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Research on the Application of Music Therapy in Residential Environments

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Abstract This paper proposes an optimization scheme for residential acoustic environments based on the Iling formula and standing wave theory. A music-based low-frequency electromagnetic vibration physiological feedback therapy system was designed to achieve synergistic effects between music therapy and physiological parameter monitoring. Forty healthy adults aged 20–35 were selected as experimental subjects, and six different feature selection methods were applied to determine useful features. Key acoustic environment indicators were obtained through analysis of the acoustic parameters of residential spaces. Combining electroencephalogram (EEG) power spectrum and EEG coherence analysis results, the effectiveness of integrating music therapy into residential environments was validated. Analysis of residential space acoustic parameters revealed no significant differences in sound signal reception time between central and lateral sound source positions. The sound signal reception time difference between the front and rear measurement points was 25.91 ms, with significant differences in early reflection sound reception changes between 0–50 ms at the front and rear measurement points. After music therapy, the participants showed a significant increase in coherence in the alpha band occipital region, while other regions showed a slight downward trend. The changes in beta band coherence were more significant, with an increase of 0.152 ($p<0.01$) in frontal region coherence and a decrease of 0.081 ($p<0.05$) in temporal region coherence. This demonstrates that music therapy conducted in a residential environment can serve as an effective method for regulating negative emotions and cognitive attention, while EEG signal characteristics can serve as an effective assessment tool.

Index Terms music therapy, residential acoustic environment, acoustic parameters, EEG signals, physiological information

I. Introduction

In modern urban life, residential environments have become an increasingly important concern for many people. As urbanization accelerates, issues such as noise pollution have become more prominent, and people's demands for living environments have grown increasingly stringent [1]. Among these, the acoustic environment of residential areas is a critical issue affecting people's health and quality of life. Many countries have already enacted regulations requiring developers to disclose the noise levels of their properties to homebuyers [2]-[4]. Considering noise prevention and reduction measures during the planning and design stages of residential communities, and conducting acoustic environment design, reflects a people-centered approach, enabling residential development to achieve satisfactory social, economic, and ecological benefits [5], [6]. Currently, acoustic environment quality has become the second-largest health-impacting factor [7]. Acoustic landscapes, as an important evaluation indicator of living environments, have become a key consideration in residential environment design [8]. Literature [9] indicates that there is a significant correlation between different soundscapes and changes in residents' sound libraries and psychological states. Music can alleviate residents' depressive symptoms, pleasant sounds can increase heart rate and reduce skin conductance, and traffic sounds influence residents' evaluations of residential sound environment quality. Literature [10] observed the reactions of dementia patients in nursing homes to additional sound stimuli affecting their emotions and sense of security, and developed an acoustic environment framework suitable for dementia patients in nursing homes to improve their health and behavioral status. Therefore, to achieve a healthy residential environment, it is necessary to explore the intervention effects of acoustic environment regulation on issues such as chronic stress and sleep disorders. Music therapy is a natural therapy that provides patients with specific types of music based on its composition, helping them achieve physiological and emotional unity and harmony, with significant intervention effects on humans.

Quantum mechanics has proven that all things in the universe are composed of vibrational energy, and the human body is no exception [11]. It is generally believed that sound is the most important form of vibrational energy, from which other forms of vibration are derived. Different energy fields produce different effects, and any vibrational energy can have either beneficial or harmful effects on the mind and body [12], [13]. On one hand, the frequency and sound pressure of musical sound waves can trigger physiological responses. The frequency, rhythm, and regular sound wave vibrations of music constitute a form of physical energy. Moderate physical energy can induce harmonious resonance in human tissue cells, causing resonance in the cranial cavity, intestinal cavity, or specific tissues. This resonance phenomenon induced by sound waves directly influences human brain waves, heart rate, breathing rhythm, and consciousness [14]-[18]. When a person is in a beautiful and pleasant musical environment, it can improve the functions of the nervous system, cardiovascular system, endocrine system, and digestive system, promoting the secretion of active substances beneficial to health, and regulating blood flow and neural transmission within the body [19]-[22]. On the other hand, the frequency and sound pressure of musical sound waves can trigger psychological responses. Beneficial music can enhance the excitability of the cerebral cortex, improve mood, stimulate emotions, and invigorate the spirit. It also helps alleviate negative psychological states such as tension, anxiety, depression, and fear caused by psychological or social factors, thereby enhancing stress resilience [23]-[26].

Music therapy has different effects across various age groups, identities, and disease symptoms. A study [27] conducted a five-week music intervention on college students with sleep disorders, involving two consecutive sessions per week of pre-sleep deep breathing, relaxation techniques, and listening to music for over 30 minutes. This significantly improved their sleep quality, accompanied by improvements in depressive and anxiety symptoms. Literature [28] reported that music therapy for information technology workers can help reduce their depression levels. Literature [29] shared that music therapy can alleviate anxiety, stress, sleep disorders, and labor pain in pregnant women, while promoting fetal activity and basal fetal heart rate. Similar effects have been observed in military personnel. Literature [30] found that remote music therapy and community music activities were effective in reducing anxiety, pain, and depression levels, and that the two forms of music intervention were not mutually exclusive. In current studies, music therapy is often applied to patients with various conditions. For example, literature [31] summarized that music therapy in nursing homes elicited various positive responses, such as promoting social interaction, alleviating depressive symptoms, improving physical health, and reducing irritable behavior. For special patients, study [32] targeted dementia patients, their families, and staff residing in elderly care institutions, conducting a six-month group music therapy and recreational choir singing program, which improved their psychological state, sense of joy, participation, and interpersonal interactions. Study [33] confirmed that personalized music interventions help improve sleep quality in community-dwelling elderly dementia patients. Literature [34] utilized music-based upper limb therapy as part of a comprehensive rehabilitation environment for adults with hemiplegia following a stroke. Patients exposed to the musical environment experienced reduced depressive symptoms and increased enjoyment. Due to travel restrictions during the pandemic, literature [35] introduced home-based personalized music therapy for children with neurodevelopmental disorders, improving their sleep quality and reducing parental stress.

This paper first analyzes the impact of parameters such as reverberation time and standing wave effects on residential acoustic environments based on acoustic theory. A music therapy system integrating low-frequency vibration and physiological feedback was designed, with hardware filtering and real-time monitoring to enhance treatment precision. Statistical analysis of the impulse response measurement results of objective acoustic parameters in residential environments evaluates the applicability of integrating music therapy into residential environments. Electroencephalogram (EEG) data from participants are collected, and wavelet packet transform methods are used to extract EEG rhythms. Based on EEG signal analysis, the study explores the effects of music therapy on improving EEG signals and emotional states.

II. Music therapy integrated into residential environment design

With the acceleration of modern life, the impact of residential environments on physical and mental health has attracted increasing attention. Music therapy, as a non-pharmaceutical intervention, has demonstrated unique advantages in relieving stress and regulating emotions. However, how to effectively integrate music therapy into residential environments still requires research from multiple dimensions, including acoustic design, technical implementation, and effect evaluation.

II. A. Sound quality design evaluation parameters

II. A. 1) Reverberation time and frequency response characteristics

After the indoor sound source stops producing sound, the process of sound energy attenuation is called reverberation, which has a significant impact on human hearing. The concept of reverberation time refers to the time it takes for the sound to attenuate by 60 dB after the indoor sound field stabilizes and the sound source stops producing sound. This led to the development of Sabine's formula:

$$RT_{60} = \frac{0.163V}{\alpha S} \tag{1}$$

When applying the Sabine formula, if the average sound absorption coefficient indoors is greater than 0.2, the calculation results will differ significantly from the actual situation. Later, based on the Sabine formula, some corrections were made to derive the more accurate Illin formula:

$$RT_{60} = \frac{0.163V}{-SLn(1-\alpha)+4mV} \tag{2}$$

In the equation: V —volume, α —average sound absorption coefficient, S —indoor surface area, $4m$ —air absorption coefficient.

From the above equation, it can be seen that the Ilyn formula is closer to the actual situation than the Binn formula. This is because when the average sound absorption coefficient α is large, such as when it approaches 1, $-Ln(1-\alpha)$ approaches infinity, and the reverberation time RT_{60} approaches 0, better reflecting the actual situation.

II. A. 2) Standing waves and acoustic coloring effect

(1) Standing wave principle

The sound field in a room is altered by constraining certain sound energy to change the output distribution of the sound source. At different distances from the sound source, the sound pressure at each frequency is different, and the sound pressure relative to the room's resonance frequency is much higher. A room is similar to an instrument in that it is a multi-resonance system and a three-dimensional resonance system, capable of forming many different frequencies of normal waves along the axial, tangential, and oblique directions.

The formula for calculating the oblique resonance frequency is as follows:

$$f_{nx,ny,nz} = \frac{c}{2}\sqrt{\left(\frac{n_x}{L_x}\right)^2 + \left(\frac{n_y}{L_y}\right)^2 + \left(\frac{n_z}{L_z}\right)^2} \tag{3}$$

In the equation, L_x, L_y, and L_z represent the length, width, and height of the room, respectively, in meters; n_x, n_y, and n_z are zero or any positive integer, but cannot all be zero at the same time.

From the above equation, it can be seen that if any one of n_x, n_y, or n_z is zero, the tangential resonance frequency can be calculated; if two are zero, the resonance frequency corresponding to a certain axial direction can be determined. If all three types of waves are considered, the number of axial, tangential, and oblique resonance frequencies in a living room is astonishing. Estimate the number of resonance frequencies below frequency f in a rectangular room:

$$N = \frac{4\pi f^3 V}{3c_0^3} + \frac{\pi f^2 S}{4c_0^2} + \frac{fL}{8c_0} \tag{4}$$

In the equation, N —the average number of standing waves with frequencies below f, L —Total perimeter of the rectangular room $L = 4\left(L_x + L_y + L_z\right)$, S —Total wall area of the rectangular room $S = 2\left(L_x L_y + L_x L_z + L_y L_z\right)$, C_0 —Sound velocity

From the above calculation principle, it can be seen that in certain vibration modes, the resonance frequencies are the same, i.e., resonance frequency degeneracy occurs. Within the range of degenerate resonance frequencies, sounds with frequencies equivalent to the resonance frequency are greatly amplified, causing distortion of the original sounds in the room, also known as "frequency distortion."

(2) Reasonably controlling room proportions

Theoretical analysis indicates that the ratio of the room's side lengths determines the number and density of standing waves in the room. To overcome the phenomenon of degeneracy and make the resonance frequency distribution as uniform as possible, it is necessary to select the size, proportions, and shape of the room.

Currently, optimal proportions for room dimensions (length, width, and height) have been derived mathematically from wave acoustics. For residential living rooms, numerous examples demonstrate that excessive room depth exacerbates sound coloration, while overly small areas indicate significant standing wave influence. Therefore, to minimize sound coloration in a living room, it is essential to strive for a larger area while avoiding excessive depth, thereby determining appropriate room proportions.

At the same time, appropriate room proportions are merely a necessary condition for achieving good acoustic performance. In practice, many rooms with good acoustic performance do not fall within these ranges. Therefore, as long as sound absorption and diffusion treatments are appropriately applied, satisfactory results can generally be achieved.

II. B. Music-Low Frequency Electromagnetic Vibration Physiological Information Feedback Treatment System

II. B. 1) General Framework

Currently, the evaluation of the efficacy of music therapy systems relies solely on the subjective feelings of the patients, with limited research on the quantification of physiological parameter indicators. Therefore, this system has been designed with a physiological indicator detection module to promptly feed back the patient's physical condition information to the host computer for processing, enabling the system to adjust the treatment plan in real-time based on the actual treatment situation. The circuit framework of the music-low-frequency electromagnetic vibration physiological information feedback therapy system designed in this paper is shown in Figure 1. The system is primarily divided into three modules: the vibration module, the physiological parameter detection module, and the host computer software system.

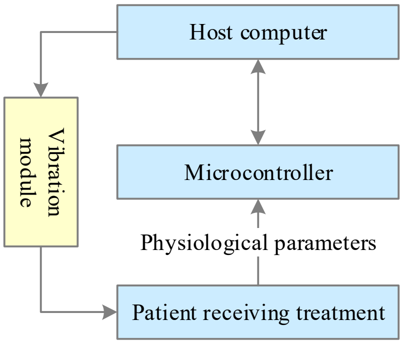


Figure 1: Overall framework of the system

The system operates as follows: Audio signals sent from the host computer are amplified and processed, then output directly through headphones for the patient to listen to music. At the same time, the signals are filtered through a low-frequency filter and drive a low-frequency transducer to allow the patient to feel the sound wave vibrations. Meanwhile, the hardware detection system collects human physiological parameters and transmits them to the host computer via RS232 for real-time display and storage.

II. B. 2) Vibration Module Design

Low-frequency music sound waves can help people relax, while high-frequency music can cause tension; music with a strong rhythm and high volume can stimulate aggression, while music with a slow rhythm and moderate or low volume can calm people down; music sound waves rich in 30-150Hz sine waves have therapeutic effects on physical and mental relaxation. Therefore, this system is designed with a vibration module that only responds to 30-150Hz audio signals; it does not produce music therapy effects for signals of other frequencies.

The main components of this module include: a sound source and an amplification-frequency division-transducer device. Its primary form is a mattress. The principle framework of this module is shown in Figure 2.

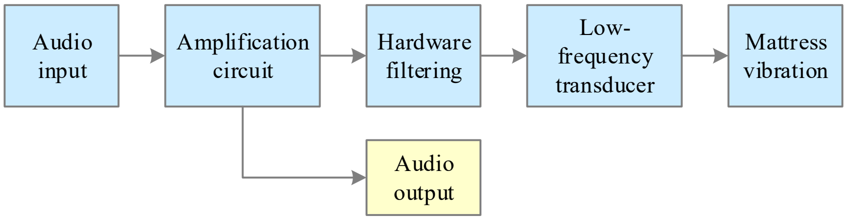


Figure 2: Overall framework of the vibration module

There are two methods for low-frequency filtering: hardware filtering and software filtering. Software filtering involves first converting the analog signal into a digital signal, then processing the digital signal using a filter function, and finally converting the processed useful digital signal back into an analog signal. The advantage of software filtering is its superior filtering performance, but the design process is complex and costly. Hardware filtering, on the other hand, is primarily achieved using resistors and capacitors. Its advantages include low cost and ease of implementation, but its filtering performance is inferior to that of software filtering. Since the filtering requirements for this system are not particularly stringent, after comprehensive consideration, the system adopts hardware filtering, which achieves system functionality while also reducing costs. The hardware filtering circuit is shown in Figure 3.

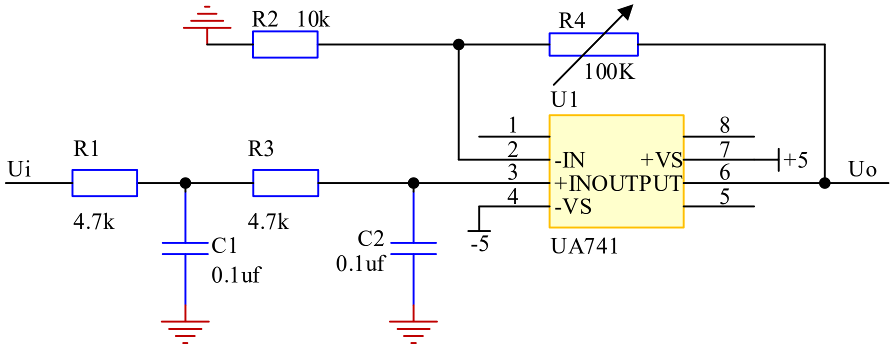


Figure 3: Hardware filter circuit

Due to the wide transition band of the first-order low-pass filter circuit, a simple second-order low-pass filter circuit is used in the system. Its amplification factor is shown in Equation (5).

$$\begin{aligned} Au &= \frac{U_0}{U_i} = \frac{A_{up}}{1+(3-A_{up})j\omega RC+(j\omega RC)^2} \\ &= \frac{A_{up}}{1-\left(\frac{f}{f_0}\right)^2 + j\cdot\frac{1}{Q}\cdot\frac{f}{f_0}} \end{aligned} \tag{5}$$

Among them, the magnification is shown in Equation (6).

$$A_{up} = 1+\frac{R_2}{R_1} \tag{6}$$

The cutoff frequency is shown in Equation (7).

$$f_0 = \frac{1}{2\pi RC} \tag{7}$$

The quality factor is shown in equation (8).

$$Q = \frac{1}{3-A_{up}} \tag{8}$$

After passing through two stages of RC low-pass filter circuits, the input voltage exhibits a logarithmic amplitude-frequency characteristic that decreases at a rate of -40 dB per decade in the high-frequency range, resulting in filter characteristics that closely approximate ideal conditions. This essentially meets the requirements of the measurement system.

III. Analysis of the application of music therapy in residential environments

III. A. Experimental Design

III. A. 1) Music Selection and Test Subjects

This study selected 40 healthy adults aged 20–35 as experimental subjects, including 22 males and 18 females, all of whom had no history of hearing impairment or neurological diseases. The experimental environment was selected from a typical residential setting. The selection of musical materials was based on the International Emotional Music Database and the EMO-DB database. Through preliminary pre-experiments, 40 musical excerpts with clearly defined emotional valence were screened (20 negative emotional music pieces and 20 positive emotional music pieces). All musical excerpts were assessed and confirmed by a professional music therapy team for their emotional induction effects. Negative musical materials were primarily selected from minor-key, slow-tempo works, with an average intensity of 55–65 dB. Positive music materials were selected from major-key pieces in a moderate to fast tempo, with an average intensity of 60–70 dB. The experimental environment was controlled under standard residential living room acoustic conditions.

III. A. 2) Physiological measurements

Skin conductance activity (EDA) is a useful physiological signal that is sensitive to emotional changes. EDA responses fluctuate slowly but significantly, reflecting the current emotional state, and have been shown to be strongly correlated with cognitive load.

Blood volume pulsation (BVP) refers to the measurement of blood volume flowing through specific tissues in the body. It is typically measured during each pulse. BVP has been shown to be correlated with changes in emotional state. For example, higher stress levels are believed to be reflected by lower BVP levels, and vice versa.

Skin temperature (ST) is another commonly used physiological measurement indicator. Although it is a relatively slow indicator, it can still show correlations with different emotional states.

Pupil dilation (PD) refers to the measurement of pupil changes over time and is considered a highly effective feature in emotion recognition. Changes in pupil diameter are believed to reflect changes in brain state. Pupil dilation has been used as an indicator of emotional arousal.

III. A. 3) Experimental Design

The experimental procedure began with the calibration process of the physiological sensors. Participants answered some basic demographic questions at the start of the experiment. Then, participants listened to each piece of music and rated it using a series of scores based on six different emotional rating scales. These scales include Sadness → Happiness, Anxiety → Comfort, Depression → Excitement, Unpleasantness → Pleasantness, Stimulation → Calming, and Tension → Relaxation. The first four ratings are used to understand participants' overall impressions of the music itself, while the other two ratings ask participants about their feelings while listening to the music. These metrics are described in detail in the study, and subjective ratings are based on the Likert scale. At the end of the experiment, participants provided some overall comments on the musical pieces in a post-experiment questionnaire. To analyze the emotional scores provided by participants, the scores were visualized in a two-dimensional emotional model based on their arousal levels. The two-dimensional emotional model of emotion and arousal is shown in Figure 4, compared to modeling emotions using discrete labels.

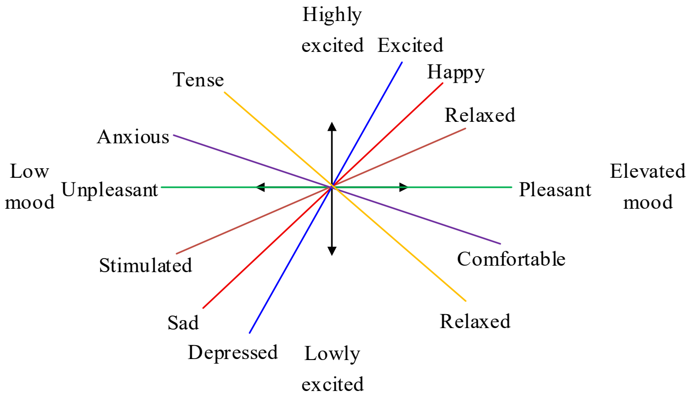


Figure 4: Two-dimensional emotional model of emotions and arousal

After collecting the raw physiological signals, they are analyzed through multiple steps. The complete experimental process is shown in Figure 5.

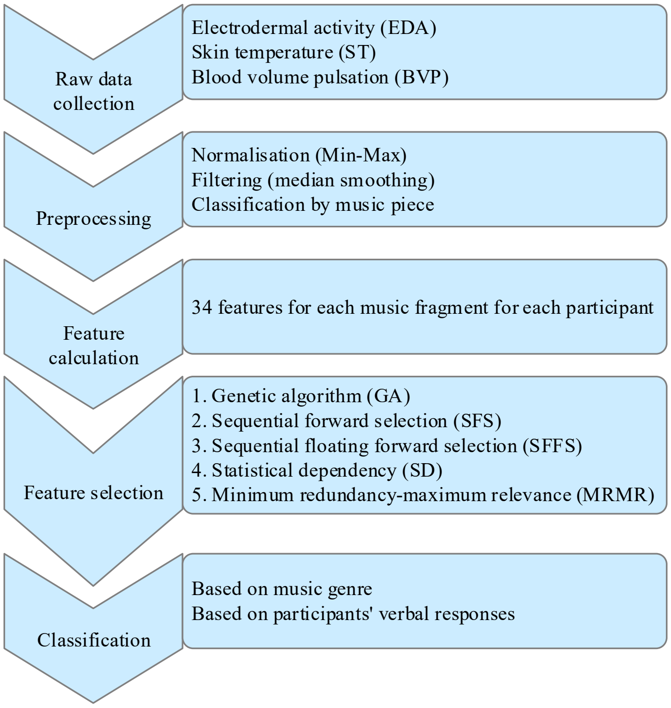


Figure 5: The overall steps of the experiment

III. B. Analysis of acoustic parameters in residential spaces

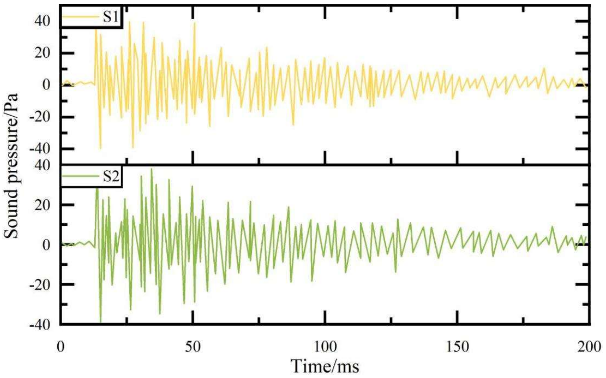
Measurements of acoustic parameters in residential spaces were conducted, and the results of the impulse response measurements are shown in Table 1. The spatial measurement results include typical ranges such as STEaryc and EDTa that do not meet ISO standards. The following sections will provide a detailed discussion of the measurement results for acoustic parameters.

Table 1: Measurement Results of impulse Response

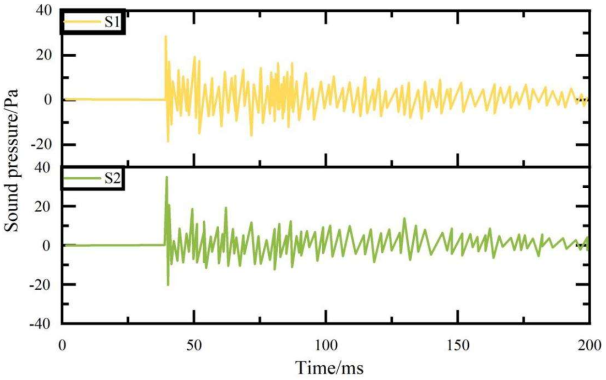
Space	Acoustic parameter	S1	S2	Mean value	ISO standard scope
A	STEaryc(dB)	-4.97*	-7.03*	-6.22*	-22dB~-7dB
	STLatec(dB)	-14.57	-12.33	-14.18	-22dB~-12dB
B	Lp,A,B(dBA)	42.6	44.8	47.9	-
	EDTa(s)	0.81*	0.74*	0.79	0.9s~2.5s
	T30a(s)	0.84	0.82	0.79	-
	C80b(dB)	5.2*	3.7	4.6*	-4dB~+4dB
	D50b(dB)	0.63	0.54	0.61	0.25~0.65
	Gb(dB)	19.46*	20.18*	19.47*	-3dB~+9dB

Two measurement points, A1 and A6, which are representative of the space in the living room, were selected. Their first 200 ms pulse response spectra are shown in Figures 6(a) and 6(b), respectively. In terms of sound signal delay, the A1 measurement point received sound signals at 13.32 ms and 13.78 ms for S1 and S2, respectively, while the A6 measurement point required 39.23 ms and 39.69 ms, respectively. The sound signal reception times for A1 and A6 differed by 25.91 ms. In terms of the reflected sound event sequence, there are significant differences between the A1 and A6 measurement points in the pulse spectrum between 0 and 100 ms.

The data and chart results indicate: (1) There is no significant difference in the sound signal reception time between the central and lateral sound source positions. (2) The difference in sound signal reception time between the front and rear measurement points is 25.91 ms. (3) There is a significant difference in the early reflected sound reception changes between the front and rear measurement points in the 0-50 ms range, with the front measurement point receiving significantly more early reflected sounds than the rear measurement point.



(a)A1



(b)A6

Figure 6: Spike response profile for the first 300ms

Early decay time and reverberation time analysis: The early decay time (EDT) measurement results for residential spaces were compared based on the average values of the 100 Hz–3000 Hz frequency band in accordance with regulatory requirements. The average EDT values for each measurement point are shown in Table 2. Analysis of the measurement results reveals the following:

(1) The average EDT in the 100Hz-3000Hz octave band for the living room is 0.79s. Among these, the low-frequency EDT (0.69s) is relatively low, while the mid-frequency (0.82s) and high-frequency (0.88s) EDTs are higher, indicating that early sound energy decay is faster at lower frequencies.

(2) The EDT values at the middle and rear measurement points are significantly higher than those at the front measurement point, with the maximum difference between measurement points being 0.47 seconds, far exceeding the minimum detectable difference (JND). This indicates that the early sound energy distribution in the residential living room is uneven.

Table 2: Mean EDT values at each measurement point

	A1	A2	A3	A4	A5	A6	Mean value
100Hz	0.58	0.54	0.56	0.81	0.67	0.69	0.64
200Hz	0.52	0.59	0.66	0.83	0.81	0.99	0.73
500Hz	0.64	0.58	0.73	0.92	0.89	0.95	0.79
1000Hz	0.65	0.71	0.91	0.93	0.88	0.99	0.85
2000Hz	0.68	0.72	0.88	0.97	0.99	1.07	0.89
3000Hz	0.69	0.72	0.86	0.99	0.94	1.03	0.87
Mean value	0.63	0.64	0.77	0.91	0.86	0.95	0.79

III. C. Preprocessing of experimental data

III. C. 1) Experimental Materials

To effectively evoke the target emotion, 20 pieces of music labeled as low valence and low arousal (LVLA) were carefully selected as negative music materials to induce negative emotions in the subjects. Additionally, 20 pieces of music labeled as high valence and low arousal (HVLA) were selected as input data for emotional music visualization. Using the constructed emotional music visualization technology framework, corresponding visual music materials were generated to alleviate participants' negative emotions. To ensure the reliability of emotion induction, the music content should be simple and easy to understand, the music duration should not be too long (approximately 40 seconds per track), and the emotional distribution of the selected music segments should be relatively distinct. The emotional distribution of the 40 music segments is shown in Figure 7.

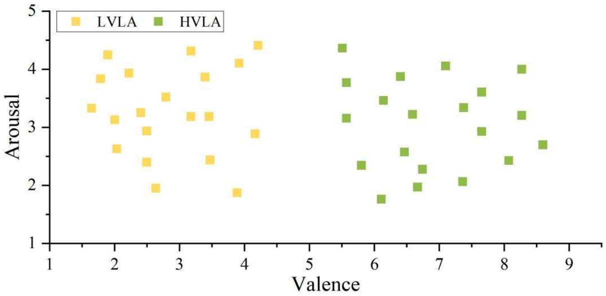


Figure 7: Emotional distribution of the music segments

III. C. 2) Data preprocessing

Collecting EEG data from participants, a specific dataset was selected for analysis. The 4-channel EEG data is shown in Figure 8. The raw EEG signals contain a significant amount of artifact noise, which severely affects signal quality. Therefore, it is essential to preprocess the collected EEG data.

For non-physiological artifacts such as power line noise, a Butterworth bandpass filter was employed to retain frequency components between 0.3 Hz and 50 Hz. For biological artifacts, since the frequency band of eye movement artifacts is similar to that of EEG signals, it is difficult to remove them using filters. When the eyes move vertically up and down, vertical eye movement artifacts (VEOG) are easily generated, while horizontal eye movement artifacts (HEOG) are produced when the eyes move horizontally left and right. As shown in Figure 8, Channel A is located in the frontal region of the brain, close to the eyes, and the signal from this channel is significantly affected by vertical and horizontal EOG artifacts. To address the signal interference caused by EOG artifacts, the experiment employed Independent Component Analysis (ICA) to remove EOG artifacts.

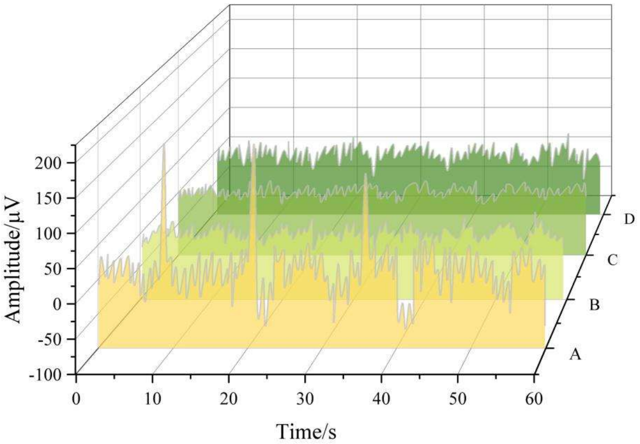


Figure 8: 4-channel EEG data collected

III. C. 3) Frequency Band Division

The rhythmic signals in the Alpha and Beta frequency bands of electroencephalographic (EEG) signals can effectively reflect a person's emotional state and emotional changes. The experiment employs the wavelet packet transform method, which has high time-frequency resolution, to extract EEG rhythms. According to the Nyquist sampling theorem, the sampling frequency of the wavelet packet transform is 125 Hz, which is half of the EEG signal sampling frequency of 250 Hz. Therefore, the wavelet packet component with a coefficient of (0,0) corresponds to the frequency range of 0–125 Hz, while those with coefficients of (1,0) and (1,1) correspond to the frequency ranges of 0–62.5 Hz and 62.5–125 Hz, respectively. Similarly, the wavelet packet components for each node in the seven-layer wavelet packet tree can be obtained. By reconstructing the wavelet packet components at different frequencies, the rhythm signals in the Alpha and Beta bands can be obtained. The divided EEG rhythm signals are shown in Figure 9. The wavelet packet coefficients for reconstructing the Alpha and Beta waves are [(6,1),(7,5)] and [(6,13),(6,14),(3,1),(3,2)], respectively.

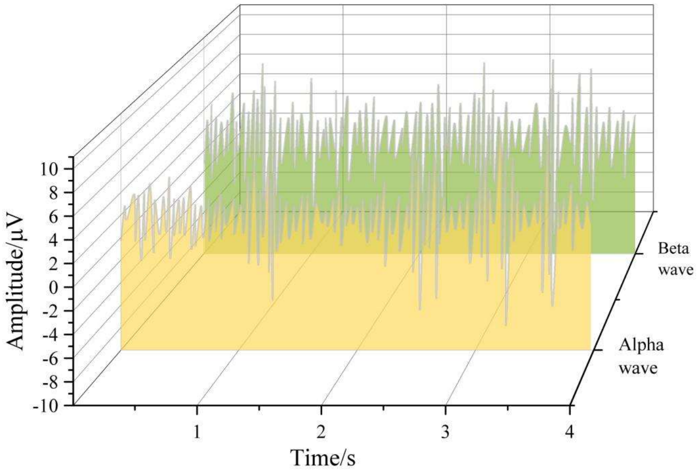
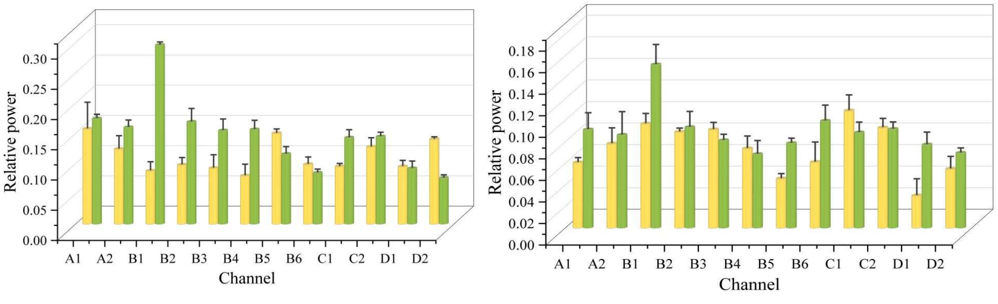


Figure 9: Electroencephalogram rhythm signal

III. D. Analysis of emotional and attentional improvement effects based on electroencephalographic signals

III. D. 1) Emotion EEG signal feature analysis based on power spectrum

The EEG signals were decomposed using db4 wavelets to obtain EEG signal data in the Alpha and Beta frequency bands. The power values of these two EEG signal frequency bands were calculated in the frequency domain, divided by the power value of the EEG signal before wavelet decomposition, to obtain the energy ratio of each frequency band relative to the full frequency band, i.e., the relative power value. The changes in relative power before and after the experiment are shown in Figure 10 (a~b). In the Alpha band, the relative power values of the electrode pairs A1-A2, B1-B4, and C1-C2 after the experiment were greater than those before the experiment. In the Beta band, the relative power values of the electrode pairs A1-A2, B1-B2, B5-B6, and D1-D2 after the experiment were greater than those before the experiment.



(a)Alpha wave (b)Beta wave

Figure 10: Relative power changes before and after the test

III. D. 2) Analysis of emotional EEG signal features based on EEG coherence

This study calculated the alpha and beta band EEG coherence of the frontal region A, temporal region B, central region C, and occipital region D, which are associated with functions such as emotion and cognition. The average values for all subjects are shown in Table 3, which illustrates the changes before and after the experiment. In the alpha band, the occipital region showed a significant increase in coherence, while the other regions showed a slight decrease. Changes in Beta-band coherence were more pronounced, with frontal lobe coherence increasing by

0.152 ($p < 0.01$) and temporal lobe coherence decreasing by 0.081 ($p < 0.05$). These results suggest that music therapy improves emotional well-being by regulating functional connectivity between specific brain regions, with enhanced functional coupling between the frontal and occipital lobes potentially representing a key neural mechanism underlying this effect.

Table 3: Changes before and after the test

	A	B	C	D
Alpha	0.502±0.127	0.488±0.201	0.328±0.166	0.645±0.218
	0.489±0.192	0.475±0.183	0.301±0.184	0.673±0.147
Difference	-0.013	-0.013	-0.027	0.028**
Beta	0.201±0.174	0.433±0.186	0.173±0.121	0.498±0.164
	0.353±0.183	0.352±0.194	0.231±0.155	0.471±0.193
Difference	0.152**	-0.081*	0.058	-0.027

IV. Conclusion

This study systematically explored the application of music therapy in residential environments through theoretical analysis and experimental verification.

Analysis of the acoustic parameters of residential spaces revealed no significant differences in sound signal reception times between central and lateral sound source locations. The difference in sound signal reception times between the front and rear measurement points was 25.91 ms, with significant differences in early reflection sound reception changes between the front and rear measurement points in the 0–50 ms range. The average EDT in the living room across the 100 Hz–3000 Hz octave bands was 0.79 s, with lower EDT values in the low-frequency range (0.69 s), moderate values in the mid-frequency range (0.82 s), and higher values in the high-frequency range (0.88 s). The EDT at the mid-rear measurement points was significantly higher than at the front measurement points, with the maximum EDT difference between measurement points reaching 0.47 s, far exceeding the minimum detectable difference (JND).

After music therapy, the relative power values of the A1-A2, B1-B4, and C1-C2 electrode pairs in the Alpha band were higher after the experiment than before. In the Beta band, the relative power values of the electrode pairs A1-A2, B1-B2, B5-B6, and D1-D2 were higher after the experiment than before. In the Alpha band, the occipital region showed a significant increase in coherence, while other regions showed a slight decrease. The changes in coherence in the Beta band were more pronounced, with an increase of 0.152 ($p<0.01$) in the frontal region and a decrease of 0.081 ($p<0.05$) in the temporal region. These results suggest that music therapy achieves emotional improvement by regulating functional connectivity between specific brain regions, with enhanced functional coupling between the frontal and occipital regions potentially being an important feature of its neural mechanism.

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