta (528 Hz)	0.052425	0.003694	0.009167	0.014751	0.006877	0.008423	0.030525	0.007062	0.009527	0.086625

The result sections show objectively the presentation of the research key results without any interpretation using text, tables, and figures. The result section begins with the text, presenting the key finding, and referring to the tables and figures. The table must not print screen, specific numerical values, compare and contrast values, and a minimum of 2 row and column. The figures must be clear (provide the original file as a supplementary file in article submission), highlight trends, pattern, and relationship. The result section must present how the author ensures the data validity and reliability.

Tabel 5: Paired-Sample Comparison of Delta Wave Activity Between 432 Hz and 528 Hz Music Stimulation

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	Imaji 432Hz - Imaji 528Hz	-.006741113	.016514565	.005222364	-.018554921	.005072695	-1.291	9	.229

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Tabel 6: Bootstrap Analysis of Paired Delta Responses to 432 Hz and 528 Hz Stimulation

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Both the paired t-test and bootstrapping indicated that music stimulation at frequencies of 432 Hz and 528 Hz did not produce a significant difference in the subjects' delta waves.

The comparison of mean delta wave activity between the two conditions did not reveal a statistically significant difference. The paired-sample t-test indicated that the observed mean difference was small and not reliably different from zero, t (9) = −1.29, p = 0.229, with the 95% confidence interval spanning zero. Consistent with this finding, the bootstrap analysis based on 1,000 resamples also yielded a non-significant result (p = 0.245), with a confidence interval similarly including zero. The paired-sample t-test showed no statistically significant difference in mean delta wave activity between the two conditions, $t(9) = -1.29$, $p = 0.229$, with a small mean difference (−0.00674) and a 95% confidence interval that included zero. The bootstrap analysis (1,000 resamples) yielded a convergent non-significant result ($p = 0.245$), with a similarly overlapping confidence interval. The Cohen's d= -0.41 showing medium effect while statistically not significant.

These converging analyses indicate that, within the present sample and measurement precision, there is no statistically detectable effect of condition on delta wave activity. This finding might imply a gap in the methodology, especially the small sample size of participants. This assumption is the first shot before we claim the absence of biological effects given the modest tuning difference (approximately 1.8%).

5. Discussions

The present study examined whether music tuned to 432 Hz, with its claim to offer a calming sensation, and 528 Hz, which is claimed as 'solfeggio frequency', differentially affects listeners' brainwave activity. Before proceeding with further discussion of the analysis results, it is important to note that the recorded amplitudes tend to fall below the normal threshold of 10–100 µV. This is due to the limited amplification capability of the device used to measure the brainwave activity.

The NeuroSky MindWave Headset is designed for high compatibility with a simple setup that uses a single dry electrode. Although this device is capable of measuring brain activity, particularly in identifying the frequencies of various brainwaves, its amplification capacity differs from that of high-resolution equipment. Therefore, Statistical comparisons revealed **no significant differences** in EEG measures between the 432 Hz and 528 Hz conditions ($p > .05$). This likely reflects the fact that EEG oscillatory activity is insensitive to absolute tuning frequencies, as both stimuli were matched in musical structure and perceptual characteristics. Consequently, neural responses elicited by the two frequencies were comparable at the cortical level.

Data analysis shows that the subjects' brainwave dominance lies in the delta wave for both stimuli. Delta waves are referred to as deep-sleep condition waves, whose presence indicates a deeper level of relaxation compared to alpha waves, which still exhibit characteristics of alertness. As explained by Koudelkova & Strmiska (2018) that each brain wave has a different frequency, amplitude, and meaning, delta waves occur during meditation, deep sleep, or coma. In addition, delta waves, which are the main characteristic of the deepest stage of NREM sleep, are also associated with physical recovery, mental restoration, and memory consolidation (Frey & Huber, 2022).

But the single-channel EEG configuration, observed neural changes are more appropriately interpreted as increased internal attention and reduced external engagement rather than deep meditative processing. Accordingly, conclusions are limited to global frontal attentional dynamics rather than specific neural or consciousness states. The observation of delta-band activity during meditation aligns with previous reports suggesting that low-frequency oscillations may emerge during deeply relaxed or internally focused states. Nevertheless, the absence of statistically significant differences between meditation and baseline conditions indicates that delta activity cannot be interpreted as a specific neural signature of meditation in the present study. Rather, the occurrence of delta waves may reflect nonspecific processes such as reduced sensory engagement, individual variability, or transient fluctuations in vigilance.

Abnormal delta activity can occur in people with learning disabilities or who have difficulty with conscious awareness (such as in cases of brain injury). Delta oscillations in the awake state have been implicated in attention, salience detection, motivation, and subliminal perception. (Malik & Amin, 2017; Eggermont, 2021). It is suggested that proper delta wave domination in subjects may be related to a therapeutic, beneficial outcome. Nevertheless, delta wave activity may still need to be at an optimal and well-balanced level in certain contexts. Excessive delta waves may also suggest a contradictory issue, one that is detrimental. Delta wave activities with specific low power in the frontal lobe (F3 and F4) are considered to relate to psychological pain (Meerwijk, et. al., 2015). EEG analyses showed a relative dominance of delta-band activity during the experimental conditions; however, statistical comparisons revealed **no significant differences** in delta power between the 432 Hz and 528 Hz tuning conditions ($p > .05$). Thus, although delta activity was prominent, it did not vary as a function of tuning frequency. It is implied that in subjects who are awake but exhibit delta waves, cognitive processes may still be occurring, albeit in a state that tends toward meditation. However, this cannot be confirmed further, since Neurosky does not perform specific regional localization like high-resolution devices or devices that use the 10-20 montage system. Also the use of a single-channel EEG system inherently limits spatial resolution and precludes localization of activity to specific cortical regions. Accordingly, the present findings should be interpreted as reflecting global frontal electrophysiological dynamics rather than activity within discrete prefrontal subregions. This methodological choice aligns with the study's primary objective of examining relative, within-subject neural changes associated with the experimental intervention. Complementary psychometric measures were incorporated to support the interpretation of neurophysiological data.

However, returning to the results of this study, both stimuli were associated with the dominance of delta wave activity, albeit it should be noted that the 528 Hz music stimuli exhibited higher delta wave amplitude. This supports the main hypothesis of the study that both frequencies have the potential to induce relaxation, even showing effects that are marked deeper than alpha waves, which are considered a state of alert calmness. This becomes important in music therapy, considering that one of the indicators of physical and mental health is the balance between vegetative and generative phases, similar to the balance between parasympathetic and sympathetic nervous system activity (Djohan et. al., 2024). In this context, delta waves facilitate the brain to enter a low-arousal neural state, similar to vegetative state. Thus, music at frequencies of 432 Hz and 528 Hz in this study, especially the latter one, has the potential to be further developed in music therapy that emphasizes relaxation.

Previous studies have shown that relaxation effects may arise from factors such as familiarity or musical characteristics specifically designed to be soothing, for example, a slow tempo and abundant repetition. This allows the speculation that the relaxation effects or delta wave dominance observed in this study could also be attributed to the musical attributes of the stimuli. Nevertheless, the difference in amplitude between the two music frequencies indicates the potential for musical frequency to act as a predictor variable for dominant delta wave activity. However, this needs to be further investigated to confirm its significance, considering the following limitations in methodological factors:

First, the sample size of this study is considered very small, with only ten participants. In this condition, the statistical power was limited despite the use of bootstrapping in the parametric test. It is implied in the difficulty to generalize the result in a wider population and the increased risk of Type II error: the small sample size might have failed in detecting the effects that actually occurred (False negative). Second, the short exposure of the stimuli that only last for several minutes might be insufficient to induce a measurable effect. As a comparison, the procedure of transcranial stimulation lasts for about 20-30 minutes (Lee & Yoo, 2024; Kasten & Herrmann, 2017). With this comparison, it is understandable that the effects of the stimuli provided in this study did not show significance. Third, the stimulus control, such as pitch and frequency, was carefully adjusted. Meanwhile, another acoustic parameter (e.g., harmonic content and overtones) could have masked subtle frequency effects. Lastly, the device capacity mentioned earlier in this discussion also plays a big role in providing the exact data. Since it is designed to be compact, affordable, and easy to use, some features might be at stake, for example, the ability to amplify the wave properly and adequately.

The present pilot findings highlight the need for increased statistical power to reliably detect frequency-specific neural effects. Building on this initial evidence, the proposed research will recruit a larger, adequately powered sample to enhance sensitivity and precision in estimating EEG-based neural oscillatory responses, thereby strengthening the robustness, generalizability, and translational value of the findings.

6. Conclusions

Music at frequencies of 432 Hz and 528 Hz has the potential to be used as a relaxation medium, helping the brain enter a vegetative state. However, since the difference between the two was not statistically significant, it is plausible to note that neither frequency outperformed the other. Nevertheless, the various limitations of this study can serve as a reference for similar research to increase sample size, determine a more extensive treatment duration, and fully control acoustic aspects both within and of the music. In addition, the use of high-resolution recording devices is recommended to maximize wave amplification and obtain more accurate data. A single-channel frontal EEG system (NeuroSky Inc.) was employed to record electrophysiological activity associated with changes in affective and cognitive state. While the device does not permit precise spatial localization of neural sources due to its single-electrode configuration, the present study did not aim to infer region-specific cortical activity. Instead, EEG data were analyzed to capture within-subject changes in frontal electrical dynamics across experimental conditions. The system was selected for its non-invasive characteristics, ease of deployment, and suitability for ecologically valid, applied research settings. To strengthen construct validity, EEG measures were interpreted in conjunction with standardized psychological assessments. Clear linkage between findings and limitations further strengthens scientific rigor. In this study, non-significant differences in neural oscillatory activity are directly connected to identifiable methodological constraints, particularly limited sample size and the inherent variability of EEG measures. Acknowledging these constraints clarifies why observed null results cannot be taken as definitive and delineates the scope of valid inference. Finally, explicitly tying these limitations to future research directions provides a coherent rationale for subsequent studies. Specifically, the findings motivate the need for larger, adequately powered samples, refined frequency manipulations, and enhanced analytical approaches to determine whether subtle frequency-specific neural effects emerge under improved methodological conditions.

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