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Research Article

Differences in brain electrical activity between musicians and non-musicians while listening to 440 Hz and 432 Hz musical compositions

Hasan Batuhan Dirik
Corresponding Author, Assist.Prof.Dr. Hasan Batuhan Dirik, Lokman Hekim University, Faculty of Sports Sciences, Ankara, Turkiye. **Email:** batuhandirik@gmail.com **ORCID:** 0000-0003-3463-4469

Cemile Bengi Baraz Çınar
Assoc. Prof. Dr. Anadolu University, State Conservatory, Department of Piano, Eskisehir, Turkiye.
Email: cbbaraz@anadolu.edu.tr **ORCID:** 0000-0002-7639-0012

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Abstract
The aim of this study was to examine the effects of music played at 432 Hz and 440 Hz on brain electrical activity, considering the specialization in music. The study included 11 non-musicians and 10 musicians, with participants completing two sessions, 24 hours apart. In the first session, participants listened to the 432 Hz Samuel Osmond Barber "Adagio for Strings Op. 11" and the 440 Hz Petrovich Mussorgsky "Night on Bald Mountain" compositions. In the second session, the 440 Hz "Adagio for Strings Op. 11" and the 432 Hz "Night on Bald Mountain" were performed. Brain electrical activity was assessed using coherence and Power Spectral Density (PSD) methods. The results revealed differences in brain electrical activity between musicians and non-musicians when listening to music at different frequencies. In the PSD analysis, a two-way ANOVA showed a significant group effect ($p < 0.05$; ηp2=0.086) in the O1 channel within the theta frequency. Post hoc Tukey HSD tests revealed that O1 theta values were higher in musicians. Additionally, a significant frequency effect was observed in the Pz channel within the theta frequency ($p<0.05$; ηp2=0.128), with 440 Hz producing higher Pz theta values. In the T8 channel, a significant frequency effect was found across the alpha 1, alpha 2, and beta 1 bands ($p<0.05$; ηp2=0.103, 0.102, 0.118), with higher values observed at 440 Hz, but no significant group effect or interaction between group and frequency. Furthermore, coherence analysis indicated higher coherence values in the fronto-occipital region while listening to music at 432 Hz ($p<0.05$; ηp2=0.101). In conclusion, the findings suggest that music frequency can influence brain activity and that there are significant differences in brain responses between musicians and non-musicians.

Keywords
connectivity, EEG, frequency, music therapy, musical expertise

Introduction
Sounds, such as noise, human voice, or musical compositions, constitute a significant aspect of our environment, influencing our behaviors and emotions. Through sound, we establish communication not only with fellow humans but also with various species (Frühholz et al., 2016). Moreover, musical evaluations play a substantial role in the scientific realm. For instance, neuroscientists explore the impact of music on the treatment of certain diseases (Rodríguez-Rodríguez et al., 2022; Sesso & Sicca, 2020), performance changes in sports-related activities (Atan, 2013; Belkhir et al., 2019), shopping and marketing dynamics (Yi & Kang, 2019), meditation practices (Hernandez-Ruiz & Dvorak, 2021), and sleep disorders (Dubey et al., 2019). The investigation of musical effects on the brain electrical activity considerably increased in the last decade.

Music has been linked to various advantages in sound processing, contributing to structural and functional enhancements in certain cognitive abilities while also inducing neuroplasticity (Herholz & Zatorre, 2012; Neves et al., 2022). Recent studies over the past decade have underscored the correlation between music training and executive functions, specifically in inhibitory control, cognitive flexibility, and working memory (D'Souza et al., 2018; Ding et al., 2018; Li et al., 2015). The exploration of experience-based modifications resulting from musical exposure is deemed crucial for understanding arousal-related neurophysiological changes. In this context, electroencephalogram (EEG) emerges as a well-suited method for investigating such changes due to its provision of high temporal resolution. EEG is a powerful non-invasive method for the investigation of brain electrical activity via electrodes on the scalp surface. Brain oscillations are commonly classified based on their frequency intervals measured in Hertz (Hz), known as sub-bands, including delta (1-4 Hz), theta (4-8 Hz), alpha (8-12 Hz), beta (12-30 Hz), and gamma (+30 Hz). These sub-bands are intricately linked to a diverse range of somatic, visual, auditory, motor, perceptual, and cognitive functions. Notably, specific investigations have suggested a correlation between heightened alpha activation and exposure to music (Verrusio et al., 2015).

The reference frequency of musical instruments was identified as 440 Hz in the 1950s and officially confirmed as a global standard by the International Organization for Standardization (ISO) in 1975, although efforts toward this standardization began much earlier, with ISO initially recommending 440 Hz in 1939 to resolve discrepancies across European orchestras (Gribenski, 2021). In 1989, the Schiller Institute, associated with Lyndon LaRouche, sought to challenge this prevailing standard by petitioning the Italian legislature to adopt 432 Hz instead, a slightly lower reference pitch believed to align more closely with natural resonances and to offer a more harmonious experience. This initiative gained notable support from prominent opera figures such as Placido Domingo, Luciano Pavarotti, Renata Tebaldi, and Birgit Nilsson, yet ultimately failed to achieve legislative change. Nevertheless, the Schiller Institute continued to advocate for 432 Hz, arguing that it was indispensable for preserving the authenticity of Western art music and resonated with broader movements promoting music's connection to natural vibrations (Rosenberg, 2021; Haynes, 2002).

After years, the 432 Hz reference frequency unexpectedly gained popularity in the online sphere. Various writings and shares have emerged claiming the efficacy of 432 Hz in multiple aspects of music, although these claims often lack a scientific basis. Among these assertions are that 432 Hz enhances emotional balance, strengthens mental clarity, and even aligns better with natural frequencies. However, within scientific areas, there is a widespread consensus that musical frequency preferences are subjective and lack a scientific foundation (Palmblad, 2008). Evidence supporting the idea that 432 Hz provides a special 'natural harmony' is either insufficient or inconclusive. On the other hand, the surge in popularity of 432 Hz is propelled by alternative music communities and the influence of digital media. On platforms like YouTube and other music-sharing platforms, a plethora of content revolves around popular songs and new compositions transformed to 432 Hz. Such content often claims to offer listeners a more 'natural' or 'harmonious' experience (Rosenberg, 2021). In light of all this information, it remains uncertain whether the purported effects of 432 Hz music on human physiology are mythical or grounded in scientific reality.

Some studies reported the effect of 432 Hz music on the human organism such as heart rate and stress quantification (Calamassi & Pomponi, 2019; Menziletoglu et al., 2021; Calamassi et al., 2022; Di Nasso et al., 2016). Despite several studies with EEG and musical exposure, in the different frequencies, musical compositions' effects on EEG sub-bands and coherence are not clear yet. In light of these considerations, the present study aims to investigate the coherence and power spectral density (PSD) values of the brain electrical activations during the listening of music at 432Hz and 440Hz among both musicians and non-musicians. We hypothesized that there would be differences in coherence and spectral density values within the frontal cortex, an area actively involved in cognitive processes, and the temporal cortex, which plays a crucial role in auditory processing and comprehension of auditory stimuli.

Method

Participants

The sample size was determined to be 24 participants based on a power analysis conducted using G*Power (effect size = 0.25, power = 0.80, α = 0.05). 24 right-handed participants were recruited for the study. Before the experiment, the participants were not informed about the song they would listen to. 3 people who stated that they were familiar with the songs after the recordings were finished were excluded from the study (11 non-musicians, 10 musicians, age: 32.74±7.43). The musician group comprised participants who were either students or graduates of the Faculty of Fine Arts or Conservatory, and who continued to engage in musical processes as instrumentalists playing at least one instrument or as vocalists. The non-musician group consisted of participants who had never played any musical instrument throughout their lives and had not undergone any music education. The participants stated that they had no neurological or psychological disease and had normal hearing abilities. This study was approved by the ethical committee of Anadolu University (329087). Alcohol and caffeinated drinks are indicated to affect the electrical activity in the brain. Therefore, the participants were instructed not to consume caffeinated or alcoholic drinks at least 24 hours before the experiments (Ajjimaporn et al., 2022). The process and risks associated with the study were explained to the participants, and written informed approval was acquired.

Experimental Procedure

EEG data were recorded in Eskisehir Technical University, Movement and Motor Control Laboratory. The participants joined two experiment days ~24 hours apart. Before listening to music, participants were seated comfortably on a chair. Electrode locations were prepared using an abrasive gel (Nuprep, Weaver and Co., Aurora CO) to reduce impedance level. Conductive gel (Electro-Gel, Electrocap International Inc., USA) was injected into electrodes. Then resting state EEG (rsEEG) was recorded for 3 min in eyes-closed (EC) condition before each experiment day. Two musical compositions which have 432 Hz and 440 Hz were performed. On the first visit participants sequentially listened to 432 Hz Samuel Osmond Barber's "Adagio for Strings Op.11" and 440 Hz Petrovich Mussorgsky's "Night on Bald Mountain" with ~10 minutes intervals. During the second visit, the participants sequentially listened to 440 Hz Samuel Osmond Barber's "Adagio for Strings Op.11" and 432 Hz Petrovich Mussorgsky's "Night Bald on Mountain" compositions ~10 minutes intervals.

The selection of Samuel Barber's Adagio for Strings Op.11 and Modest Mussorgsky's Night on Bald Mountain in this study is driven by the stark contrasts between the two works. Samuel Barber's Adagio for Strings Op.11 and Modest Mussorgsky's Night on Bald Mountain exhibit striking differences in both musical structure and emotional atmosphere. Adagio for Strings is characterized by a slow tempo, minimal melodic development, and a delicate orchestration that fosters a melancholic and introspective mood. The piece progresses with subtle harmonic transitions, primarily utilizing strings to create a sense of emotional depth and introspection, gradually building in intensity without departing from its serene and contemplative character. In contrast, Night on Bald Mountain is marked by fast tempos, expansive orchestral forces, and the prominent use of brass instruments, generating a dramatic tension that evokes an eerie and supernatural atmosphere. The work features sudden dynamic shifts and intense thematic material, with the orchestration being far more vibrant and explosive. While Barber's composition creates a sustained emotional resonance through its simplicity and subtlety, Mussorgsky's piece is driven by dramatic contrasts and energetic orchestral color, emphasizing external conflict and visceral excitement. The fundamental contrast between these two works lies in Barber's focus on a gradual emotional buildup within a serene framework, while Mussorgsky's piece thrives on vivid orchestral textures and rapid shifts in mood to convey tension and fear.

All recordings were acquired at the same time of the day. During the experiments, the temperature of the recording room was 24 °C and the lights were dimmed. Both musical compositions were converted from 440Hz to 432Hz (-31,7 cents) using Audacity software (ver.3.1). After the converting was done, an experienced sound engineer checked these sound files. It is thought that the sound level affects the electrical activities of the brain (Pavlygina et al., 2004). Therefore, before the experiments sound level was checked using the NIOSH sound level meter (Crossley, 2021), and the mean level was kept between 74dB and 79dB. Musical compositions were played using 4 speakers (Pioneer, S-H210V, S-CR30) and 1 amplifier (Pioneer, VSX-609RDS).

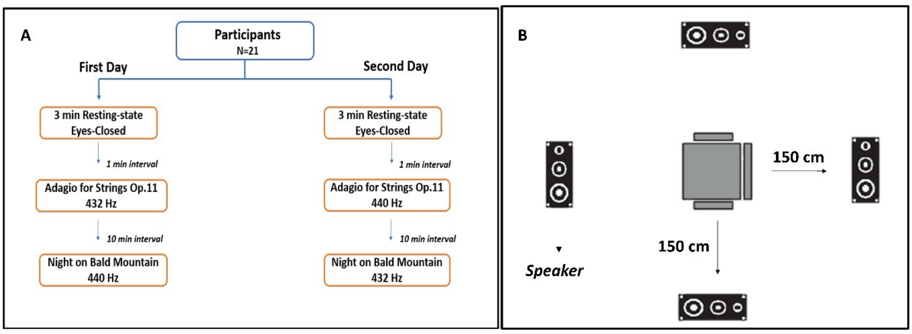

Figure 1. (A). Experimental design of the study; (B) Sitting and EEG recording position

Data Acquisition

EEG data were recorded using the Mentalab Explore device which has 9 channels of AG/AgCl wet electrodes (Mentalab US LLC / 2670 Worden St #19 San Diego, CA 92110). The proper cap size was selected for the participant's head from M and S sizes. Electrodes were located on Fp1, Fp2, Fpz, T7, T8, O1, O2, Pz, and M2 (ground-reference). M2 electrode were placed on the right mastoid. Impedance levels were kept below 10 kΩ during experiments. The sampling rate was selected at 250 Hz and recorded online with a 0,5-100 Hz band-pass filter and a 50 Hz notch filter was used to remove the power line interference in the signal.

Signal Processing

EEG data were processed with MATLAB R2022a (The Mathworks, Natick, MA, USA) and EEGlab v2022 (Delorme and Makeig, 2004). Recorded data were filtered between 0.1 and 40 Hz using an IIR Butterworth filter (8 order, 48dB/oct) in EEGlab software. Then Artifact Subspace Reconstruction (ASR) was used (SD=10) (Chang et al., 2018; Plechawska-Wojcik et al., 2019) for the artifact rejection process. Following this, we improved the spatial information of the artifact-free EEG epochs through the application of surface Laplacian estimation. Surface Laplacian estimation acts as a spatial filter for the distribution of EEG potentials, mitigating the volume conductor effects of the head and eliminating the impact of the electrode reference (Carvalhaes and De Barros, 2015).

We used the individual alpha frequencies (IAPF) method to reduce the individual differences between participants (Klimesch, 1999). First data were analyzed with Welch's modified periodogram method (window length 1 sec; 50% overlap; 0.1 frequency resolution; Hanning window). Then, IAPF was identified for each participant in EC rsEEG data, and sub-bands were determined according to IAPF. Theta frequency band was defined as IAPF-6 Hz to IAPF-2 Hz, alpha1 frequency band was defined as IAPF-2 Hz to IAPF, alpha2 frequency band was defined as IAPF to IAPF+2 Hz, beta1 frequency band was defined as IAPF+2 Hz to 20 Hz, beta2 frequency band was defined as 20 Hz to 30 Hz. The data obtained during music listening has been normalized in percentage terms using rsEEG data. The calculation formula is as follows:

$$\left(\frac{EEG_{music} - EEG_{base}}{EEG_{base}}\right) \times 100$$

Where EEG_{music} represents EEG data (coherence or PSD) during listening to musical composition and EEG_{base} represents resting state EEG data (coherence or PSD). This procedure was conducted to ensure the standardization of the obtained data. Subsequently, coherence was calculated for 28 electrode pairs in the 5 frequency bands (theta, alpha1, alpha2, beta1, beta2) using the 'mscohere' algorithm in MATLAB. This analysis aimed to assess the degree of synchronization or correlation between the signals recorded from these electrode pairs. PSD values were analyzed with Welch's modified periodogram method in five frequency bands (window length 1 s, 50% overlap; 0.1, frequency resolution, and Hanning window).

Statistical Analysis

The R software was utilized for the statistical analysis of PSD and coherence data. The statistical analysis involved a two-way ANOVA (Analysis of Variance) to examine the difference of group (musician, non-musician), and frequency (432Hz, 440Hz) on a dependent variable measured across electrode pairs (for coherence) and electrodes (for PSD). Post-hoc Tukey HSD tests were conducted on factors showing significance. The effect size was calculated using partial eta squared (ηp2) for the effect of group, frequency, and interaction between group and frequency. The analysis was carried out separately for each frequency band and electrode pair. The significance level was set at 0.05, ensuring that results with a p-value below this threshold were considered statistically significant.

Results

Coherence and PSD patterns of Adagio for Strings Op.11

In the coherence analysis, a two-way ANOVA revealed a significant group effect ($p < 0.05$) in the theta frequency for the T7Pz electrode pair, in the alpha 1 frequency for the T8O1 and Fp2Fpz electrode pairs, in the alpha 2 frequency for the T8O1, T7O1, and FpT7 electrode pairs, and in the beta 1 frequency for the Fp1O1 electrode pair. Additionally, significant frequency effects were observed in the Fp1T8 theta, O1Fpz alpha 1 and beta 1, T8Pz alpha 1, T8O1 alpha 1 and alpha 2, and beta 1, Fp2Pz alpha 2, Fp2O2 alpha 2, and Fp1O1 alpha 2 channels. Furthermore, significant interaction effects between frequency and group were found in the T7Pz, Fp2Fpz, and T8Fpz electrode pairs. There were also significant interactions between group and frequency in the T7Pz theta, Fp2Fpz alpha 1, T8Fpz, and Fp2Fpz beta 1 frequencies. Tukey HSD post hoc tests for the group effect revealed that T7Pz theta ($p = 0.035$), T8O1 alpha 1 ($p = 0.016$), T7O1 alpha 2 ($p = 0.035$), and T8O1 alpha 2 ($p = 0.027$) were significantly higher in musicians. Additionally, Fp2Fpz alpha 1 ($p = 0.036$), Fp1T7 alpha 2 ($p = 0.026$), and Fp1O1 beta 1 ($p = 0.027$) were significantly higher in non-musicians. The Tukey HSD post hoc tests for frequency effects revealed that the Fp1T8 theta, O1Fpz alpha 1 and beta 1, T8Pz alpha 1, T8O1 alpha 1 and alpha 2, and beta 1, Fp2Pz alpha 2, Fp2O2 alpha 2, and Fp1O1 alpha 2 electrode pairs were significantly higher for the 432 Hz frequency.

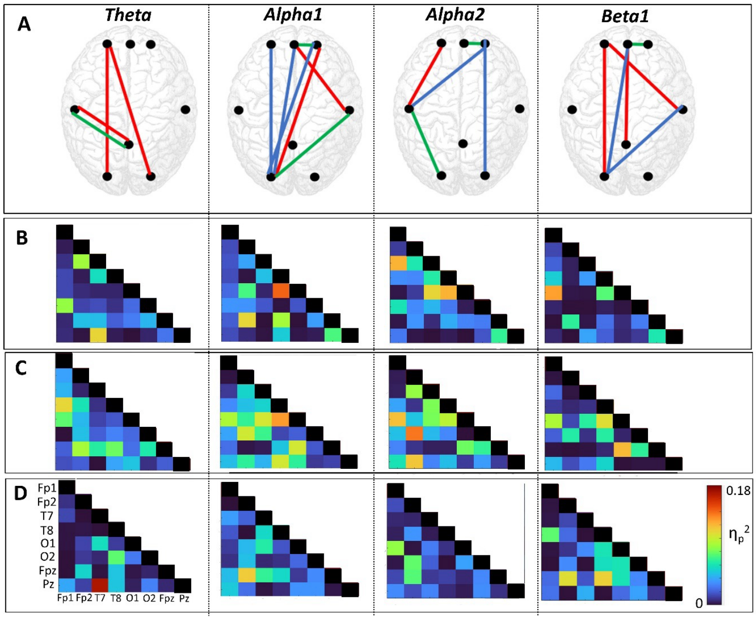

Figure 2. The results of the coherence and partial eta squared in theta, alpha 1, alpha 2, and beta 1 frequencies for Adagio for Strings Op.11 composition. (A) Significant effect and interaction of group and frequency. Black dots represent the electrode locations. Red lines represent the significant effect of the group, blue lines represent the significant effect of frequency, and green lines represent the significant interaction between the group and frequency. (B) The results of parietal eta squared in the group effect in theta, alpha 1, alpha 2, and beta 1 frequencies. (C) The results of parietal eta squared in the frequency effect in theta, alpha 1, alpha 2, and beta 1 frequencies. (D) The results of parietal eta squared in the interaction between group and frequency in theta, alpha 1, alpha 2, and beta 1 frequencies.

In the PSD analysis, a two-way ANOVA revealed a significant effect ($p < 0.05$) of the group in the O1 channel within the theta frequency. Moreover, significant frequency effects were observed in the Pz channel in the theta frequency. Notably, there were significant interactions between group and frequency in the Pz channels in the theta frequency. Post hoc Tukey HSD tests for the group effect revealed that O1 theta values were higher in musicians. Additionally, the frequency effect showed that 440 Hz had higher values in Pz theta.

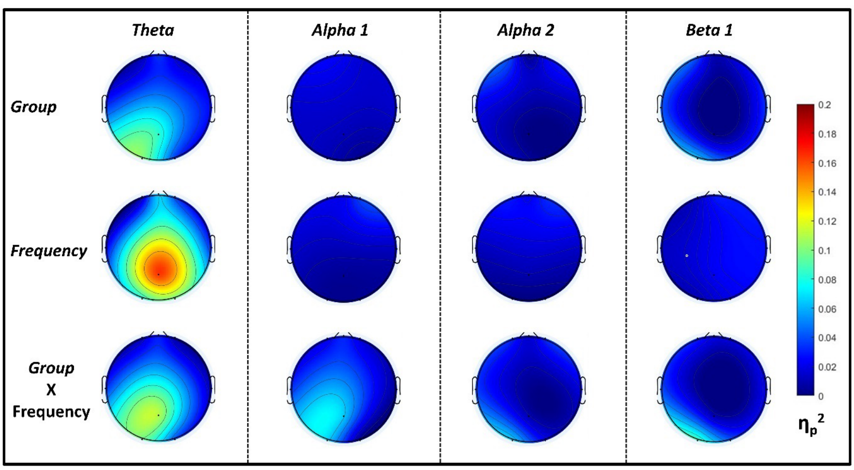

Figure 3. The topographic map of the effect size of PSD in theta, alpha 1, alpha 2, and beta 1 frequency for Adagio for Strings Op.11 composition.

Coherence and PSD patterns of Night on Bald Mountain

In the coherence analysis, a two-way ANOVA revealed a significant group effect ($p < 0.05$) in the theta frequency for the T7Pz and Fp1O1 electrode pairs, in the alpha 1 frequency for the Fp2O1 electrode pair. Additionally, significant frequency effects were observed in the O1O2 theta, and O2Fpz electrode pairs in alpha 1. There were also significant interactions between group and frequency in the T7Pz theta, O1O2, T8O1, Fp2Fpz alpha 1, and T8Pz beta 1. Tukey HSD post hoc tests for the group effect revealed that T7Pz theta and Fp2O1 were significantly higher in musicians, but Fp1O1 electrode pairs were significantly higher in non-musicians. Additionally, significant frequency effects were observed in the O1O2 theta and O2Fpz alpha1. Tukey HSD post hoc tests for the frequency effect revealed that O1O2 theta and O2Fpz alpha 1 were significantly higher in 432Hz.

In the PSD analysis, a two-way ANOVA revealed a significant effect ($p < 0.05$) of the frequency in the T8 channel within the alpha 1, alpha 2, and beta 1 frequency bands. Post hoc Tukey HSD tests for the frequency effect revealed that T8 apha1, T8 alpha 2, and T8 beta 1 values were higher in 440Hz. There was no significant effect of group and interaction between group and frequency.

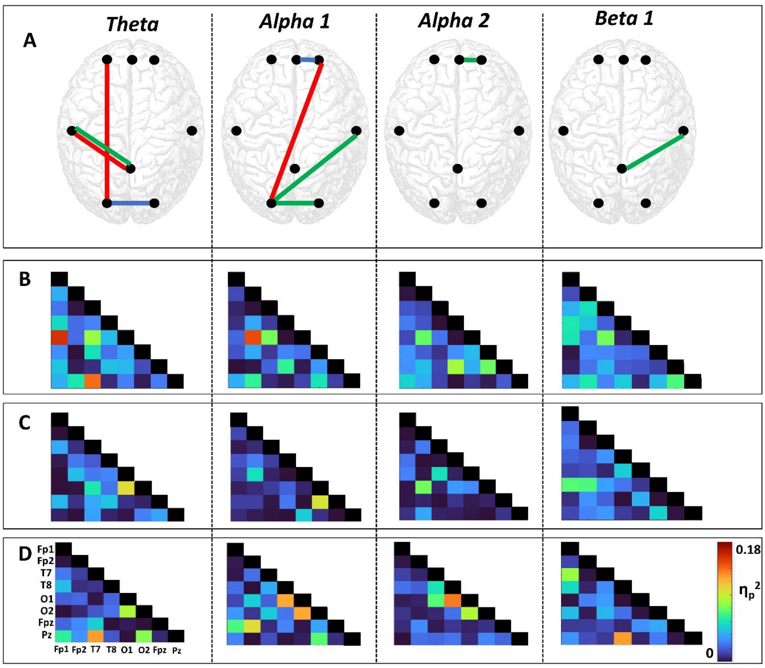

Figure 4. The results of the coherence and partial eta squared in theta, alpha 1, alpha 2, and beta 1 frequencies for Night on Bald Mountain composition. (A) Significant effect and interaction of group and frequency. Black dots represent the electrode locations. Red lines represent the significant effect of the group, blue lines represent the significant effect of frequency, and green lines represent the significant interaction between the group and frequency. (B) The results of parietal eta squared in the group effect in theta, alpha 1, alpha 2, and beta 1 frequencies. (C) The results of parietal eta squared in the frequency effect in theta, alpha 1, alpha 2, and beta 1 frequencies. (D) The results of parietal eta squared in the interaction between group and frequency in theta, alpha 1, alpha 2, and beta 1 frequencies.

In the PSD analysis, a two-way ANOVA revealed a significant effect ($p < 0.05$) of the frequency in the T8 channel within the alpha 1, alpha 2, and beta 1 frequency bands. Post hoc Tukey HSD tests for the frequency effect revealed that T8 apha1, T8 alpha 2, and T8 beta 1 values were higher in 440Hz. There was no significant effect of group and interaction between group and frequency.

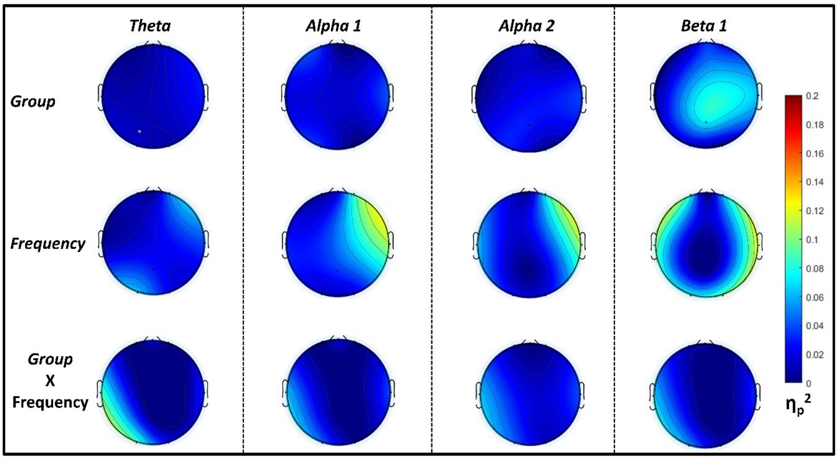

Figure 5. The topographic map of the effect size of PSD in theta, alpha 1, alpha 2, and beta 1 frequency for Night on Bald Mountain composition.

Discussion

This study aims to investigate differences in coherence and PSD patterns during the listening of two different musical compositions at 432 and 440 frequencies among musician and non-musician participants. In line with this objective, EEG data obtained during the listening of musical compositions at 432 and 440 frequencies were analyzed and compared across 28 electrode pairs (coherence) 8 electrodes (PSD), and 5 frequency bands.

In this study, the focus is initially on the differences in brain electrical activations observed when listening to different musical compositions between musicians and non-musicians. Our results indicate that musicians exhibit higher coherence values in the temporo-parietal and temporo-occipital regions. On the other hand, non-musician participants show higher coherence values in the fronto-occipital and fronto-temporal regions. Moreover, PSD results showed that O1 channel in theta frequency was higher in non-musicians. Music education is a significant factor that induces structural and functional changes in the human brain. Particularly in professional musicians, noticeable alterations are observed in processes such as increased temporal discrimination abilities (Agrillo and Piffer, 2012), enhanced auditory perception, relevant cortical arrangements (Francois and Schon, 2011), and effective working memory (George and Coch, 2011). Mikutta and colleagues (2014), reported that professional musicians exhibit more consistent features during music listening. In this context, our study demonstrates that the most prominent differences in expertise related to music manifest in the temporal, parietal, and occipital regions of the brain. These findings contribute significantly to our understanding of the effects of music education on the brain.

In our study, aimed at understanding the effects of musical experience on brain activity, participants were exposed to two different types of musical compositions. The first composition, titled " Adagio for Strings Op.11" was characterized by a slow tempo, while the other, titled " Night on Bald Mountain" had a higher tempo. The results obtained indicated that the slow-tempo music elicited a broader regional coherence in participants' EEG findings. These significant observations provide a new perspective on how the characteristic features of musical compositions can create distinct effects on brain activity. Husain and colleagues (2002) examined the effects of tempo and mode variations in Mozart's sonatas on spatial ability, arousal, and mood were investigated. It was reported that listening to music played at a fast tempo and in a major mode enhanced spatial task performance. Tempo changes influenced arousal, while mode changes affected mood. In this context, our study contributes to understanding the complex interactions of music by demonstrating that slow-tempo music establishes broad regional coherence, while tempo and mode changes affect brain activity.

In the last decade, there has been a noticeable surge in the popularity of 432 Hz, particularly in online platforms. This frequency is often associated with claims of various effects on mental and emotional well-being. For instance, the latest study conducted by Di Nasso and colleagues (2016) specifically aimed to examine the effects of 432 Hz music on patients' vital signs, particularly during root canal treatment. They have found that listening to music during the root canal treatment process positively influences the overall health status of patients. The study suggests that the use of music as a supportive element in this treatment process can reduce stress levels and enhance the general well-being of patients. In another similar study, Menziletoglu and colleagues (2021) reported that 432 Hz music exposure was associated with reduced anxiety levels during the preoperative stage in dental treatment. Moreover, some studies reported the effect of 432 Hz music on the human organism such as heart rate and stress quantification (Calamassi & Pomponi, 2019; Calamassi et al., 2022). These studies demonstrate the positive effects of 432 Hz on various emotional states. Despite studies demonstrating the positive effects of 432 Hz on various emotional states, research on the impact of 432 Hz on brain electrical activities is limited. To address this gap, our conducted study aimed to reveal differences in brain electrical activations during the listening of both musical compositions. Specifically, in the fronto-occipital, and temporo-occipital regions, we found that 432 Hz exhibited higher coherence values compared to 440 Hz. These findings contribute to our understanding of the specific effects of musical frequency on brain activations, suggesting that 432 Hz may enhance activation in certain brain regions, potentially positively influencing emotional states.

Conclusion

Our study aimed to examine the differences in brain electrical activation observed between individuals interested and not interested in music while listening to compositions at different frequencies. Increased coherence values in the temporo-parietal and temporo-occipital regions among musicians indicate that they exhibit more coordinated brain activations during the music listening process. On the other hand, non-musician participants show higher coherence in fronto-occipital and fronto-temporal regions, suggesting that individuals not engaged in music experience more intense interactions in different brain areas. The study also highlights that slow-tempo music induces broader regional coherence and, by demonstrating higher coherence values in the 432 Hz frequency, particularly in fronto-temporal, fronto-occipital, and temporo-occipital regions, suggests that this frequency may lead to stronger activation in specific brain areas and positively influence emotional states. These findings contribute to a more detailed understanding of the complex interaction between music experience, composition characteristics, and frequency.

Recommendations

Recommendations for Further Research

It is recommended that future research investigates the cognitive, emotional, and behavioral effects of different music genres on individuals. In this context, examining music's impact within various age groups, cultural settings, or specific situations (e.g., learning, stress management, or physical activity) could provide significant contributions to the literature. Additionally, supporting these studies with both quantitative and qualitative methods would enable a more comprehensive evaluation of the findings.

Recommendations for Applicants

While traditional analysis methods such as Power Spectral Density (PSD) and coherence are commonly employed, it is recommended that future studies incorporate alternative analytical techniques. Specifically, time-frequency analysis, effective connectivity, and artificial intelligence-based methods can enable a more detailed examination of the data, allowing for a better understanding of the dynamic changes, temporal, and frequency components of the signals. These approaches can enhance the accuracy of the findings and provide deeper insights. Furthermore, the application of multivariate analysis techniques could offer a more comprehensive exploration of the interactions and relationships between different factors.

Limitations

In this study, we evaluated two different musical compositions using only PSD and coherence methods. This study serves as a pilot for a larger-scale research project. In future research, we suggest developing a more comprehensive approach by incorporating alternative methods such as phase locking value and graph theory to expand the analysis methodology. Additionally, we suggest working with a larger music sample that includes various musical genres and frequencies. This way, we foresee that a more extensive evaluation, enhancing the generalizability of the results, will be achieved.

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Biodata of Authors

Dr. **Hasan Batuhan Dirik,** a faculty member at Lokman Hekim University's Faculty of Sports Sciences, continues his work. He focuses on research related to Sport Sciences and Neuroscience.

Affiliation: Lokman Hekim University, Faculty of Sports Science, Ankara, Turkiye.

Email: batuhandirik@gmail.com

ORCID: 0000-0003-3463-4469

Personel Web Site: https://avesis.lokmanhekim.edu.tr/hbatuhan.dirik

Research Gate: https://www.researchgate.net/profile/Hasan-Dirik-3?ev=hdr_xprf

Google Scholar: https://scholar.google.com/citations?user=R5LqvfMAAAAJ&hl=tr&oi=ao

Dr. **Cemile Bengi Baraz** continues her work in the Piano Department of the State Conservatory at Anadolu University. She focuses on studies in Music and Performing Arts.

Affiliation: Anadolu University, State Consevatory, Department of Piano, Eshisehir, Turkiye.

Email: cbbaraz@anadolu.edu.tr

ORCID: 0000-0002-7639-0012

Google Scholar: https://scholar.google.com/citations?user=GIgofbsAAAAJ&hl=tr&oi=ao