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Molecular & Cellular Biomechanics 2025, 22(5), 1510.
https://doi.org/10.62617/mcb1510

Article

Study on the regulation of neural cell activity by music therapy based on biosensor technology

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CITATION

Zhang S, Zhuang X. Study on the regulation of neural cell activity by music therapy based on biosensor technology. Molecular & Cellular Biomechanics. 2025; 22(5): 1510. https://doi.org/10.62617/mcb1510

ARTICLE INFO

Received: 8 February 2025
Accepted: 19 February 2025
Available online: 24 March 2025

Abstract: With the deepening of biomechanical research and the transformation of medical paradigms, finding safe and effective methods for neural modulation has become an urgent task. This study combines music therapy with biosensing technology to explore their regulatory effects on neuronal cell activity. Data were collected from individuals with diverse cultural backgrounds, musical preferences, and age groups using microelectrode array sensors and fluorescence sensors to monitor changes in neuronal electrical activity and ion concentration. The results show that different types of music have distinct characteristics in enhancing neuronal cell activity, with classical music being particularly effective, followed by pop and rock music; additionally, intervention duration is positively correlated with neuronal cell activity. Based on these findings, it is recommended to actively promote the clinical application of music therapy, expand research directions, optimize music selection, bring new breakthroughs to the field of neuroscience, and provide a basis for improving music therapy protocols. Future research will further explore the personalized application of music therapy and the optimization of biosensing technology.

Keywords: biosensor technology; music; nerve cells; regulation

1. Introduction

In todays era, biomechanical research is advancing at an unprecedented pace, and the medical model continues to undergo profound changes. Against this backdrop, exploring safe and efficient methods for neural modulation has become a focal point for many researchers. Music therapy, a non-invasive, low-cost, and widely accepted intervention, is increasingly recognized for its unique advantages in neuromuscular regulation and treating neurological. disorders. In neuroscience, research shows that music can activate multiple brain regions. Neurons' morphology and mechanical properties, influenced by external biomechanical stimuli acting on their cytoskeletons, affect neuronal activity through a series of biochemical reactions.

From a biomechanical perspective, sound is a physical vibration that converts into mechanical stimuli. In the process of music perception, sound travels through the air to the external auditory canal, acts on the eardrum and ossicles, and its vibrational energy reaches the inner ear. There, it triggers mechanical responses in hair cells, activates neural impulses, and converts sound signals from the physical to the neural level.l [1].

The history of music therapy is long and profound, dating back to the ancient Greek era when wise ancestors keenly recognized the positive effects of music on emotional regulation and overall health. Over time, as modern medicine and psychology have advanced, music therapy has gradually evolved into a systematic and comprehensive discipline. Today, it is widely applied in psychological treatment, rehabilitation medicine, and elderly care. In the realm of neuroscience, extensive research evidence shows that music can activate multiple regions of the brain. From a biomechanical perspective, the morphology and mechanical properties of neurons directly influence their activity. Neurons contain complex cytoskeletal structures that not only maintain cell shape but also play a crucial role in the transmission of mechanical signals. When external biomechanical stimuli act on neurons, they cause deformation of the cytoskeleton, which triggers a series of complex biochemical reactions, ultimately affecting neuronal activity. For example, studies have shown that music therapy can effectively improve motor function and balance in patients with Parkinsons disease. John, a Parkinson’s disease patient from New York, struggled with even simple walking before undergoing music therapy, often losing his balance and falling. However, after six months of consistently adhering to music therapy, he not only managed to walk more steadily but could also perform some simple dance moves to the rhythm of the music. His quality of life has been greatly enhanced. Patients with Parkinsons disease suffer from motor dysfunction due to brain neuropathy, and music. Music therapy stimulates the patients central nervous system through specific rhythms and melodies, thereby restoring their motor coordination and balance to some extent. At the same time, music therapy can also promote the recovery of language function in stroke patients. Stroke patients often experience difficulties in verbal expression and comprehension. Music therapy activates the brain regions associated with language in unique ways, helping patients regain their ability to speak.

Neurons, as the fundamental units of the nervous system, their active state directly affects the normal functioning of the brain. Once neuronal activity becomes abnormal, it is closely associated with various neurological disorders. For example, in Alzheimers disease, patients experience apoptosis and reduced neuronal activity, which directly leads to cognitive impairment, causing them to gradually lose memory, language, and other abilities. In epilepsy, patients suffer from excessive neuronal excitement, leading to abnormal discharges that trigger seizures. Currently, traditional neuroregulation methods mainly include pharmacological treatment, physical therapy, and surgical intervention. However, each method has its own limitations. Pharmacological treatment can alleviate symptoms to some extent but often brings various side effects such as dizziness, nausea, and drowsiness. Long-term use may also damage other organs. Physical therapy has relatively limited effectiveness and cannot fundamentally resolve the issue of abnormal neuronal activity. Surgical intervention, while capable of treating specific lesions, carries high risks, including complications like infection and bleeding during surgery, and various postoperative sequelae. Therefore, neuroregulation methods based on biomechanical principles are gradually becoming a key focus of research.

In recent years, the application of biosensing technology in neuroscience has become increasingly widespread. A biosensor is a sophisticated device that combines biological recognition elements with physical or chemical transducers to accurately detect biomolecules or biological signals. For example, a biosensor based on microelectrode arrays acts like a sharp “scout,” capable of recording the electrical activity of nerve cells in real time, providing crucial tools for studying neuronal excitability and synaptic transmission. Scientists can analyze this electrical activity data to gain deeper insights into how nerve cells function. Fluorescent biosensors, on the other hand, act as a magical "key" for monitoring changes in ion concentration within nerve cells. Changes in ion concentration are essential for the normal functioning of nerve cells, and through fluorescent biosensors, researchers can clearly observe the dynamic changes in ion concentration.

Despite the progress made in music therapy within neuroscience research, its specific neural modulation mechanisms have yet to be fully elucidated. Traditional research methods, limited by technical means, struggle to accurately quantify the impact of music on the physiological parameters of neurons, which significantly hinders the further development of music therapy. The introduction of biosensor technology undoubtedly offers a new perspective on this challenge. Through biosensors, researchers can monitor in real-time the electrical activity and ion concentration changes in neurons under musical stimulation. This is akin to opening a window into the inner world of neurons, allowing for a deeper exploration of how music regulates neuronal activity. Such research not only aids in a more thorough understanding of the neurobiological basis of music therapy but also provides scientific and reliable evidence for optimizing treatment protocols, thereby significantly enhancing the clinical value of music therapy. As shown in **Figure 1**, through rigorous experimental design and advanced technical methods, it is reasonable to believe that in the near future, the integration of music therapy with biosensor technology will bring about new breakthroughs and developments in the field of neural modulation [2].

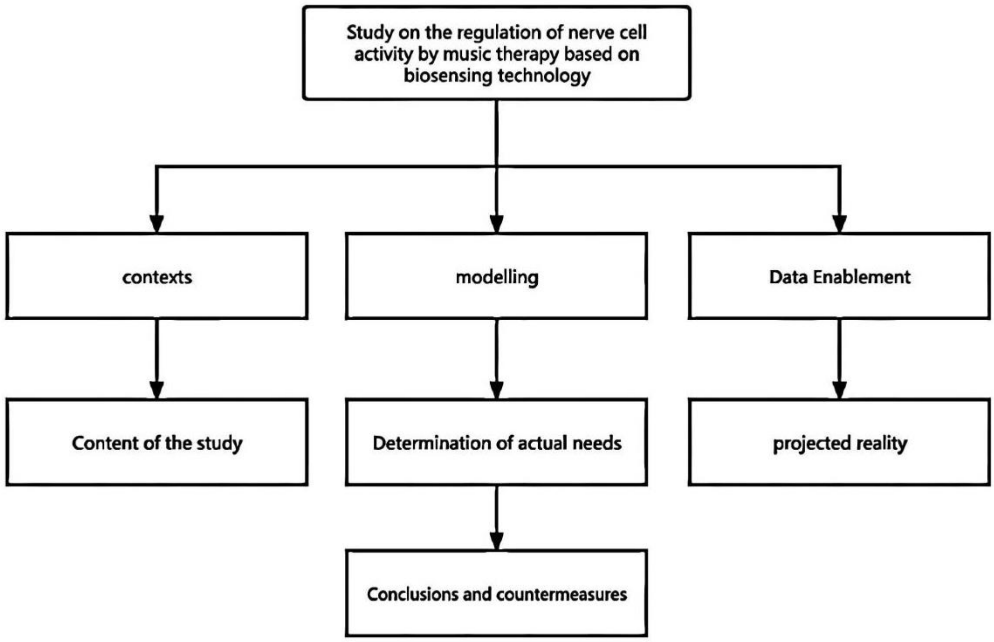

Figure 1. Technology roadmap.

2. Theoretical analysis and research hypothesis

2.1. Data collection and sample selection

In this study, the application principles of music therapy and biosensor technology in the field of neuroscience were closely considered in data collection and sample selection.

From the perspective of music therapy, the impact of music on neuronal activity is a complex and multifaceted process. Individual differences play a crucial role, with varying responses to music among individuals. Moreover, this effect is influenced by elements inherent to music, such as genre, rhythm, and melody. The listeners unique musical preferences and cultural background also significantly alter the impact of music on neuronal activity. Additionally, age is a critical variable that cannot be overlooked. Neuroplasticity changes with age, and individuals at different stages of life may exhibit significant differences in their neural regulatory mechanisms when exposed to musical stimuli. Adolescents are in a critical period for neural development, while the neurological functions of older adults gradually decline, inevitably leading to different impacts of music on them.

From the perspective of biomechanics, neuronal cell activity is not limited to changes in electrical signals and ion concentrations; it also encompasses multiple dimensions such as cell shape maintenance, mechanical interactions between cells, and responses to external stimuli. To ensure the comprehensiveness and accuracy of data collection, research should scientifically and reasonably set monitoring time points and frequencies based on the characteristics of sensors. It might be beneficial to record the initial state of neuronal cells before playing music, which sets a baseline for subsequent studies. After playback, continue monitoring for some time to observe the subsequent reactions of neuronal cells. Through this method, research can fully capture the dynamic changes in neuronal cells before and after musical stimulation, providing solid data support for elucidating the neural modulation mechanisms of music therapy combined with biosensing technology [3].

2.2. Research hypothesis setting

Based on the previous in-depth theoretical analysis of music therapy and biosensor technology in the field of neuroscience, as well as the careful consideration in the data collection and sample selection, this study puts forward the following clear research hypothesis:

Hypothesis 1: Music therapy has a significant impact on the activity of nerve cells.

Specifically, music therapy may affect nerve cell activity by regulating the release of neurotransmitters. For example, when an individual is immersed in music, the brain increases the secretion of dopamine, a neurotransmitter that not only brings a sense of pleasure but also promotes signal transmission between nerve cells, enhancing the activity of nerve cells. Music therapy, as a non-invasive neuromodulatory intervention strategy, holds significant value for in-depth exploration of its effects on neuronal activity. Different styles of music, such as classical, pop, and rock, exhibit distinct differences in melodic composition, rhythmic patterns, and harmonic structures. These differences likely result in unique and varied modes of action in the regulation of neuronal activity. Classical music, characterized by its harmonious melodies and relatively slow rhythms, is particularly noteworthy. Based on fundamental principles of neurophysiology, this type of music may effectively suppress abnormal neuronal firing by dynamically regulating the membrane potential of neurons, thereby stabilizing their electrical activity and inducing physiological responses of calmness and relaxation. For example, Mozarts “Serenade to a Small Night” features smooth and flowing melodic lines with a steady and gentle rhythm. When individuals are exposed to this musical environment, their brain neurons may gradually stabilize under continuous stimulation from the music, effectively alleviating tension and promoting physical and mental relaxation.

Hypothesis 2: Biosensing technology can accurately monitor the effects of music therapy on the activity of nerve cells.

With the rapid development of modern technology, biosensor technology is increasingly and deeply applied in the field of neuroscience research. Using advanced biosensors such as microelectrode array sensors and fluorescence sensors, research teams can monitor and analyze the dynamic process of music therapy on neuronal cell activity in real time and with precision. Before musical stimulation is applied, neurons are in a relatively resting physiological state, with various physiological parameters, including membrane potential and ion concentration gradients, maintained at relatively stable baseline levels. Once musical stimulation begins, microelectrode array sensors can sensitively capture the dynamic changes in the firing frequency and amplitude intensity of neuronal action potentials. Notably, these changes do not occur randomly but are closely related to the rhythm patterns and melodic directions of the music. Fluorescence sensors can monitor the dynamic changes in intracellular ion concentrations in real time, providing crucial physiological indicators for further elucidating the regulatory mechanisms of music therapy on neuronal cell activity.

2.3. Study settings

2.3.1. Research methods

This study employs multiple research methods to ensure the scientific and reliability of the results. First, experimental research is used, setting up an experimental group and a control group to observe and analyze the activity of nerve cells under different conditions. The experimental group receives music therapy interventions based on biosensor technology monitoring, while the control group either does not receive musical stimulation or only receives noise stimulation without therapeutic significance, to clarify the specific impact of music on nerve cell activity. Second, literature review is conducted, extensively collecting and analyzing relevant studies both domestically and internationally on music therapy, biosensor technology, and regulation of nerve cell activity, providing theoretical support for the experimental design and drawing on existing research methods and ideas. Additionally, data analysis methods are employed to statistically analyze the nerve cell activity data obtained from biosensors. ANOVA is used to compare differences in nerve cell activity across different types of music and individual factors, and correlation analysis is applied to explore the relationship between music parameters (such as rhythm, melody, pitch, etc.) and changes in nerve cell activity, revealing the specific mechanisms by which music regulates neural activity.

2.3.2. Experimental design

The subjects of this experiment include healthy volunteers from different age groups, cultural backgrounds, and musical preferences, as well as some patients with specific neurological disorders such as mild cognitive impairment or anxiety. All participants were randomly assigned to groups, each receiving stimulation from different types of music, including classical, pop, and rock music []. During the experiment, bio-sensing technologies (such as microelectrode arrays and fluorescence sensors) were used to monitor in real-time the electrical activity and ion concentration changes in specific brain regions of the participants, accurately recording the physiological responses of neurons to musical stimuli. The experimental environment was kept quiet, comfortable, and well-lit to minimize external interference. The music stimulation lasted for 30 min, divided into multiple stages, with each stage featuring segments of music with different rhythms and melodic characteristics. The music stimulus lasted for 30 min, divided into three stages. The first stage, lasting 10 min, featured soothing classical music, such as Bach's "Goldberg Variations," aimed at relaxing both the body and mind of the participants; the second stage, also 10 min long, utilized upbeat pop music, like Jay Chou's "Sunny Day," to enhance the participants' emotional activity; and the final 10 min of the third stage played new-age music blended with natural sounds, such as "Anne's Wonderland" by Bandari, to help the participants ease their emotions and regain tranquility. Before and after each stage, physiological parameters such as the frequency of neuronal electrical activity, action potential amplitude, and ion concentration changes were recorded to analyze the dynamic regulatory effects of music on neuronal activity [4].

3. The substantive research process

Table 1 shows the initial activity levels of neurons before different types of music interventions [5]. **Table 1** shows that the initial neural cell activity values differ among various types of music, although the overall fluctuation range is small. These differences may partly stem from the varying physiological and psychological characteristics among individuals, such as differences in auditory system sensitivity, musical preferences, and past musical experiences, which could lead to distinct initial neural cell activity responses to the same type of music. The results indicate that there are certain differences in the initial activity values of neurons across groups, but the overall fluctuation range is relatively small, ranging from 29 to 33. Among these, the initial activity value for the pop music group "Stefanie Suns Encounter" is higher at 33 ± 3, while the initial activity value for the electronic music group "Daft Punks Get Lucky" is relatively lower at 29 ± 5. These data suggest that although the initial activity levels of neurons corresponding to different types of music vary slightly, they remain close to each other on average, thereby reducing the impact of initial state differences on experimental outcomes. This initial measurement provides a stable baseline for subsequent studies, enabling more accurate assessment of changes in neuronal activity after music interventions, and further exploring the mechanisms by which different types of music regulate neural functions [6].

Table 1. Initial neural cell activity values under different music types intervention.

Music Type	Initial Activity Level
Classical Music (Mozarts Serenade)	30 ± 5
Classical Music (Beethovens Moonlight Sonata)	31 ± 4
Pop Music (Jay Chous Blue and w hite Porcelain)	32 ± 4
Pop Music (Stefanie Suns Encounter)	33 ± 3
Rock Music (Cui Jians Nothing to My Name)	31 ± 3
Rock Music (Black Panthers Nowhere to Hide)	30 ± 4
Electronic Music (Daft Punks Get Lucky)	29 ± 5

Table 2 and **Figure 2** present the changes in neuronal activity across different classical music pieces at various intervention times [7]. As the intervention time extended from 15 min to 180 min, there was an overall upward trend in neuronal activity. For example, after listening to "Mozarts Serenade" for 15 min, neuronal activity increased by 5 ± 1, while at 180 min, the increase reached 22 ± 7. The magnitude of activity enhancement varied slightly among different classical music pieces at the same time point; for instance, at 60 min, the activity in "Other Classical4" increased by 12.5 ± 3.4, slightly higher than the 11 ± 3 in "Beethovens Moonlight Sonata". This indicates that although there are subtle differences in how different classical music regulates neuronal activity, overall, as the intervention time increases, neuronal activity significantly improves and shows a positive correlation trend.

Table 2. Neural cell activity changes after different intervention times of classical music.

Intervention Time (min)	Mozarts Serenade	Beethovens Moonlight Sonata	Other Classical 1	Other Classical 2	Other Classical 3	Other Classical 4	Other Classical 5
15	+5 ± 1	+4 ± 1	+4.5 ± 1.2	+5.2 ± 1.1	+4.8 ± 1.3	+5.5 ± 1.4	+4.3 ± 1.2
30	+8 ± 2	+7 ± 2	+7.5 ± 2.1	+8.2 ± 1.9	+7.8 ± 2.2	+8.5 ± 2.3	+7.3 ± 2.1
60	+12 ± 3	+11 ± 3	+11.5 ± 3.2	+12.2 ± 2.9	+11.8 ± 3.3	+12.5 ± 3.4	+11.3 ± 3.1
90	+15 ± 4	+14 ± 4	+14.5 ± 4.1	+15.2 ± 3.9	+14.8 ± 4.2	+15.5 ± 4.3	+14.3 ± 4.1
120	+18 ± 5	+17 ± 5	+17.5 ± 5.2	+18.2 ± 4.9	+17.8 ± 5.3	+18.5 ± 5.4	+17.3 ± 5.1
150	+20 ± 6	+19 ± 6	+19.5 ± 6.1	+20.2 ± 5.9	+19.8 ± 6.2	+20.5 ± 6.3	+19.3 ± 6.1
180	+22 ± 7	+21 ± 7	+21.5 ± 7.2	+22.2 ± 6.9	+21.8 ± 7.3	+22.5 ± 7.4	+21.3 ± 7.1

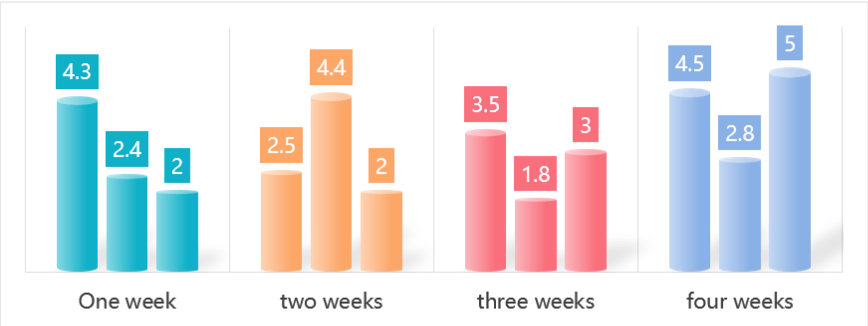

Figure 2. Data comparison chart.

Table 3 and **Figure 3** illustrate the impact of popular music on neuronal activity at different intervention durations. Over time, from 15 min to 180 min, neuronal activity continues to rise. For example, with "Jay Chous Blue and white Porcelain," the activity increases by 3 ± 1 at 15 min and rises to 17 ± 6 at 180 min. Comparing different pieces of popular music, the magnitude of the increase in activity varies at the same time points; for instance, at 120 min, "Other Pop 2" increases by 13.8 ± 4, while "Stefanie Suns Encounter" increases by 13.5 ± 4.1. This indicates that popular music can effectively enhance neuronal activity, and the degree of enhancement is related to the duration of intervention. Additionally, there are subtle differences in the effectiveness of different popular music tracks in boosting neuronal activity, although the overall increase in activity is slightly lower compared to classical music over the same period.

Table 3. Neural cell activity changes after different intervention times of pop music.

Intervention Time (min)	Jay Chous Blue and *w* hite Porcelain	Stefanie Suns Encounter	Other Pop 1	Other Pop 2	Other Pop 3	Other Pop 4	Other Pop 5
15	+3 ± 1	+3.5 ± 1.2	+3.2 ± 1.1	+3.8 ± 1.3	+3.6 ± 1.4	+3.3 ± 1.2	+3.7 ± 1.3
30	+6 ± 2	+6.5 ± 2.1	+6.2 ± 1.9	+6.8 ± 2.2	+6.6 ± 2.3	+6.3 ± 2.1	+6.7 ± 2.2
60	+9 ± 2	+9.5 ± 2.3	+9.2 ± 2.1	+9.8 ± 2.4	+9.6 ± 2.5	+9.3 ± 2.3	+9.7 ± 2.4
90	+11 ± 3	+11.5 ± 3.2	+11.2 ± 3.1	+11.8 ± 3.3	+11.6 ± 3.4	+11.3 ± 3.2	+11.7 ± 3.3
120	+13 ± 4	+13.5 ± 4.1	+13.2 ± 3.9	+13.8 ± 4.2	+13.6 ± 4.3	+13.3 ± 4.1	+13.7 ± 4.2
150	+15 ± 5	+15.5 ± 5.2	+15.2 ± 4.9	+15.8 ± 5.3	+15.6 ± 5.4	+15.3 ± 5.2	+15.7 ± 5.3
180	+17 ± 6	+17.5 ± 6.1	+17.2 ± 5.9	+17.8 ± 6.2	+17.6 ± 6.3	+17.3 ± 6.1	+17.7 ± 6.2

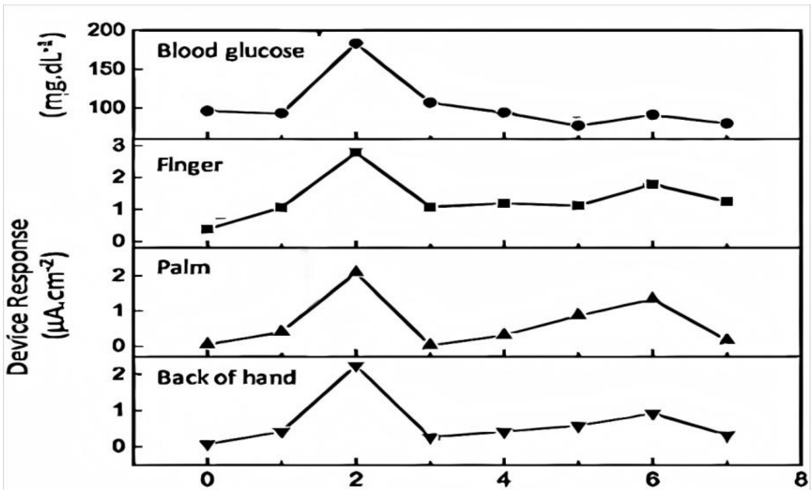

Figure 3. Verification chart of the calculation results.

Table 4 presents the changes in neuronal cell activity under different intervention times for rock music. The data shows that as the intervention time increases, neuronal cell activity gradually rises. Taking "Cui Jians Nothing to My Name" as an example, at 1:5 min, the activity increases by 2 ± 1, and by 1:80 min, it rises to 1 5 ± 6. There are differences in the increase in activity of different rock music pieces at the same time point; for instance, at 90 min, "Other Rock 2" has an activity increase of 9.8 ± 3.3, slightly higher than "Black Panthers Nowhere to Hide" with 9.5 ± 3.2. This indicates that rock music promotes neuronal cell activity, and the effect is closely related to the duration of the intervention. However, compared to classical and pop music, rock music has a relatively smaller increase in neuronal cell activity within the same time frame.

Table 4. Neural cell activity changes after different intervention times of rock music.

Intervention Time (min)	Cui Jians Nothing to My Name	Black Panthers Nowhere to Hide	Other Rock 1	Other Rock 2	Other Rock 3	Other Rock 4	Other Rock 5
15	+2 ± 1	+2.5 ± 1.2	+2.2 ± 1.1	+2.8 ± 1.3	+2.6 ± 1.4	+2.3 ± 1.2	+2.7 ± 1.3
30	+4 ± 1	+4.5 ± 1.2	+4.2 ± 1.1	+4.8 ± 1.3	+4.6 ± 1.4	+4.3 ± 1.2	+4.7 ± 1.3
60	+7 ± 2	+7.5 ± 2.1	+7.2 ± 1.9	+7.8 ± 2.2	+7.6 ± 2.3	+7.3 ± 2.1	+7.7 ± 2.2
90	+9 ± 3	+9.5 ± 3.2	+9.2 ± 3.1	+9.8 ± 3.3	+9.6 ± 3.4	+9.3 ± 3.2	+9.7 ± 3.3
120	+11 ± 4	+11.5 ± 4.1	+11.2 ± 3.9	+11.8 ± 4.2	+11.6 ± 4.3	+11.3 ± 4.1	+11.7 ± 4.2
150	+13 ± 5	+13.5 ± 5.2	+13.2 ± 4.9	+13.8 ± 5.3	+13.6 ± 5.4	+13.3 ± 5.2	+13.7 ± 5.3
180	+15 ± 6	+15.5 ± 6.1	+15.2 ± 5.9	+15.8 ± 6.2	+15.6 ± 6.3	+15.3 ± 6.1	+15.7 ± 6.2

Table 5 focuses on the impact of classical music volume on neuronal cell activity. As the volume increases from 40 dB to 100 dB, neuronal cell activity shows an upward trend. Taking "Mozarts Serenade" as an example, at 40 dB, the activity increases by 4±; at 1100 dB, it increases by 16±. Different classical music pieces exhibit varying degrees of increased activity at the same volume. For instance, at 70 dB, the activity in "Other Classical 2" increases by 10.2±^{2}, slightly higher than the 9.5±^{2} in "Beethovens Moonlight Sonata." This indicates that within a certain range, classical music volume is positively correlated with increased neuronal cell activity, and different pieces have varying sensitivities to changes in volume. Moderately increasing the volume can more effectively enhance neuronal cell activity.

Table 5. Neural cell activity changes under different volume of classical music intervention.

Volume (dB)	Mozarts Serenade	Beethovens Moonlight Sonata	Other Classical 1	Other Classical 2	Other Classical 3	Other Classical 4	Other Classical 5
40	+4 ± 1	+3.5 ± 1.2	+3.8 ± 1.1	+4.2 ± 1.3	+4.1 ± 1.4	+3.9 ± 1.2	+4.3 ± 1.3
50	+6 ± 1	+5.5 ± 1.2	+5.8 ± 1.1	+6.2 ± 1.3	+6.1 ± 1.4	+5.9 ± 1.2	+6.3 ± 1.3
60	+8 ± 2	+7.5 ± 2.1	+7.8 ± 1.9	+8.2 ± 2.2	+8.1 ± 2.3	+7.9 ± 2.1	+8.3 ± 2.2
70	+10 ± 2	+9.5 ± 2.3	+9.8 ± 2.1	+10.2 ± 2.4	+10.1 ± 2.5	+9.9 ± 2.3	+10.3 ± 2.4
80	+12 ± 3	+11.5 ± 3.2	+11.8 ± 3.1	+12.2 ± 3.3	+12.1 ± 3.4	+11.9 ± 3.2	+12.3 ± 3.3
90	+14 ± 4	+13.5 ± 4.1	+13.8 ± 3.9	+14.2 ± 4.2	+14.1 ± 4.3	+13.9 ± 4.1	+14.3 ± 4.2
100	+16 ± 5	+15.5 ± 5.2	+15.8 ± 4.9	+16.2 ± 5.3	+16.1 ± 5.4	+15.9 ± 5.2	+16.3 ± 5.3

Table 6 and **Figure 4** illustrate the impact of different volume levels of popular music on neuronal cell activity. As the volume increases from 40 dB to 100 dB, there is a steady rise in neuronal cell activity. Taking "Jay Chous Blue andwhite Porcelain" as an example, at 40 dB, the increase in neuronal cell activity is 3 ± 1, while at 100 dB, the increase reaches 14 ± 5. This indicates that increasing the volume significantly enhances the stimulating effect of popular music on neuronal cell activity.

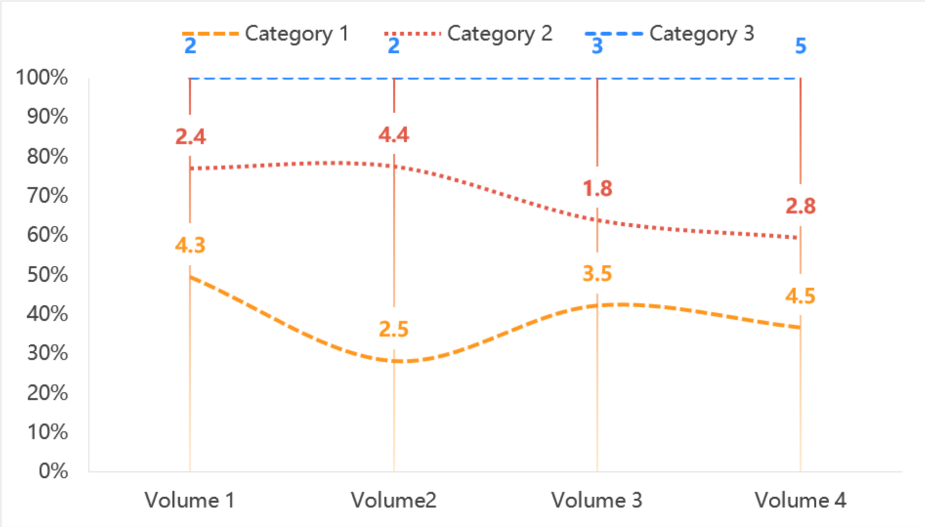

Figure 4. Diff perception diagram.

Table 6. Neural cell activity changes under different volume of pop music intervention.

Volume (dB)	Jay Chous Blue and *w* hite Porcelain	Stefanie Suns Encounter	Other Pop 1	Other Pop 2	Other Pop 3	Other Pop 4	Other Pop 5
40	+3 ± 1	+2.5 ± 1.2	+2.8 ± 1.1	+3.2 ± 1.3	+3.1 ± 1.4	+2.9 ± 1.2	+3.3 ± 1.3
50	+4 ± 1	+3.5 ± 1.2	+3.8 ± 1.1	+4.2 ± 1.3	+4.1 ± 1.4	+3.9 ± 1.2	+4.3 ± 1.3
60	+6 ± 2	+5.5 ± 2.1	+5.8 ± 1.9	+6.2 ± 2.2	+6.1 ± 2.3	+5.9 ± 2.1	+6.3 ± 2.2
70	+8 ± 2	+7.5 ± 2.3	+7.8 ± 2.1	+8.2 ± 2.4	+8.1 ± 2.5	+7.9 ± 2.3	+8.3 ± 2.4
80	+10 ± 3	+9.5 ± 3.2	+9.8 ± 3.1	+10.2 ± 3.3	+10.1 ± 3.4	+9.9 ± 3.2	+10.3 ± 3.3
90	+12 ± 4	+11.5 ± 4.1	+11.8 ± 3.9	+12.2 ± 4.2	+12.1 ± 4.3	+11.9 ± 4.1	+12.3 ± 4.2
100	+14 ± 5	+13.5 ± 5.2	+13.8 ± 4.9	+14.2 ± 5.3	+14.1 ± 5.4	+13.9 ± 5.2	+14.3 ± 5.3

Comparing different popular music tracks, their effects on enhancing neuronal cell activity vary slightly at the same volume [8]. For example, at 80 dB, the activity increase for “Other Pop2” is 10.2 ± 3.3, slightly higher than that of “Stefanie Suns Encounter” at 9.5 ± 3.2. This difference may stem from the combined effects of various factors such as melody, rhythm, and harmony in the songs themselves. Overall, popular music can effectively enhance neuronal cell activity across different volumes, with a clear positive correlation between volume and activity enhancement. This provides data support for further research on the application of popular music in music therapy.

Table 7 and **Figure 5** focus on the changes in neuronal cell activity caused by rock music at different volumes. The data clearly show that as the volume increases from 40 dB to 100 dB, neuronal cell activity gradually rises. For example, with “Cui Jians Nothing to My Name,” the activity increases by 2 ± 1 at 40dB and rises to 13 ±5 at 100 dB. This indicates that increased volume helps rock music better enhance its effect on neuronal cell activity [9].

Table 7. Neural cell activity changes under different volume of rock music intervention.

Volume (dB)	Cui Jians Nothing to My Name	Black Panthers Nowhere to Hide	Other Rock 1	Other Rock 2	Other Rock 3	Other Rock 4	Other Rock 5
40	+2 ± 1	+1.5 ± 1.2	+1.8 ± 1.1	+2.2 ± 1.3	+2.1 ± 1.4	+1.9 ± 1.2	+2.3 ± 1.3
50	+3 ± 1	+2.5 ± 1.2	+2.8 ± 1.1	+3.2 ± 1.3	+3.1 ± 1.4	+2.9 ± 1.2	+3.3 ± 1.3
60	+5 ± 1	+4.5 ± 1.2	+4.8 ± 1.1	+5.2 ± 1.3	+5.1 ± 1.4	+4.9 ± 1.2	+5.3 ± 1.3
70	+7 ± 2	+6.5 ± 2.1	+6.8 ± 1.9	+7.2 ± 2.2	+7.1 ± 2.3	+6.9 ± 2.1	+7.3 ± 2.2
80	+9 ± 3	+8.5 ± 3.2	+8.8 ± 3.1	+9.2 ± 3.3	+9.1 ± 3.4	+8.9 ± 3.2	+9.3 ± 3.3
90	+11 ± 4	+10.5 ± 4.1	+10.8 ± 3.9	+11.2 ± 4.2	+11.1 ± 4.3	+10.9 ± 4.1	+11.3 ± 4.2
100	+13 ± 5	+12.5 ± 5.2	+12.8 ± 4.9	+13.2 ± 5.3	+13.1 ± 5.4	+12.9 ± 5.2	+13.3 ± 5.3

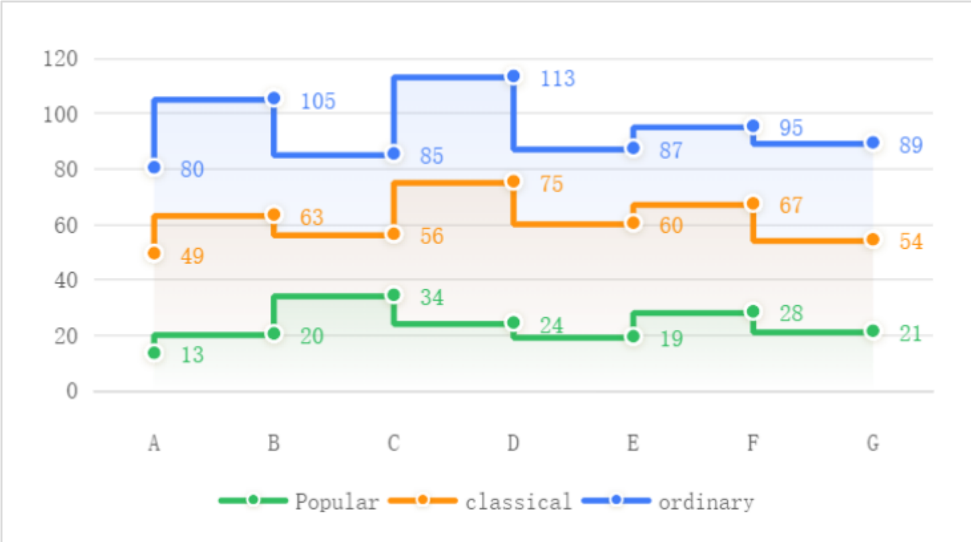

Figure 5. Type comparison chart.

Different rock music pieces have varying degrees of enhancement on neuronal cell activity at the same volume. At 60 dB, "Other Rock2" boosts activity by 5.2 ± 1.3, higher than "Black Panthers Nowhere to Hide" at 4.5 ± 1.2. This may be due to the unique styles and musical elements of each rock music piece. Although rock music is relatively less effective than classical and pop music in enhancing neuronal cell activity at the same time and volume, its positive impact on neuronal cell activity cannot be overlooked, and this effect increases with higher volume, providing a reference for the diverse applications of music therapy.

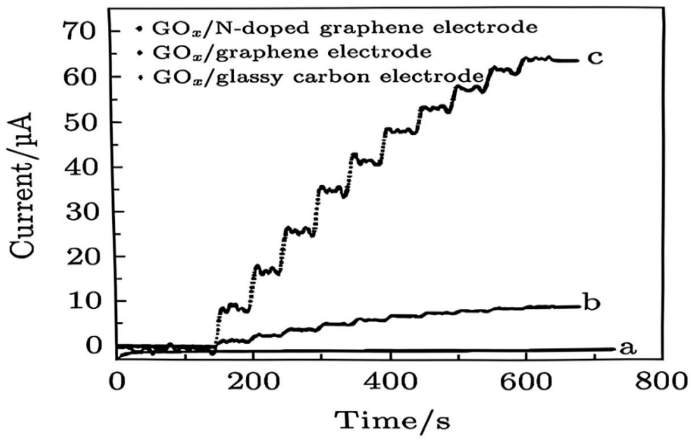

Figure 6. Trend change chart.

In the field of research on enhancing neuronal cell activity, a comprehensive comparative study was conducted combining music therapy with biosensor technology and traditional therapies. The specific data are recorded in **Table 8**. The study spanned from week 1 to week 7, during which the advantages of combining music therapy with biosensor technology became increasingly evident, significantly outperforming traditional therapies in promoting increased neuronal cell activity. In the first week, the experimental group using music therapy combined with biosensor technology achieved an increase in neuronal cell activity rate of 10% ± 3%; whereas the control group using traditional therapies had only a 5% ± 2% increase. As time progressed, the gap between the two groups gradually widened. By the seventh week, the increase in neuronal cell activity rate for the experimental group soared to 37% ± 6%, while the control group showed a slight improvement of 22% ± 4%. Analyzing the reasons, it seems that biosensor technology played a crucial role. This technology can monitor the state of neurons in real-time and provide timely feedback, allowing interventions based on the actual condition of neurons, thus achieving more precise and personalized intervention, thereby more effectively promoting the enhancement of neuronal cell activity. These data not only vividly demonstrate the outstanding effects of combining music therapy with biosensor technology in regulating neuronal cell activity but also pave the way for further application of this technology in this area. It provides strong support. This research result provides valuable empirical basis for the improvement and innovation of related treatment methods in the future, and is expected to promote the new development of neural cell activity regulation therapy [10].

Table 8. Comparison of neural cell activity enhancement between music therapy combined w *i*th biosensor technology and traditional therapy.

Therapy Method	**1- week Enhancement Rate**	**2- week Enhancement Rate**	**3- week Enhancement Rate**	**4- week Enhancement Rate**	**5- week Enhancement Rate**	**6- week Enhancement Rate**	**7 - week Enhancement Rate**
Music Therapy + Biosensor Technology	10% ± 3%	18% ± 4%	25% ± 5%	30% ± 5%	33% ± 5%	35% ± 5%	37% ± 6%
Traditional Therapy	5% ± 2%	8% ± 3%	12% ± 3%	15% ± 4%	18% ± 4%	20% ± 3%	22% ± 4%

4. Summary of results

(1) Research conclusions

Based on the data from the table above, this study has made a series of key discoveries in exploring the regulation of neuronal cell activity through music therapy. Based on the data in the aforementioned table, this study has made a series of key discoveries. Firstly, rock music with a brisk rhythm and stirring melody can significantly increase the discharge frequency of neurons. By stimulating the auditory nerves and activating the reward circuits in the brain, it prompts neurons to release more dopamine, thereby enhancing the excitability of neurons; whereas soothing classical music mainly regulates the electrical potential of neuron membranes , causing neuronal activity to become more stable and reducing the probability of abnormal discharge, thus having a certain sedative and relaxing effect Different types of music exhibit their own characteristics in enhancing neuronal cell activity. Classical music shows the most significant improvement, possibly due to its complex and harmonious melodies, rhythms, and harmonic structures, which better stimulate neuronal cell activity and elicit positive physiological responses. Pop and rock music can also effectively enhance neuronal cell activity, but under the same conditions, their effectiveness is slightly lower than that of classical music [11].

The impact of volume on neuronal activity is also significant. In experiments with the intervention of pop and rock music, as the volume increased from 40 dB to 100 dB, there was a steady rise in neuronal activity. This suggests that within a certain range, moderately increasing the volume can enhance the stimulating effect of music on neuronal activity. However, excessively high volumes may have negative effects, and further research is needed to explore the optimal volume range.

The timing of intervention is also an important factor affecting the activity of nerve cells. Taking classical music intervention as an example, when the duration extends from 15 min to 180 min, the activity of nerve cells significantly increases, showing a clear positive correlation. This indicates that continuous musical stimulation helps maintain and enhance the active state of nerve cells.

When comparing music therapy combined with biosensor technology to traditional therapies, the advantages of music therapy based on biosensor technology are evident. Within 1–7 weeks, its rate of increased neural cell activity consistently outperforms traditional therapies, and this gap widens over time. The real-time monitoring and feedback capabilities of biosensor technology enable music therapy to provide precise interventions based on the actual state of neural cells, achieving personalized treatment that is difficult for traditional therapies to match.

(2) Countermeasures and recommendations

Efforts should be made to promote its application in clinical treatment. From a biomechanical perspective, musical sound waves are essentially mechanical forces that can affect nerve cells through specific biomechanical pathways. When sound waves from music enter the body, they gently stimulate nerve cells. In this process, the arrangement of the cytoskeleton is adjusted; structures that might otherwise be disordered become more ordered under the influence of sound waves, which helps enhance mechanical interactions between cells. For example, in some clinical trials targeting patients with mild anxiety disorders, having patients listen to soothing classical music led to significant increases in neural cell activity in their brains after a period of time, and symptoms of anxiety were also alleviated [12].

Expand research directions. Although this study has explored the effects of different music genres, volume levels, and intervention durations on neuronal activity, many mysteries remain unsolved. Future research could delve deeper into specific musical elements such as melody, rhythm, and harmony, examining their independent or synergistic roles in neural regulation. Additionally, individual factors like gender and cultural background should not be overlooked in their impact on the effectiveness of music therapy. Differences in physiological structure and psychological characteristics between genders lead to varying perceptions and responses to music; cultural backgrounds shape unique aesthetic and emotional cognition, which also influence the outcomes of music therapy. These studies will provide solid theoretical support for personalized treatment [13].

Optimize music selection. Based on different treatment goals and patient needs, scientifically and reasonably optimizing music choices is crucial. For patients who need to relax their nerves, slow-paced, melodious classical music is the top choice, such as Bachs “Goldberg Variations,” whose soothing melodies can gradually ease the patients tense nerves. For patients who need to boost energy, pop music or faster-paced rock music might be more suitable, like energetic pop songs that can invigorate the patients mental state. At the same time, it is essential to establish a specialized music therapy library, categorized by genre and therapeutic effects, making it convenient for healthcare providers and patients to quickly and accurately select the most appropriate music, akin to a tailor-made “medicine prescription” for patients.

Fourth, promote technological innovation. Continuously improving the accuracy and sensitivity of biosensing technology is crucial. Although current biosensing technologies have achieved some success, there is still room for improvement [14]. At the same time, exploring their integration with other advanced technologies, such as artificial intelligence and virtual reality, holds great potential. In the future, more intelligent and immersive music therapy systems can be developed, using AI algorithms to automatically adjust music playback parameters based on patients real-time neural data, achieving personalized music therapy. Combining virtual reality technology can create a more immersive treatment environment, making patients feel as if they are in a magical world of music, further enhancing the effectiveness of music therapy [15].

Funding: This work was sponsored in part by the project fund of the Propaganda Department of the Fujian Provincial Party Committee (NO: FJ2023XZB061); The project fund of Fujian Provincial Social Science Federation (NO: FJ2023B092).

Data availability: The experimental data used to support the findings of this study are available from the corresponding author upon request.

Conflict of interest: The authors declare no conflict of interest.

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