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Research on the Mechanism of Music Perception in the Perspective of Neuroscience

Yun Fang*

Jianghan University, Wuhan 430000, Hubei Province, China

***Corresponding author:** Yun Fang, 18186495054@sina.com

Abstract: Music perception and creation is a complex cognitive process, starting from listening to music to understanding the meaning of the piece, and so on. With the development of neuroscience, we can now better understand the mechanism of music perception on a neural basis. The purpose of this study is to review the current research methods on the mechanism of music perception in terms of neurology, including fMRI, EEG, ERP and other techniques. Besides, this article also discusses the application and research progress of these technologies in music perception, aesthetics, and emotion processing. The conclusion of this paper shows that the neuroscience can provide us with new perspective to deeply understand the neural mechanism of music perception, which is of great significance to strengthening music education and music therapy.

Keywords: Music aesthetics; Perception mechanism; Brain science; fMRI; EEG; ERP

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1. Introduction

The perception mechanism of music aesthetics refers to the process in which the human brain perceives and restores musical stimuli. Music triggers a series of neural responses, from the auditory cortex to a complex network of internal prefrontal cortex, amygdala, ventral prefrontal cortex, zonal gyrus, and hippocampus. These neural activities reflect musical features like sound intensity, pitch, melody, rhythm, harmony, timbre, etc. It also involves networks and systems that trigger emotional responses, enhance memory, and enhance cognitive abilities. However, music appreciation, performance, or creation, are all cognitive processes. These processes involve in many aspects, from the cognition of musical elements to the recognition and comprehension of emotion and connotation. The neural mechanism of these cognitive processes has been highlighted in the neuroscience field. In recent years, the development of neuroscience, especially the brain imaging technology, provides us with a more convenient way to understand the neural basis of music. This technique can reveal the temporal and spatial features of neural activities involved in music processing, which will not only enhance our understanding of music cognition and emotion, it also provides new directions and methods for research in the fields of music education and therapy.

2. Neuroscience methods and techniques

2.1. The origins of neuroscience

Neuroscience is an interdisciplinary frontier science, which aims to study the structure, function and mechanism of the human brain in order to better understand the nature of human cognition, emotion, behavior and so on. The origins of neuroscience can be traced back to the 19th century, when ultrasonic processing was used in neuropsychology to complement the analysis of visual electroencephalography, which became increasingly complex in the 20th century. By the end of 20th century, experts in electroencephalography and audio technology had come together to develop the brain-computer music interface (BCMIS), a remarkable achievement spanning multiple disciplines. This interface significantly expanded the creative possibilities for patients and artists alike.

In 1929, the German psychiatrist Hans Berger (1873–1941) published the first report on human electroencephalography (EEG), which described a method for recording EEG activity using noninvasive scalp electrodes. In 1934, a renowned neurophysiology and Nobel Prize laureate, Edgar Adrian (1889–1977) first described the conversion of EEG data into sound (1934). Although these early experiments focused on recording brain waves in healthy conditions, electroencephalograms soon proved to be of particular value in clinical diagnosis. In fact, in the next few decades, EEG readings will greatly improve neurological diagnosis.

By the late 1960s, there was a new paradigm shift in brain-wave ultrasonic processing, when popular cybernetics and scientific breakthroughs led to the field of biofeedback, in which biological processes are measured and fed back to the same person to gain control of these processes. In 1958, the American psychologist Joe Kamiya first demonstrated that subjects could effectively learn to control their alpha activity when provided with real-time auditory feedback, but the technique did not catch on until he published an easy-to-understand paper in 1968. Since the alpha rhythm has long been associated with a peaceful mental state, EEG biofeedback (later known as neurofeedback) was soon used to treat a variety of neuropsychiatric disorders, attention-deficit hyperactivity disorder (ADHD), depression, and epilepsy.

At that time, people began to use signal detectors to record neuronal activity and compared it with data related to behavior, perception and so on. This method was called "physiological psychology" in the broad sense. With the development of science and technology, especially brain imaging technology, people can better understand the movement of neurons and the interaction of neural circuits. Functional magnetic resonance imaging (fMRI), electroencephalogram (EEG) and event-related potential (ERP) were used to study the aesthetic mechanism of music.

2.2. Applications of brain imaging in music research

In the field of music research, brain imaging techniques can reveal the functional divisions of the human brain, which can be used to infer the main cognitive processes, emotional perception, and perceptual components of music processing. Besides, music research also involves the study of musical elements such as rhythm, melody, harmonic patterns, chords, dynamics, emotions, etc.

2.2.1. Functional magnetic resonance imaging

fMRI is widely used to explore the neural mechanisms of music processing. It can track variations in blood flow across distinct brain regions, creating a functional map of brain activity based on these changes. By analyzing the results of studies using fMRI, we can understand the brain regions associated with music processing. For example, the temporal, parietal, occipital, brainstem, cerebellum, amygdala, prefrontal motor areas, and so on. The "musical nerves" (i.e., widely activated brain structures), which are diffusely distributed in the central cortex and temporal lobe, are thought to play a crucial role in music processing.

For example, in 2009, Fritz *et al.* conducted a study titled "Universal Recognition of Three Basic Emotions in Music" [1]. They examined individuals from 15 diverse cultures to explore how three fundamental emotions (happiness, sadness, and fear) are perceived in music across various cultural contexts. The participants' responses to these emotions were captured using fMRI. The results Fritz's study showed that people have a universal understanding of these three emotions in music even with different cultural background. Listening to music composed of these emotions activated several brain regions, including the bilateral frontal lobe, the right temporal lobe, the right amygdala, and the left basal ganglia. The activation of the right temporal lobe indicates that emotional information in music might be processed and segregated within this region. Similarly, the activation of the left basal ganglia implies its potential role in emotional processing and memory functions.

In the "Cortical Dynamics of Human Music Perception: An fMRI Study on Effects of Musical Training" [2], Itoh *et al.* used fMRI to record the activity of various brain regions in a group of subjects, they compared the brain activity of musically trained people with that of non-musically trained people. The participants were identify musical elements of a soundtrack such as instrumental sounds, loudness and trill, as well as the emotional components of music. By comparing brain activity data between musically trained and untrained subjects, it was found that when the musically trained subjects were exposed to more complex and challenging music, there was increased activity in the prefrontal cortex, parietal lobe, temporal lobe and cingulate gyrus. These areas are involved in cognitive functions such as attention control and working memory. This region is involved in cognitive functions such as attention control and working memory. In addition, music training can improve one's sensitivity to music, making it easier for one to hear the complexity and emotional components of music. This research has important implications for areas such as music education and music therapy. Additionally, it confirms the substantial value of neuroimaging technology in investigating music processing and perception.

In 2013, a study by Salimpoor *et al.* titled "Interactions between the Nucleus Accumbens and Auditory Cortices Predict Music Reward Value" revealed that various genres of music elicit specific brain activity patterns, triggering intense pleasure responses in regions associated with reward and emotions. The researchers found that regions such as the auditory cortex, amygdala, and hippocampus are associated with emotional features of music, and these regions are thought to be involved in emotional processing and memory encoding. In addition, regions such as the prefrontal cortex and striatum, which play important roles in reward processing and behavioral decision-making, are also associated with the rewarding features of music. The rewarding aspects of music encompass melody, harmony, rhythm, emotional expression, and cultural symbols. These elements can evoke pleasure and emotional responses from the audience, influencing their perception and preference for music.

During the experiment, the researchers used 10 pieces that the subjects had never heard before, ranging from jazz to rock and classical music. The experiment used a cross-over design, where each participant listened to different short tracks. Subsequently, fMRI was utilized to gather brain imaging data, allowing the researchers to observe changes in participants' brain activity as they listen to different types of music. After listening to each piece, the participants were asked to rate each piece that they listened to, and the results were recorded. The researchers analyzed the subjects' brain imaging data and self-report data to find patterns of brain activity for different types of music, and compared them with corresponding pleasure responses. The relationship between music and the brain was further explored.

Koelsch delved into the impacts of music on the brain and the neural mechanisms underlying emotional responses in his article "Brain Correlates of Music-Evoked Emotions" [4]. He first described how music causes the release of dopamine, which leads to feelings of pleasure or pleasure. Then, he further explored the neural mechanisms by which music triggers emotional experiences in the brain. These include motor neuron activity, interaction between cortical and subcortical structures, activation of right temporal lobe and insula, etc. Using the techniques of fMRI and magnetoencephalography (MEG), he combined evidence to reveal how music affects brain function in cognitive, emotional, memory, and reward domains. He found that emotional expression of music can enhance language comprehension and memory, and the male hormone testosterone can enhance this effect. The book also suggests that musical training can promote the development of brain structures involved in music and language processing.

2.2.2. Electroencephalography (EEG)

EEG is a commonly used physiological signal recording technique that measures the electrical activity of brain neurons that has a higher resolution compared to fMRI, positron emission tomography (PET) or other signal analysis techniques. This technique can analyze temporal features of music such as melody, rhythm, motion, etc.

For example, in 2018, Sanyal's research team described the process of testing using EEG technology in their paper "Music of Brain and Music on Brain: A Novel EEG Sonification Approach" [5]. In their study, they initially gathered psychological data based on human responses by assessing the mood of selected acoustic segments. Then, they carried out EEG responses using the same musical segments as stimuli. Five frontal (F3, F4, FP1, FP2, and FZ) and temporal (T3/T4) electrodes were selected for auditory and cognitive assessment. They employed a wavelet transform technique to extract alpha frequency waves from the EEG signals, as alpha waves are mainly linked to emotional activity linked with musical segments. Then, they used the MFDXA technique to evaluate two nonlinearities: the level of correlation between non-stationary signals (in this case, the output of an EEG signal and the input of an acoustic music signal). The results showed that the correlation was significantly increased in the music-induced state compared the auditorial control state. In the case of emotional music, the correlation coefficient showed clear evidence to support the quantification of emotion at specific electrodes in the human brain. In this experiment, a strong correlation was found between the music segment and the frontal pole of EEG. The correlation was found to decrease under the influence of happy and sad music. It was found that sad music resulted in a greater decrease in the correlation compared to that of happy music. Therefore, there is direct quantitative evidence for a correlation between music and EEG signals, as well as the level of arousal between the electrodes for mood music stimuli.

I did a study in 2022, which is described below.

(i) Subjects

The subjects involved were healthy junior music education students. The subject participated in the experiment voluntarily, and they were informed of the details of the experiment.

(ii) Materials

The audios used in this experiment were Chinese music "River Water" (sad) and "Step by Step High" (happy), which are pieces that depicts two types emotions. The duration of each audio clip was 2 minutes. Because of the individual differences of the subjects, no audio clip was cut off for each stimulus.

(iii) Procedure

The EEG experiment was carried out in a room at about 2 pm. In the experiment, the subjects were placed in a relaxed environment and sat on a comfortable chair, and they listened to the soundtracks with their eyes closed. Nineteen electrodes were positioned according to the International 10/20 system on the subjects' EEG recording caps (refer to **Figure 1**). Impedance tests indicated readings below 5 KΩ. The EEG recording system (Recorders and Medicare Systems) functioned at a recording rate of 256 samples per second, using custom software for root mean square (RMS) calculations. Raw EEG signals were filtered through both low-pass and high-pass filters with a cut-off frequency range of 0.5 to 35 Hz. Electrical interference at 50 Hz was mitigated using notch filters, whereas an electromyography filter was used to eliminate muscle artifacts. Reference electrodes a_1 and a_2 were placed at the ears. The same reference electrode was placed across all channels for the sake of consistency. The frontopolar midline electrode (Fpz) was designated as the ground electrode.

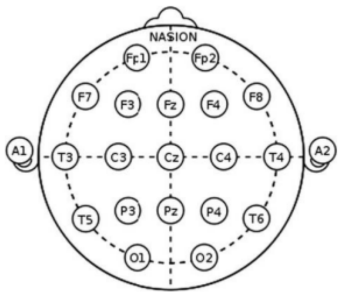

Figure 1. Electrode positions for each 10–20 system

(iv) EEG feature extraction

The first song "River Water" is a *guanziqu* (wind instrument piece). Wind instruments are very expressive. There are two types of wind instruments, one is made of wood, and another type is made of bamboo. Woodwind instruments are more high-pitched, solid, resonant, and mellow; bamboo-wind instruments is more delicate, deep, and rich. The experimental piece was played by a woodwind instrument. The 2nd song "Step by Step High" is the Guangdong music, the melody is lively and exciting, and the piece has many layers and a motivating melody. The EEG signals of the two emotionally different pieces of music are shown in **Figure 2** and **Figure 3**.

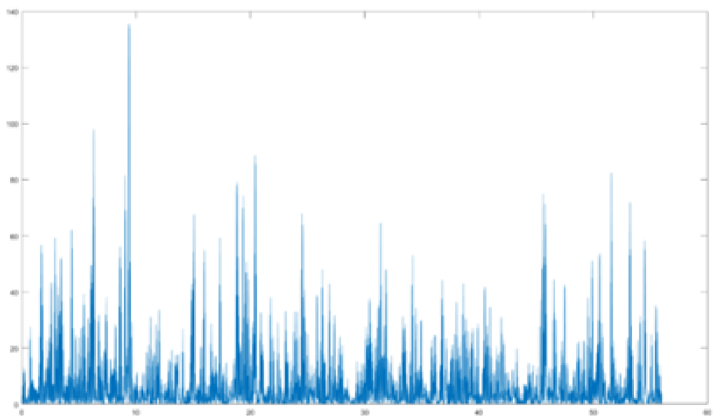

Figure 2. EEG signal after band-pass filtering of "River Water"

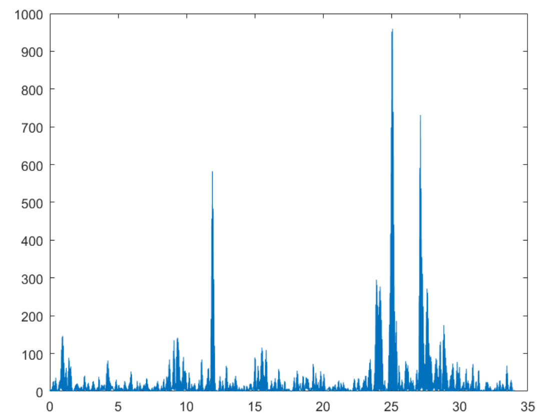

Figure 3. EEG signal after band-pass filtering of "Step by Step High"

Through the observation of the graph, the processing patterns in positive and negative emotional stimuli are distinctive. The correlation between frontal electrode and frontal electrode decreased for happy music; while for sad music, the same correlation increased strongly. When listening to "Step by Step High" When listening to "Step by Step High," the association was most pronounced for F3-FP1, F3-FP2, F4-FP1, T3-T4, and F4-T4, indicating closer communication between brain regions and increased synchronous activity. The F3-FP1 and F3-FP2 combinations were less correlated when listening to "River Water," indicating that the signals between the two electrodes were less correlated. It also indicates decreased synchronous activity between different brain regions. These observations reveal how neuronal signals from different lobes are related to each other in the cognitive process of emotional music stimuli. The classification of emotions is most prominent in the increase or decrease of interlobar/intralobar correlations in the temporal lobe. In addition, activity in the different lobes of the brain corresponding to the processing of certain musical emotions is an interesting finding of this study. Further studies corresponding to other electrodes and various emotional music stimuli are still needed to obtain more robust and concrete results in this field.

2.2.3 Event-related potential (ERP)

ERP is a technique for recording brain signals by electroencephalography (EEG). ERP recordings usually involve presenting participants with a piece or an element of music and recording the brain's response to that stimulus. In general, EEG signals are recorded using software that presents the stimulus. Commonly used stimuli include individual notes, chords, melodies, songs, and so on. The main characteristic of ERP signals is the wave response that appears within a few hundred milliseconds after being stimulated, forming a set of peaks and troughs with positive and negative phases and shorter duration.

ERP signals are usually analyzed using the following ways: selecting specific ERP components and performing quantitative analysis, calculating the temporal and spatial characteristics of ERP signal, and comparing the ERP signals with other studies through component analysis.

In 2016, Daniele Schön Mireille Besson *et al.* [6] conducted research using both electrophysiological and behavioral methods to investigate how pitch and interval are processed during music reading. Specifically, they examined whether pitch and duration in music reading are processed separately or together. In their study, participants were presented with target notes that varied in pitch or duration, and they were asked to make judgments regarding matches or mismatches in the corresponding dimensions. The results showed that the consistency of the target notes in the unrelated dimensions had no effect on ERP, indicating that pitch and duration were processed independently.

ERP is used to understand cognitive, emotional, sensory, and motor processes, and it represents a direct measure of neural activity. These methods are challenging for ERP researchers, as the accuracy and psychological reliability of the methods are questionable. Furthermore, scholars have been investigating the accuracy of data quality assessment in characterizing ERP scores. To improve the measurement methods, researchers focused on identifying psychometrically reliable measures of brain activity to determine whether these measures could be used to make valid statistical inferences in surveys within and between subjects. The conclusion that statistical inferences lead to unreliable data can be achieved by quantifying the internal consistency of the measurement, which is the reliability of a psychological measurement and characterizes the quality of the measurement. Measurements with a high degree of internal consistency are essential for inter-subject study about neurometry and correlations between individuals.

3. Conclusion

The development of neuroscience shows us the structure, function and psychological mechanism in the brain. This paper focuses on the application of neuroscientific methods to investigate the mechanism of music perception. These methods include fMRI, EEG, ERP, and other signal analysis techniques. Through the application of these technologies, we can better understand the neural basis of music processing, cognition, emotion recognition, and expression, in relation brain function. In addition, neuroscientific research is of great significance in the fields of music creation and appreciation, music therapy, and music education. Although there have been some breakthroughs, there are still some technical limitations in exploring the mechanism of music processing in terms of neuroscience. For example, brain imaging cannot provide detailed images at the level of individual neurons, which may be useful in understanding the richness and diversity of an observer's auditory experience.

In the future, we look forward to the continuous development and innovation of brain science and technology to further refine our understanding of music processing, cognitive and emotional processing, etc. These developments will further contribute to fields such as music education, music therapy, and music theory. In addition to exploring the mechanism of music perception, neuroscience and technology can also be applied to music therapy, which can be used to treat a variety of diseases. For example, learning difficulties, insomnia, anxiety, and depression. In addition, neuroscience have also contributed to the development of music education. Research on children's brains has indicated that those undergoing musical training experience accelerated development. Neurological areas associated with music exhibit higher activity rates in children with musical education compared to those without. Conversely, in non-musically trained children, the activation of these brain regions is notably slower. These findings imply that music education can potentially enhance cognitive abilities and language development in children. In short, neuroscience and technology are an important method to explore the mechanism of thoughts and behaviors. Besides, it is also important in the field of music research. Music is an important part of human culture that brings joy and affection. Through neuroscience and technology, we can understand music processing more deeply, which will be useful for music creation, appreciation and education. Although there are still limitations in neuroscience and technology, we believe that with the continuous progress and development of technology, we will have a deeper understanding of music from the perspective of neurology and psychology, so as to make further breakthroughs and create a better future.

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Disclosure statement

The author declares no conflict of interest

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