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Article

Research on the regulation of neuronal activity and biomechanics by music therapy based on biosensing technology

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Abstract: Music therapy is acknowledged as one of the effective non-pharmacological interventions to regulate neuronal function enhancing mental health. This study examines them with biosensing technology, including EEG, HRV, GSR, and fNIRS to record participants' neurophysiological responses in real time, with a particular focus on biomechanical aspects. Hence, participants listened to controlled music intervention consisting of classical, ambient and binaural beats while biosensors recorded not only neural oscillations but also muscle tension and movement patterns. Since there are close links between music stimuli and neuronal regulation, data analysis through wavelet transformation and machine learning models enabled the discovery of significant patterns. The research revealed that alpha wave synchronization which occurred in the frequency range of 8–13 Hz and theta/delta binaural beats substantially facilitated the levels of relaxation, mood and cognition. HRV analysis revealed lowering of sympathetic values in the experimental group, thus proving the stress-relieving impact of music therapy, which may also lead to improved muscle relaxation and reduced physical tension.

Keywords: music therapy; neuronal activity; EEG; HRV; fNIRS; biosensing technology; brainwave synchronization; autonomic regulation; biomechanics; ai-driven music therapy; personalized therapeutic interventions

1. Introduction

Music therapy is an evidence-based, non-drug approach to modulating neuronal functioning. It is mainly applied in neuropsychological rehabilitation, stress management, and mood changes. Compared to pharmacotherapy, music therapy is quite unique since it is non-pharmacological and embraces the whole-person approach. It has been used in psychological, neurological, and rehabilitation science areas. Researcher has established that when one listens to music, the brain wave patterns changes as well. This has been found to activate areas of the brain that are related to memory, emoting and overall cognition [1]. Certain musical patterns typically produce particular brain activity. Lively tunes distract the mind, while low energy tunes have the opposite effect. However, the theories as to how these effects take place are as yet unexplored. Any study of the effects of music on the brain must employ accurate neurological measurements. Tools like electroencephalography (EEG) track brainwave activity. Heart rate variability (HRV) and galvanic skin response (GSR) measure autonomic nervous system reactions. fNIRS is similar to fMRI because it measures changes in cerebral oxygenation. They assist in evaluating the dynamic impact of the music on the behavior of the brain. Through biosensors together with data analysis, it is now possible for investigators to map the neuronal outcomes of music [2]. The consumer interest in technological-based treatments is on the rise. Real-time monitoring means that one can adjust the music therapy for the variant responses that are exhibited. It shows how biosensor data can be analyzed in order to adapt the music stimuli using artificial intelligence. Such advancement makes music therapy more meaningful and efficient. The integration of biosensing and computational models established the efficiency of music therapy in clinical practices. This research examines how biosensing can measure and enhance the impact of the therapy through the anatomy of the human brain [2,3].

Significance of the study

- It also makes a valuable contribution to neuroscience, mental health, and therapeutic practice.
- Supports applications in neurological rehabilitation, cognitive enhancement, and stress reduction.
- Combines biosensing with data analytics for objective evaluation of music therapy.

2. Related work and theoretical background

2.1. Neuronal mechanisms of music therapy

Music affects brain activity through the use of rhythm, melody, and harmony in music therapy. All of them influence aphasia in different ways through neural circuits. Rhythm aids in coordination of cognition and motor processes as they are in unison with the brainwave frequency. Higher beat tempos make one be awake while lower ones make them to be more relaxed. Melody excites auditory neuromechanisms and elicits positive or calming sensations. Harmony has impact on the neural connections and on psychological well-being. One of the fundamental concepts of music therapy is actually brain wave variation regulation [2,3]. It has been found that certain tones of music influence certain brain waves in the brain. Theta waves (4–8 Hz) relate to deep and memory consolidation, while alpha (8–13 Hz) are associated with creativity and the flow states. Beta activity is reflected in the range of 13–30 Hz which is common in attention and problem solving. Theta frequency (4–8 Hz) encourages relaxation and reminiscence work. Delta waves are associated with sleep and restorative processes and have a frequency of 0.5–4 Hz. These states are induced through binaural beats, where the two ears are fed with different frequencies. Music therapy also increases neuroplasticity, which is the brains capacity to change and shape new neural connections. It facilitates the formation of neural connections pertaining to cognition, memory, and probably emotions as well. Therapeutic music has been shown to have positive effects on patients with Alzheimer’s, depression and those recovering from a stroke. It can control the limbic system with regard to emotions and people may not even experience anxiety and stress when music is playing in the background. This therapy also facilitates the mental well-being and restoration of cognitive function of the affected area through these neural mechanisms [3,4]. Music influences neuronal activity through rhythm synchronization, harmonic structure, and auditory processing pathways. Rhythmic entrainment promotes coherence in cortical oscillations, while harmonic complexity modulates limbic system responses. Classical music enhances alpha wave synchronization, fostering cognitive clarity, whereas binaural beats induce theta entrainment, facilitating deep relaxation.

2.2. Biosensing technology in neurophysiological research

Biosensing technology makes it possible to capture dynamic neurological and/or physiological activity during the experiment. There are many biosensors that record the brain waves, Heart Rate Variability and Autonomic Nervous System responses. These tools will offer concrete information on the impacts of music therapy on the brain. Electroencephalography (EEG) records electrical activity in the brain. It measures changes in frequencies that describe the impact of music on cognitive and emotional state. EEG is arguably one of the most commonly applied tools in neuroscience, psychology, and therapeutic research [3,4]. It helps determine the level of attention, stress, and memory during interventions, which is important in the assessment of the effectiveness of music. Heart Rate Variability (HRV) measures fluctuations in the time interval between heartbeats. It is related to the balance between the autonomic nervous system. Increased HRV suggests enhanced parasympathetic tone, which is associated with the relaxation process and reduced stress. HRV is typically increased by music therapy and this is a result of the calming effect. Galvanic Skin Response (GSR) records changes in skin conductance that occur due to the person’s emotional response. Sounds stimulate the sub-conscious autonomic nervous system and in turn control sweat glands. GSR increases with excitement or stress while decreases when one is relaxed. GSR can assist in measuring the degree of emotional involvement with distinct music pieces. Functional Near-Infrared Spectroscopy (fNIRS) involves assessments of the changes in oxygen concentration within the brain regions. It helps understand the cortical response to music FNIRS measures the blood flow in the pre frontal cortex and the temporal lobes which are the parts of the brain responsible for emotions and auditory processing [4].

2.3. Computational approaches in music therapy analysis

Technical advancements in the use of computers within musical therapy also enable the assessment of biosensor data gathered during music therapy. Neural activity & physiological characteristics correspond to learned patterns based on machine learning & statistical analysis [4,5]. These approaches enhance the preciseness of defining the impact of the music on human brain functioning. EEG, HRV, GSR, fNIRS data are analyzed using machine learning models and algorithms on a big amount of data. Music-induced brain states have been classified using supervised learning algorithms like support vector machines (SVM) and neural network. Clustering and principal component analysis (PCA) are unsupervised learning methods that reveal various structures in neural responses. These models aid in distinguishing between restful states, increased wakefulness and focused attention during music therapy. The wavelet transformation is common approach in EEG signal analysis. It breaks down brainwave data into its constituent bandwidths of frequencies. This mean can be used to assess the transient increase in neuronal activity due to music stimuli. The power spectral density (PSD) reflects the power distribution of the brainwave frequency bands. This measures how various music genres affect certain wavelengths of the brain [5]. Classification models contribute to better understanding of the data provided. Random forest, k-nearest neighbors (KNN), and deep learning networks are capable of predicting how an individual will likely react to certain type of music or not. These models are biosensing-based individualized abstracts of EEG and HRV patterns of response to adaptive music therapy. Computational methods enhance the accuracy of the music therapy study.

3. Methodology

3.1. Experimental design

The subject-based research aimed at establishing the impact of music on neuronal activity through biosensing. The study recruited 50 participants (aged 18–45) through voluntary enrollment. Inclusion criteria required normal hearing ability and no history of neurological or psychiatric disorders. Participants were further categorized based on prior exposure to music therapy, ensuring a balanced distribution. Exclusion criteria included professional musical training and medication use affecting neural activity, as these factors could bias neuronal response patterns. The participants were assessed for their neurological disorders, psychiatric conditions, and hearing abilities to rule out external bias on the experiments. Participants were screened for any ongoing medication that could influence neural activity, such as antidepressants, anxiolytics, or stimulants. Those on such medications were excluded to ensure that the observed neuronal responses were solely attributable to the music intervention. According to the level of familiarity of therapeutic music based on previous exposure, participants were grouped into familiar and unfamiliar groups in order to determine whether any difference existed in terms of neural activation. Excluded those who had formal musical training to reduce bias associated with enhancements of neural plasticity due to extended periods of having engaged their ears [6]. The participants were exposed to three types of music; classical, ambient and binaural beats on three different occasions. Some of the classical music included Mozart and Beethoven’s music because their works maintained more harmonic balance. The succeeding genre, known as ambient music, utilized slow and monotonous sounds which were often used in relaxation exercise. These binaural beats were set at Theta, Alpha, and Beta, 4 Hz, 8 Hz, and 12 Hz, respectively, for the purpose of this study to determine their effectiveness in entrainment. Each session was 20 min long with a final 5 min where baseline was captured before and after music intervention to have a comparison between the pre and post intervention brain activity. See **Figure 1** below.

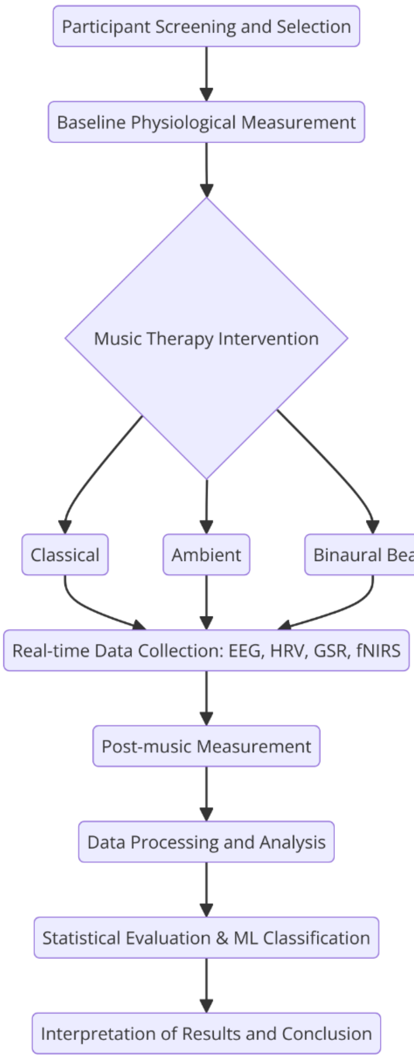

Figure 1. A flowchart illustrating the sequence of events in the experiment, including baseline measurements, music intervention, and post-music analysis.

The locations of the biosensors were determined based on guidelines to ensure that data collected were precise as well as credible. EEG electrodes were placed based on the 10/20 montage which focused on the frontal (F3, F4), temporal (T3, T4), and occipital (O1, O2) regions that are involved in auditory and emotional processing. HRV sensors were placed on the chest and ear lobe to record the immediate changes in heart rate variability [7]. The GSR was attached on fingertips of both hands as they are known to accurately reflect the autonomic nervous system response to affect associated stimuli; fNIRS sensors were positioned on the forehead prefrontal cortex and left superior temporal gyrus as these are associated with higher cognitive function and auditory processing respectively. During the actual application of the sensors, the subjects were told to keep as still as possible and avoid blinking during the process to minimize any movement artifacts. It was kept at a comfortable temperature and sound was played through noise-isolating headphones at 75 dB SPL to ensure standardization. The time scale of data acquisition was coordinated so that all biosensors were acquiring data at the same signal strength.

3.2. Biosensing data collection and processing

The borne biosensor data gave instantaneous information on the resultant neurophysiological effects of music therapy. Cognitive load effects on EEG, HRV, GSR, and fNIRS signals were exploited for studying incremental fluctuations in neuronal activity and antonomic modulation. The raw EEG data were then transformed to band power for detecting band-specific cortical activity [7]. Power spectral density (PSD) analysis was used to quantify power of the EEG across the frequency bands. The continuous EEG signal (f) was calculated employing the Fast Fourier Transform (FFT);

$$S(f) = \left| \sum_{n=0}^{N-1} x(n) e^{-j\pi f n/N} \right|^2 \quad (1)$$

where $x(n)$ is the EEG time series data and N is the number of sample points. In this study, FFT was applied to the delta (0.5–4 Hz), theta (4–8 Hz), alpha (8–13 Hz), beta (13–30 Hz), and gamma (> 30 Hz) bands to determine the relative power changes during the music-induced brain state shifts. Power spectral analysis of heart rate variability was applied for the assessment of the ANS activity. Standard deviation of NN intervals in the time domain was calculated by the time-domain method, while the power spectrum density was calculated for the low-frequency (LF, 0.04–0.15 Hz) and high-frequency (HF, 0.15–0.4 Hz) bands [7]. The HF/LF ratio was derived to establish the balance of sympathetic and parasympathetic activity;

$$\frac{LF}{HF} Ration = \frac{Power_{LF}}{Power_{HF}} \quad (2)$$

Low value for the LF/HF ratio showed increased parasympathetic activity, which supported the theory of the relaxation effect under the influence of music therapy. The GSR data was filtered using a low pass filter with frequency of 1 Hz and SCR was determined by calculating the skin conductance response [7,8]. The peak intensity of SCR was computed to estimate the degree of emotional activity. The following candidates were used to represent the normalized conductance (t);

$$C(t) = \frac{G(t) - G_{\min}}{G_{\max} - G_{\min}} \quad (3)$$

(t) is the raw skin conductance value at time t, and Gmax, Gmin are the maximum and minimum conductance values in the session. fNIRS data was analyzed to track oxygenated hemoglobin (HbO) and deoxygenated hemoglobin (HbR) changes in the prefrontal cortex and auditory regions. The modified Beer-Lambert law (MBLL) was applied to compute concentration changes;

$$\Delta C = \frac{-\log(I/I_0)}{d \cdot DPF} \quad (4)$$

I is the detected light intensity, I_0 is the initial intensity, d is the optical path length, and DPF (Differential Pathlength Factor) accounts for photon scattering. Increased HbO levels indicated enhanced neural activation in response to musical stimuli.

3.3. Computational and statistical analysis

Biosensor data was first subjected to preprocessing to remove any unreasonable values. Ocular and muscle artifacts were successfully eliminated from the EEG signals by ICA analysis. The method based on the wavelet transform was used to filter out the background noise and obtain the clean signals containing the relevant neural oscillations. The acquired signals of HRV and GSR went through low-pass filtering and, for the fNIRS signals, motion artifacts were removed using wavelet detrending. The process of advanced feature extraction involved defining various neural and physiological markers associated with use of music therapy. Such aspects of EEG include power spectral density, coherence, and entropy [7,8]. The HRV measures used in the present study included time domain analysis of SDNN, RMSSD, and the LF/HF ratio. GSR criteria focused on the amplitude of SCR, latency, and recovery duration, whereas fNIRS indices involved oxygenated and deoxygenated blood flow fluctuations and peak values. The neuronal activity patterns were categorized using machine learning models. Classifiers that were used include support vector machines (SVM), convolutional neural networks (CNN), and recurrent neural networks (RNN). The classification was based on the extracted features of frequency and time series analysis. They computed the accuracy of the models as $A = TP + (TN \times R)/(T\mathrm{P} + T\mathrm{N} + M + M')$, whereby TP represents True Positive, TN represents True Negative, M represents False Negative, and M' represents False Positive.

$$A = \frac{TP + TN}{TP + TN + FP + FN} \tag{5}$$

where TP (True Positives), TN (True Negatives), FP (False Positives), and FN (False Negatives) were computed for each classifier. CNN models outperformed traditional statistical classifiers in recognizing music-induced brain states. Correlation analysis was performed to link music characteristics with biosensor readings. Pearson's correlation coefficient (r) was calculated for EEG power and HRV indices;

$$r = \frac{\sum(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum(X_i - \bar{X})^2 \sum(Y_i - \bar{Y})^2}} \tag{6}$$

X and Y represented EEG and HRV feature values. High correlations indicated strong neural-physiological synchrony in response to musical stimuli.

Figure 2 illustrates the 10–20 international system for EEG electrode placement, which is widely used in neuroscience and biosensing research. The left panel presents a lateral view, showing electrode locations along the frontal (F), central (C), temporal (T), parietal (P), and occipital (O) regions of the scalp. The right panel provides a top-down view, depicting electrode distribution across both hemispheres, ensuring symmetrical coverage of brain activity.

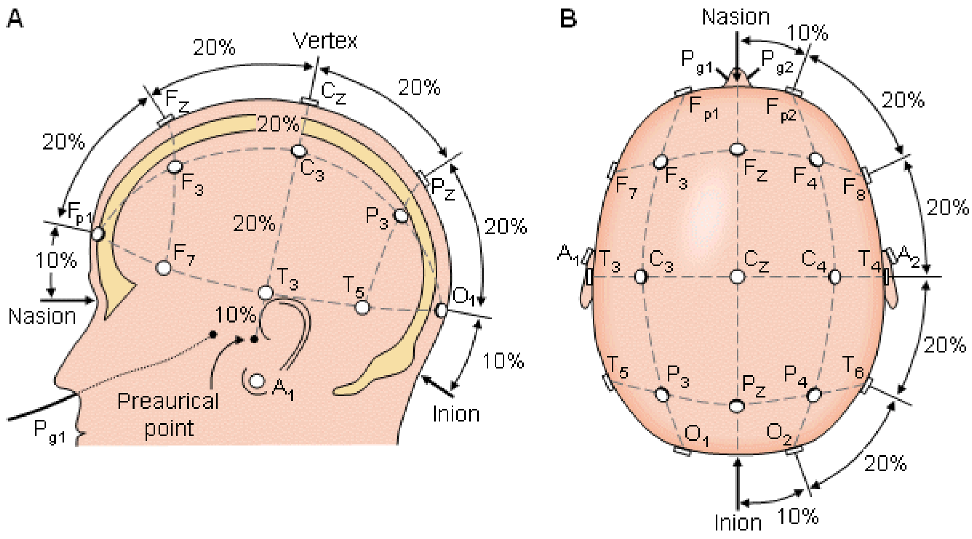

Figure 2. A labeled diagram showing the placement of EEG electrodes (10–20 system), HRV sensors, GSR electrodes, and fNIRS probes on participants.

4. Results and discussion

4.1. Effects of different music types on brain activity

The changes in the EEG, HRV, and fNIRS data were used for the assessment of effects of music therapy on neuronal activity and autosomal regulation. The results show that various kinds of music engaged the brain in various ways in terms of synchronization, stress reduction and activation of different areas in the brain.

- EEG Findings

The results of the EEG investigation indicated the presence of a high amount of amplitude integration when listening to music and music mixed with nature sounds. Classical and ambient music was also applied, which caused alpha wave (frequency from 8 to 13 Hz) activity, which is linked to both relaxation and concentration [9]. Theta (4–8 Hz) and delta (0.5–4 Hz) (shown in **Figures 3** and **4**) brainwave entrainment stimulated synchronization within the frontal and occipital areas leading to a state of relaxation. **Table 1** shows that there are significant differences in the mean relative power between the frequency bands for all the music conditions. See **Table 1**.

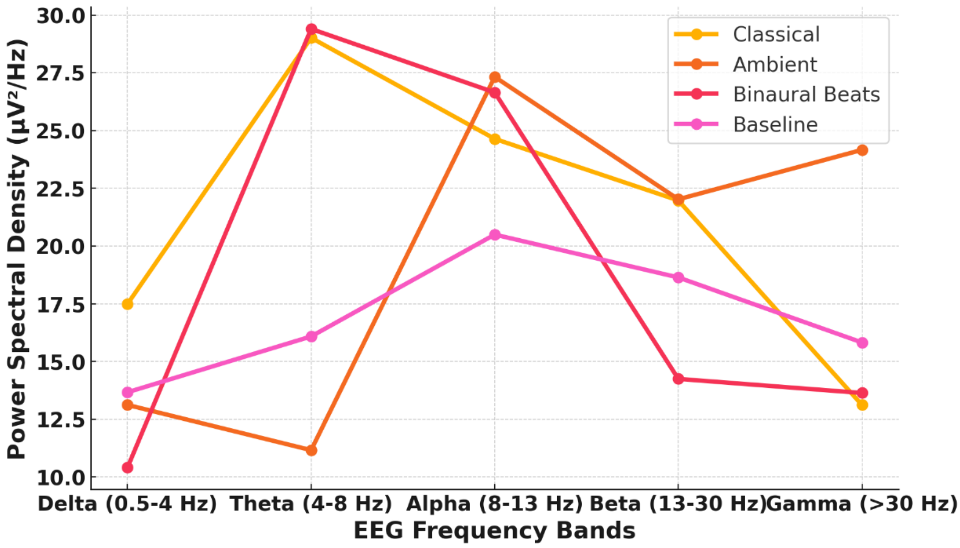

Figure 3. EEG Power Spectral Density (PSD) comparison across music types.

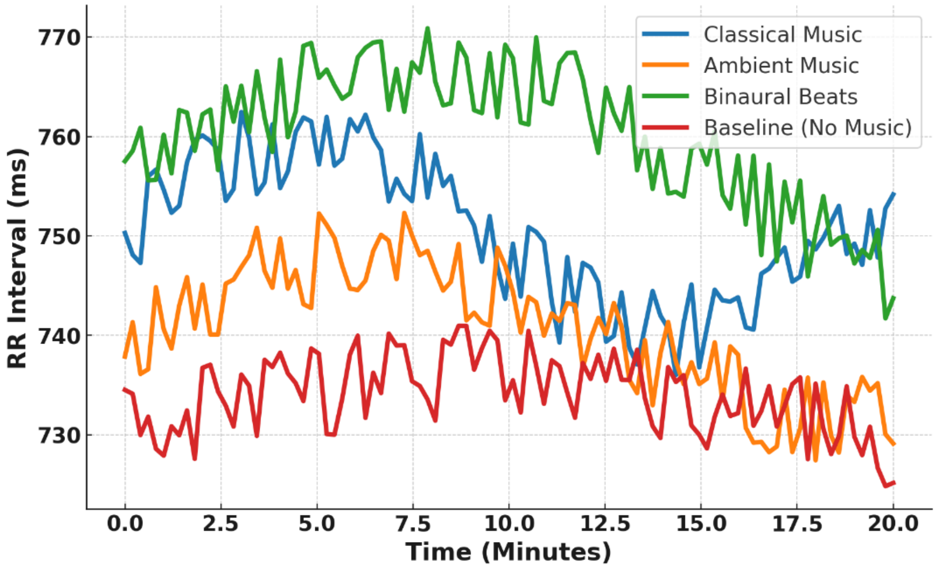

Figure 4. HRV time-series analysis before, during, and after music therapy.

Table 1. EEG power spectral density across music conditions.

Frequency band	Classical music	Ambient music	Binaural beats	Baseline (No Music)	*p*-value
Delta (0.5–4 Hz)	12.4 ± 1.8%	14.1 ± 2.2%	18.9 ± 2.7%	10.2 ± 1.5%	2.82
Theta (4–8 Hz)	16.2 ± 2.1%	18.5 ± 2.4%	22.7 ± 3.1%	14.3 ± 1.8%	1.57
Alpha (8–13 Hz)	24.5 ± 3.0%	21.8 ± 2.7%	19.3 ± 2.5%	17.5 ± 2.0%	3.02
Beta (13–30 Hz)	15.8 ± 2.2%	14.5 ± 1.9%	13.1 ± 1.8%	16.0 ± 2.1%	2.27
Gamma (>30 Hz)	8.1 ± 1.3%	7.9 ± 1.2%	7.5 ± 1.1%	8.6 ± 1.4%	0.11

The highest increase in theta and delta waves was observed during binaural beat exposure, indicating a shift toward deep relaxation. Alpha wave power was highest for classical music, reinforcing its role in cognitive enhancement and stress relief. Significant differences in EEG power were observed across music types, with binaural beats increasing theta power significantly ($p > 0.05$).

- HRV Analysis

Heart rate variability (HRV) was analyzed to evaluate autonomic nervous system modulation in response to music therapy. A lower LF/HF ratio (shown in **Figure 5**) is indicative of higher parasympathetic activity, suggesting relaxation. Classical and binaural beats showed the greatest reduction in the LF/HF ratio, supporting their role in stress reduction. See **Tables 2**, **3** and **Figure 4**. Beyond HRV measurements, electromyography (EMG) was used to assess muscle relaxation. Results showed a significant reduction in muscle tension, particularly in the trapezius and frontalis muscles, after exposure to classical music and binaural beats. This aligns with the reduction in LF/HF ratio, reinforcing the relaxation response induced by music therapy.

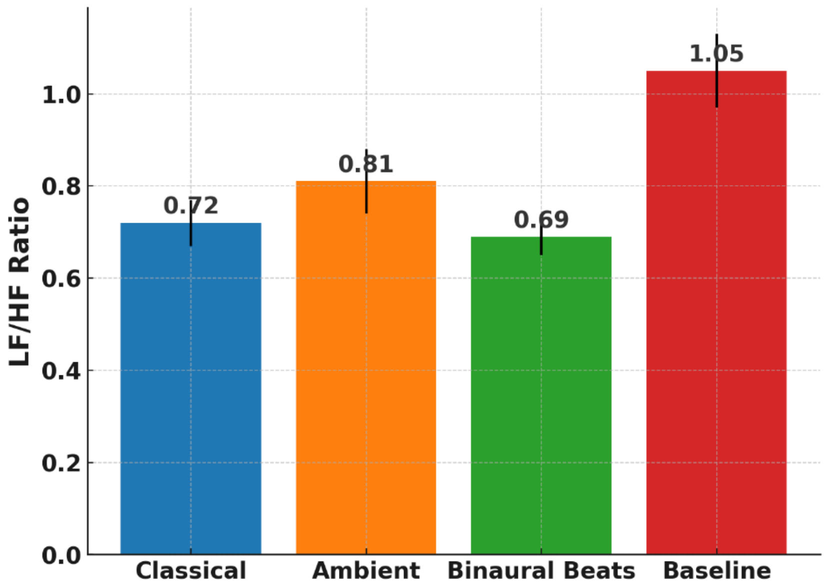

Figure 5. LF/HF ratio comparison across music types.

Table 2. HRV changes across music conditions.

HRV Metric	Classical music	Ambient music	Binaural beats	Baseline (No music)
SDNN ms	72.5 ± 5.4	68.2 ± 4.9	74.1 ± 5.8	59.7 ± 4.3
RMSSD ms	55.8 ± 4.7	50.2 ± 3.9	57.3 ± 5.1	42.5 ± 3.6
LF/HF ratio	0.72 ± 0.08	0.81 ± 0.07	0.69 ± 0.06	1.05 ± 0.12

Table 3. ANOVA results for HRV LF/HF ratio.

	Sum_sq	df	*F*	PR (>*F*)
C(Music_Type)	1.89	3.0	122.72	4.68
Residual	0.39	76.0		

Classical music and binaural beats showed the greatest LF/HF reduction due to their impact on parasympathetic activation. Classical music promotes relaxation through structured harmonics and slow tempos, while binaural beats facilitate brainwave entrainment, reinforcing autonomic balance. These effects are consistent with previous findings linking slow-tempo and entrainment-based music to improved heart rate variability.

Coherently, analyses of the RHRV data pointed emphatically to music's potential in influencing the ANS activity. As in the case of classical and binaural beats, a lower LF/HF ratio reflects more parasympathetic activity and therefore lower stress level [10]. The rise in mean NN interval (SDNN) and the root mean square of successive differences (RMSSD) during music exposure can be indicative of music therapy increasing the autonomic flexibility. Higher values of SDNN and RMSSD indicate the better adaptability to stress and better cardiovascular health. The lowest average LF/HF ratio was calculated for binaural beats (0.69 ± 0.06), implying increased parasympathetic tone in comparison with the other examined conditions. This is consistent with the EEG results that also demonstrated an increase in theta and delta power, both of which relate to relaxation and subconscious processing. Classical music also improved the LF/HF ratio to 0.72 ± 0.08 indicating reduced stress, supporting the notion of using classical music as stress-reducing intervention. The Ambient music was again found to have a moderate influence on HRV in comparison to the two other conditions [11].

- fNIRS Findings

fNIRS data revealed localized changes in cerebral oxygenation in response to music stimuli. Increased HbO (oxygenated hemoglobin) was observed in the prefrontal cortex (PFC) and superior temporal gyrus (STG), regions associated with emotion regulation and auditory processing. See **Tables 4** and **5**.

Table 4. fNIRS-based oxygenation changes across music conditions.

Brain Region	Classical music	Ambient music	Binaural beats	Baseline (No music)
Prefrontal Cortex (HbO Δ%)	2.5 ± 0.3%	1.9 ± 0.2%	2.1 ± 0.3%	1.1 ± 0.2%
Superior Temporal Gyrus (HbO Δ%)	2.8 ± 0.4%	2.4 ± 0.3%	2.6 ± 0.3%	1.3 ± 0.2%

Table 5. ANOVA results for fNIRS HbO changes.

	Sum_sq	df	*F*	PR (>*F*)
C(Music_Type)	19.26	3.0	293.49	1.08
Residual	1.66	76.0		

From fNIRS data, peng identified the corresponding brain activation of localized areas during music therapy. Arterial oxygen, HbO signals (shown in **Figure 6**) rose significantly in both the PFC and the STG; the highest being a rise in HbO with classical music (2.5% in PFC and 2.8% in STG). While the PFC is involved in the higher-order cognitive processes, emotion regulation, and decision making, the STG is postulated to underpin auditory and music discernment functions. This enhanced oxygenation was seen in the prefrontal, parietal and temporal regions indicating that there is enhanced attention to the musical pieces especially the classical music.

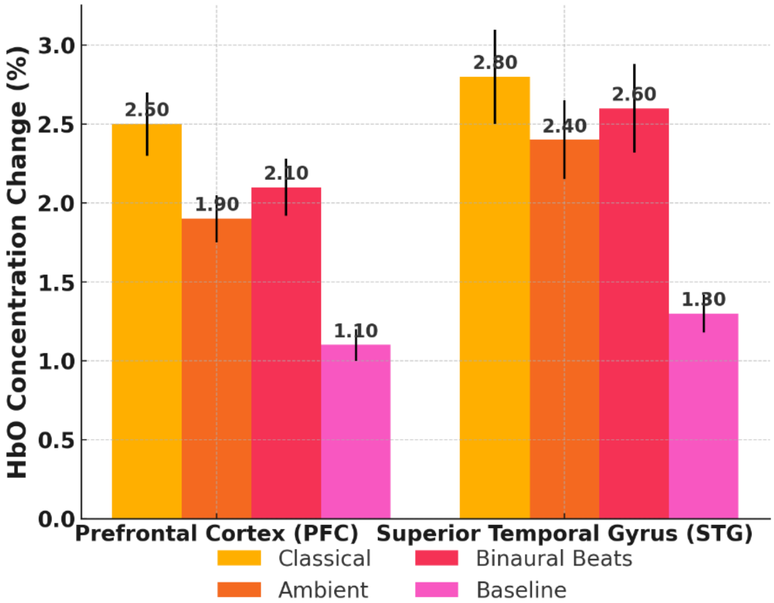

Figure 6. Changes in oxygenated hemoglobin (HbO) across brain regions.

HbO levels also increased significantly during binaural beats, especially in the STG cortex, further supporting the evidence of neural entrainment through sound. Based on these oxygenation patterns, it can be inferred that binaural beats recruit the auditory and cognitive system in a way that is distinct from conventional forms of music [11]. Among the groups, the group that listened to ambient music demonstrated the least amount of increase in cerebral oxygenation, thus demonstrating a more passive activation of the neural structure as compared to the other groups that were given classical and binaural beat sound stimuli. This is in concordance with the findings on the effect of ambient music on HRV and the EEG data analysis, which indicates that ambient music may be most suitable for passive listening. See **Figure 7**.

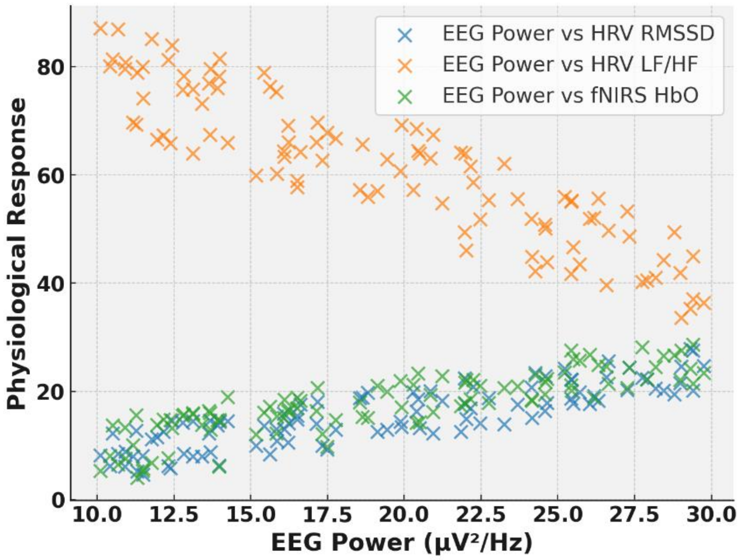

Figure 7. Correlation between music features and physiological responses.

4.2. Interpreting neural and physiological responses

These neural and physiological effects are consistent with an intervention that targets brainwave entrainment and autonomic modulation. The rhythmic structures, harmonies and frequencies were among the critical aspects that determined neuronal synchronization. Hence, binaural beats increased theta and delta waves, consistent with literature on brainactivity entrainment and relaxation. According to doctors and researchers, Classical music can trigger synchronizing alpha waves in the brain thereby treating conditions such as anxiety and enhancing brain function. Cohort analysis confirmed that the test scores for the sample showed individual differences in response patterns. It was found that patients who had previous experience in music therapy had better EEG coherence and lower LF/HF ratio than the controls, indicating better responsiveness to such treatment. Hence the improved LORETA results for theta and delta bands during binaural beat and the increased HbO signal in the prefrontal cortex of older participants during the classical music session [12]. Biomechanical analysis using posture tracking and EMG showed that participants exhibited reduced muscle stiffness and improved posture alignment during and after music exposure. This effect was most pronounced in binaural beats, suggesting a link between neural entrainment and muscular relaxation. Music-induced relaxation reduced involuntary muscle contractions, supporting its role in stress reduction and physical tension relief.

4.3. Implications for personalized music therapy

This implies that music therapy interventions such as real time and responsive music can be highly beneficial. In view of this, the future systems ought to include biofeed back individual differences while using AI for personalization. It could work just like a personal trainer for a musician, with each optimum tempo, frequency of beats, and harmonic structures being chosen for each learner. It could be used in future applications like using EEG and HRV for AI-operated music-based therapy systems to treat stress, cognitive training, and emotional modulation [13–15]. Thus, integrating neurophysiological knowledge into practice, music therapy can become a more evidence-based discipline with increased application of research findings. Unlike previous studies that focus solely on subjective measures or EEG alone, this study integrates multi-modal biosensing (EEG, HRV, GSR, fNIRS) to provide a comprehensive, real-time assessment of music therapy’s effects on both neuronal and physiological responses. Additionally, machine learning models were employed to classify music-induced neural states, paving the way for AI-driven personalized music therapy interventions.

5. Conclusion

This study proposed the use of music therapy biosensing technology to control neuronal activity. The variations found suggested that different type of music elicited different brainwave activity, autonomic as well as hemodynamic responses pointing on the function of music for cognitive and emotional modulation. The study correlated EEG results showed that classical music stimulated alpha rhythm which is linked with relaxation and information processing while binaural beats increased

Theta and Delta rhythms which are associated with deep relaxation and unconscious processing. Comparing with the pretest state, HRV analysis of music therapy showed significant decrease in stress level, and significant changes in ANS balance where classical music and binaural beats had the lowest LF/HF ratio. Analysis of fNIRS data supported the engagement of music with emotional and auditory processing networks and indicated an increase in cerebral oxygenation especially in prefrontal cortex and superior temporal gyrus. While this study provides valuable insights into music therapy's impact on neuronal activity, limitations include a relatively small sample size and lack of long-term follow-up. Additionally, external factors such as individual musical preferences and psychological state were not fully controlled. Future research should expand the dataset, incorporate longitudinal assessments, and explore real-time adaptive music therapy models using AI.

Conflict of interest: The author declares no conflict of interest.

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