Neuroaesthetics of Music: From Aesthetic Response to Neural Basis

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Abstract

In recent years, with the development of neuroscience of music and neuroaesthetics, a new research field has gradually emerged, namely the neuroaesthetics of music. This research domain focuses on the psychological processes and neural mechanisms of musical aesthetics, concentrating on perception, cognition, and emotional interpretation in musical aesthetic activities. Musical aesthetic processing elicits corresponding aesthetic responses, among which three types have garnered greater research attention: musical aesthetic emotion, judgment, and preference. Researchers have investigated the perceptual, cognitive, and emotional processing of these aesthetic responses, along with their influencing factors and neural mechanisms. These studies provide empirical evidence for our understanding of the behavioral and neural mechanisms of music and aesthetics.

Full Text

The Neuroaesthetics of Music: From Aesthetic Responses to Neural Bases

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Abstract

In recent years, with the development of neuroscience of music and neuroaesthetics, a new research field has gradually emerged: the neuroaesthetics of music. This field focuses on the psychological processes and neural mechanisms underlying musical aesthetics, concentrating on the perceptual, cognitive, and emotional interpretations that occur during aesthetic engagement with music. Musical aesthetic processing elicits corresponding aesthetic responses, among which three types have received particular attention from researchers: musical aesthetic emotion, judgment, and preference. Researchers have investigated the perceptual, cognitive, and emotional processing of these aesthetic responses, along with their influencing factors and neural mechanisms. These studies provide empirical evidence for understanding the behavioral and neural mechanisms of music and aesthetics.

Keywords: music; aesthetic experience; emotional processing; neuroaesthetics; preference

1 Introduction

The importance of music to individuals and society is self-evident. Since the Xia, Shang, and Zhou dynasties, people have been "establishing rituals and creating music,"forming a unique cultural system. Later, Confucius and Mencius carried forward this tradition, synthesizing the essence of their predecessors to create a Confucian cultural system centered on ritual, music, benevolence, and righteousness, which has been passed down and developed to this day.

In recent years, with the development of cognitive science, the neuroaesthetics of music has gradually entered researchers' field of vision. On one hand, the cognitive neuroscience of music has begun to explore the similarities and differences between music and language processing; on the other hand, neuroaesthetics focuses on investigating the aesthetic experiences and their neural bases elicited by auditory and visual stimuli (Brattico & Pearce, 2013). Music is considered aesthetic because it generates emotions, triggers memories, and manifests beauty (Juslin & Laukka, 2004).

As early as the 19th century, pioneers of experimental psychology began studying how music produces aesthetic experiences. For instance, Helmholtz linked the aesthetic properties of musical notes and scales to their psychoacoustic attributes. Subsequently, Wundt used psychological methods to investigate aesthetics and introspection, examining how people' s feelings of pleasure, tension, and excitement changed with the beats of a metronome (Miller & Buckhout, 1973).

Early research in the neuroscience of music compared perception and cognition in music with language processing and comprehension. Researchers found that shared processing mechanisms exist between music and language at both low-level stages (such as speech sound processing, interval analysis, and semantic analysis) and high-level stages (such as structural and sentence analysis) (Foster & Zatorre, 2010; Koelsch, 2011).

In recent years, neuroaesthetics has become one of the most cutting-edge, interdisciplinary, and challenging new branches in Western aesthetics. Researchers have found that from ages 6 to 9 (Nieminen, Istók, Brattico, Tervaniemi, & Huotilainen, 2011), individuals exhibit similar aesthetic experiences and appreciation activities regardless of whether they have received artistic (musical or visual arts) training (Skov, Vartanian, Martindale, & Berleant, 2018): they can perceive emotions in music or paintings, form preferences for artworks, and evaluate the beauty of artworks based on specific criteria (Istók et al., 2009).

The focus on aesthetic and emotional experiences evoked by music has prompted scholars to attempt defining musical aesthetic experience (Brattico, Bogert, & Jacobsen, 2013; Hodges, 2016). A widely accepted definition describes it as the perceptual, cognitive, and emotional interpretations that arise when an individual immerses themselves in music and directs attention to formal features based on perceptual experience (Brattico & Pearce, 2013).

As listeners, the structural features of musical works interact with individual knowledge, experience, and contextual characteristics (Juslin, 2013), generating perception of the musical work (Koelsch, 2011) and triggering emotional recognition in the individual (Juslin, Liljeström, Västfjäll, & Lundqvist, 2010). Subsequently, individuals make aesthetic judgments about the perceived musical work based on personalized aesthetic criteria (Juslin, Sakka, Barradas, & Liljeström, 2016), ultimately forming preferences for different types or styles of music (Brattico et al., 2013).

Therefore, researchers consider musical aesthetic experience to comprise three main aspects (Brattico & Pearce, 2013): first, emotional recognition (e.g., "this song is sad") and emotional contagion (e.g., "I feel nostalgia"); second, aesthetic judgment (e.g., "this song is beautiful"); and third, liking (e.g., "I like this song") and preference (e.g., "I love rock music"). This paper primarily reviews these three types of aesthetic responses to music, along with factors influencing these aesthetics such as expectation, familiarity, and individual and contextual differences, and discusses the neural bases of musical aesthetics in conjunction with cognitive neuroscience research.

2.1 Musical Aesthetic Emotional Experience and Its Neural Basis

Music is considered one of the most potent elicitors of human emotions (Scherer & Zentner, 2008). Early research on emotion generation in musical experience primarily operated within the framework of basic emotions. Researchers found that music can express and evoke basic emotions in individuals of all ages, including infants (Peretz, 2010), and that basic emotional experiences induced by music typically activate classic emotion-related brain regions (Trost, Ethofer, Zentner, & Vuilleumier, 2011).

However, traditional emotion classification methods (such as discrete emotion models or dimensional models) cannot adequately describe mixed emotions in musical experience, such as feeling both sad and enjoyable simultaneously (Hunter, Schellenberg, & Schimmack, 2008). This is because the "safety" of the aesthetic context in musical experience eliminates the potential danger associated with negative emotions, allowing people to suppress unpleasant negative effects and enjoy negative emotions (Huron, 2006; 王丁, 王超, 李红, 2018).

Through categorization tasks, researchers have found that brain regions activated by musical emotions differ from those activated by liking judgments, suggesting a possible dissociation between the neural mechanisms of musical emotion and musical reward (Brattico et al., 2016). However, only limited evidence shows that sad music can activate the caudate nucleus, which is associated with pleasure (Brattico et al., 2011; Brattico et al., 2016).

To better understand musical aesthetic emotions, researchers have distinguished between aesthetic emotions and everyday emotions. Classical aesthetic perspectives hold that aesthetic emotion is a "disinterested interest" that differs from functional emotions, occurring in contexts devoid of self-interest or goal-directed behavior (Scherer & Zentner, 2008).

Simultaneously, researchers have also distinguished between emotion perception and emotion experience in music (Scherer & Zentner, 2008). The former adopts an object-oriented perspective, emphasizing emotion perception and focusing on emotions expressed by music, which can be considered the domain of musical emotion. The latter adopts a subject-oriented perspective, emphasizing emotion experience and focusing on emotions evoked in listeners by music, which can be considered the domain of musical aesthetic emotion.

Researchers propose that emotions evoked by music constitute a complex ensemble (Scherer & Zentner, 2008), integrating influences from musical structural features (e.g., major or minor mode), listener characteristics (e.g., musically trained or untrained), performance features (e.g., solo or symphony), and contextual features (e.g., concert hall or improvisational setting), thereby generating unique emotional experiences such as wonder, transcendence, entrainment, tension, and awe.

Zentner, Grandjean, and Scherer (2008) collected data from thousands of participants, confirming a nine-factor model of musical emotions: wonder, transcendence, tenderness, nostalgia, peacefulness, power, joy, tension, and sadness, and developed a multidimensional assessment tool based on this model—the Geneva Emotional Music Scale (GEMS).

Among these emotions, three aesthetic emotions have received the most attention: awe, nostalgia, and joy. Aesthetic awe is considered a crucial feature distinguishing peak aesthetic experiences in music from casual listening (Gabrielsson & Lindström, 2010). Awe is a rare aesthetic emotion typically triggered by exceptionally beautiful music or outstanding performances in optimal acoustic environments (e.g., medieval cathedrals) (Konecni, 2005).

Currently, research on the neural mechanisms of aesthetic awe remains limited, though it may be associated with activity in the anterior cingulate cortex (ACC) and anterior regions of the insula (Koelsch, 2018).

The second important aesthetic emotion is nostalgia. Janata (2009) employed a novel paradigm to extract autobiographical memories associated with songs. Participants were presented with popular/jazz tracks from previous years, and correlation analyses were conducted between their associative ratings and cerebral metabolism. The results revealed that the dorsal region of the medial prefrontal cortex (mPFC) plays a critical role in music-evoked nostalgic experiences.

Recent research has further demonstrated that nostalgic music is significantly correlated with activity in the inferior frontal gyrus, substantia nigra, cerebellum, and insula (Barrett & Janata, 2016).

The third emotion is joy, which researchers have primarily focused on through the study of chills responses. Chills typically manifest as physiological changes such as goosebumps and shivers down the spine. Although not everyone experiences chills when listening to music, a substantial number of people report such experiences (Panksepp, 1995).

Because chills exhibit distinct physiological markers in behavior, including changes in heart rate, respiratory depth, and skin conductance, they offer advantages for research (Blood & Zatorre, 2001). Researchers have found that chills responses can activate bilateral insula, left ventral striatum, right orbitofrontal cortex, medial anterior cingulate cortex, supplementary motor area, right thalamus, and left midbrain (Blood & Zatorre, 2001).

Research by Salimpoor et al. (2011) has shown that chills responses are associated with dopamine release in the ventral striatum and activation of the nucleus accumbens (NAcc), with the caudate nucleus being activated during anticipation of music passages that induce chills.

Joy evoked by music essentially constitutes a rewarding experience (Zatorre & Salimpoor, 2013). Its neural basis involves the interaction between the superior temporal gyrus (auditory cortex) and the nucleus accumbens, which activates the NAcc and releases dopamine through functional connectivity (Martínez-Molina, Mas-Herrero, Rodríguez-Fornells, Zatorre, & Marco-Pallarés, 2016; Sachs, Ellis, Schlaug, & Loui, 2016; Salimpoor et al., 2013). The NAcc is a key reward-related brain region, and its activation is accompanied by dopamine release that evokes pleasurable feelings (Salimpoor, Zald, Zatorre, Dagher, & McIntosh, 2015).

Furthermore, emotional experiences in musical aesthetics also involve brainstem mechanisms, with activity in this region primarily triggered by the perception of consonance and dissonance (Juslin & Västfjäll, 2008). Researchers have found that perceptual responses to dissonance are often associated with irritating emotional experiences, with the neural basis primarily involving the parahippocampal gyrus and amygdala (Koelsch, Fritz, Cramon, Müller, & Friederici, 2006).

When listening to classical music expressing emotions, the parahippocampal gyrus shows lateralization advantages (Trost et al., 2011): the left parahippocampal gyrus is engaged when listening to high-arousal music, while the right parahippocampal gyrus is activated when listening to low-arousal, tender, or nostalgic music.

Conversely, the soothing feelings produced by consonant sounds may be related to processing in the brainstem and ventral striatum (Koelsch et al., 2006). Additionally, brain activation produced by consonant sounds includes the rolandic operculum, which may be associated with the automatic impulse to imagine singing along with cheerful music, as this brain region is activated even in individuals without musical training when they hear consonant sounds (Koelsch et al., 2006).

2.2 Musical Aesthetic Judgment and Its Neural Basis

Höfel and Jacobsen (2007) proposed that aesthetic processing involves three main stages: the sensation stage, central processing stage, and output stage. The sensation stage refers to perceptual processing of the object; the central processing stage includes reflection on the object' s aesthetic value and making aesthetic judgments; the output stage is related to explicit behaviors, such as aesthetic expression through painting, music, poetry, dance, and other forms.

Researchers have identified the neural bases for these three stages based on cognitive neuroscience findings: the sensation stage corresponds to occipital and temporal cortical regions involved in perceptual processing; the central processing stage corresponds to prefrontal cortex and cingulate gyrus involved in working memory, emotional responses, and cognitive control; the output stage corresponds to motor cortical regions controlling bodily movements (王乃弋, 罗跃嘉, 董奇, 2010).

As an important component of aesthetic judgment, musical aesthetic judgment is considered an individual' s evaluation of a piece of music' s aesthetic value based on a set of subjective criteria (Juslin, 2013). The cognitive processing of musical aesthetic judgment is similar to general aesthetic judgment but also has its own distinctive characteristics.

Researchers have found it difficult to identify a single criterion that explains how people judge musical aesthetic value (Juslin & Isaksson, 2014). Both musically trained and untrained individuals make judgments based on multiple features, and different listeners tend to emphasize different criteria.

Juslin et al. (2016) proposed a framework model to explain which subjective criteria people primarily rely on, assigning different relative weights to comprehensively evaluate the aesthetic value of musical works. Due to the capacity limitations of working memory on cognitive judgment, individuals can simultaneously consider between 1-4 aesthetic criteria, which mainly include beauty, skill, expression, originality, emotional arousal, information, and typicality (Juslin & Isaksson, 2014).

Listeners assign differential weights to various aesthetic criteria at specific time points. Through this balancing process, if the music is generally deemed good, it leads to liking (or preference); conversely, it results in dislike.

This model has been supported by numerous studies. Istók et al. (2009) used questionnaire surveys to examine Finnish students' views on musical aesthetic value, finding that "beauty" is a core attribute associated with musical aesthetic value. Juslin and Isaksson (2014) observed in survey research that listeners consider "beauty" as one of the most important criteria for their music selection.

Expression is another important feature of music, which people often view as a form of expression for conveying emotions. Listeners prefer the most expressive musicians and consider expression as one of the important criteria for musical aesthetic judgment (Juslin, 2013; Juslin & Isaksson, 2014).

Although not all musical performances aim for creativity, originality is considered to play an important role in musical aesthetic judgment (Juslin & Isaksson, 2014).

Skill refers to artistic abilities that people cultivate, recognize, and admire. Gabrielsson (2011) found that people sometimes consider skill factors when making aesthetic judgments and can even infer performers' skill levels simply by listening to music.

Information is also a factor influencing listeners' judgments of musical aesthetic value. Leder et al. (2004) found that listeners' subjective understanding of musical "information"may generate feelings of "cognitive mastery"or appreciation of the work' s "ingenuity," leading to aesthetic judgments.

Style is another important criterion influencing listeners' musical aesthetic judgments. Musicians can establish "typical" music of a particular style by establishing and using specific "rules." Research has confirmed that musical style is closely related to preference and constitutes one of the important criteria for musical aesthetics (Leder et al., 2004).

Researchers also believe that emotional arousal is not necessary in typical aesthetic judgment contexts (Juslin & Isaksson, 2014). However, when listeners' judgments of music are extremely good (or bad), emotional arousal (such as awe) may occur beyond evaluative liking.

Therefore, emotion, aesthetic judgment, and preference in musical experience are relatively independent. For highly "engaged" listeners, musical preference primarily reflects aesthetic judgment of music, whereas for less engaged listeners, musical preference can bypass aesthetic judgment.

Hargreaves et al. (1980) reported empirical evidence for the dissociation between musical preference and aesthetic judgment. Their survey showed that both musically trained and untrained listeners rated the quality of classical works higher than that of popular works, but this judgment did not correspond to liking ratings (i.e., preference).

In another study, researchers examining audience responses during concerts found evidence for dissociation between aesthetic judgment and emotional arousal: listeners could distinguish the perceived quality of musical performance (aesthetic judgment) from their own emotional reactions (Thompson, 2006).

Neuroimaging studies on musical aesthetics have found significant correlations between musical aesthetic judgment and activity in the orbitofrontal cortex (Blood & Zatorre, 2001; Brattico et al., 2011; Pereira et al., 2011).

Researchers manipulating musical melody and rhythm found that, compared to rhythm judgment, musical aesthetic judgment significantly activated the anterior portion of the medial frontal gyrus (Kornysheva, von Cramon, Jacobsen, & Schubotz, 2010).

Ishizu and Zeki (2011) further discovered that a small region on the medial orbitofrontal cortex (Area A1) is related to the intensity of aesthetic experience in aesthetic judgments of both music and painting.

Suzuki et al. (2008) found that, compared to judgments of harsh dissonant chords, judgments of beautiful consonant chords activated the dorsomedial midbrain nuclei, a region belonging to the brain' s dopamine reward circuit, suggesting that musical aesthetic judgment may involve the brain' s reward circuitry.

Additionally, musical aesthetic judgment involves the ventral premotor cortex and cerebellar regions, which are significantly activated when listeners make judgments of melodic beauty compared to judgments of unattractive melodies (Kornysheva et al., 2010). This may be because beautiful music cultivates behavioral responses such as the ability to sing and dance, thus musical aesthetic judgment activates motor regions.

Neuroimaging studies have also found evidence for dissociation between aesthetic judgment and emotional experience. Researchers have discovered that when participants make aesthetic judgments in aesthetic contexts, the dorsolateral prefrontal cortex and orbitofrontal cortex are typically activated (Jacobsen, Schubotz, Höfel, & Cramon, 2006; Nadal, Munar, Capó, Rosselló, & Cela-Conde, 2008), whereas judgments based on the emotional valence of stimuli activate ventromedial prefrontal regions (Kringelbach, 2005).

On the other hand, research has found that the left middle frontal gyrus and adjacent superior frontal gyrus, activated by sad music, are also activated during aesthetic judgments of pictures (Jacobsen et al., 2006) and melodies (Kornysheva et al., 2010). This may suggest that these activations reflect listeners' subjective preferences for musical pieces rather than sad emotional experiences.

2.3 Musical Preference and Its Neural Basis

Another important outcome of musical aesthetic experience is preference. Unlike musical enjoyment or subjective pleasure, preference represents a decision made about a relevant stimulus (such as a melody), typically occurring after listening to an entire piece of music or after an extended period of listening to a portion of a musical excerpt.

This decision may be based on the intensity of musical enjoyment and other internal factors (such as hearing musical excerpts that match an individual' s personality or current mood). Preference in musical aesthetics is generally defined as the static outcome of aesthetic processing and can be considered synonymous with conscious liking to some extent.

The difference is that preference remains stable over a period of time, while liking is more often viewed as a changing cognitive process (Brattico et al., 2013).

Preference for music may be related to music-evoked emotions: the more people are moved by a piece of music, the more they like it (Schubert, 2007). The gap between emotions expressed by music (external trajectory) and emotions felt by listeners (internal trajectory): the smaller the gap between these two emotional trajectories, the more likely preference will emerge (Schubert, 2007).

Additionally, preference is influenced by various social factors. For example, parents' or siblings' musical preferences often determine children' s musical preferences (Roulston, 2006).

Gender stereotypes and personality traits both influence individuals' musical preferences (Yeoh & North, 2010): women prefer classical, mainstream, ethnic music, alternative rock, and Latin and black music more, while men favor jazz, dance, rock, and functional music more. Compared to individuals with low empathy, those with high empathy experience more sadness when listening to sad music and express higher preference (Yeoh & North, 2010).

Musical preferences formed by individuals' musical knowledge, social attitudes, and other factors accumulate to create each person' s unique musical taste.

Neuroscientific research on musical preference remains relatively scarce, though existing studies suggest that musical preference may be related to lateralized brain networks.

Researchers using EEG experiments have found that when participants listen to their preferred music, the left temporal lobe responds; however, when they hear disliked music, the right fronto-temporal region responds (Altenmüller, Schürmann, Lim, & Parlitz, 2002).

Another study combining EEG and fMRI found that when participants heard beloved compositions by Bach and Mahler, left hemisphere regions were significantly activated, primarily including the middle temporal lobe and cuneus. In contrast, when they heard pieces by contemporary composers that were not well-liked, bilateral inferior frontal gyri and insula were activated (Flores-Gutiérrez et al., 2007).

Recent research has found that when individuals appreciate their preferred music, connectivity within the brain' s default mode network becomes stronger, and listening to favorite songs can alter brain connectivity between auditory regions and the hippocampus (Wilkins, Hodges, Laurienti, Steen, & Burdette, 2014).

2.4 Review of Neural Bases of Musical Aesthetic Experience

Through reviewing musical emotional experience, aesthetic judgment, and preference, we can see that these three aesthetic responses possess relative independence and temporal continuity.

Brattico et al. (2013) summarized this and proposed a model of musical aesthetic experience. From a temporal sequence perspective, aesthetic experience begins with feature analysis and integration of the aesthetic object.

Music is a highly complex sensory signal whose input begins from peripheral organs and their connections with sensory cortex, and is analyzed within the central nervous system (Koelsch, 2011).

Within 20 milliseconds after music begins, it can reach the primary auditory cortex in the middle of the transverse temporal gyrus, then travel through the ventral pathway from the superior temporal gyrus to the inferior frontal lobe, where information integration occurs.

Further processing of musical signals requires attentional and working memory resources, which involves the participation of the prefrontal cortex. Therefore, the frontotemporal network plays an important role in early musical perception and cognitive processing (Rauschecker, 2012).

In addition to processing musical information, listeners produce early emotional responses upon receiving sound signals. Emotional responses at this stage are often accompanied by activation of brain regions such as the amygdala and parahippocampal gyrus.

Researchers believe that arousal and valence constitute early emotional responses to music, which subsequently differentiate into discrete emotions (such as sadness or joy). Discrete emotional responses primarily involve activity in the prefrontal and parietal lobes and manifest as slow-wave EEG signals peaking approximately 300-600 milliseconds after sound onset (Brattico et al., 2013).

Then, listeners make aesthetic judgments about musical works based on different value criteria. Researchers have found that aesthetic judgments at this stage evoke a positive potential lasting 600-1200 milliseconds (Müller, Höfel, Brattico, & Jacobsen, 2010) and activate the superior and middle frontal gyri in the orbitofrontal cortex, as well as the anterior cingulate cortex (Kornysheva et al., 2010).

The relationship between the orbitofrontal cortex and aesthetic judgment has also been found in aesthetic judgments of other forms, such as painting (Ishizu & Zeki, 2013).

Accompanying aesthetic judgment are aesthetic emotions (such as nostalgia, awe, etc.), which differ from previous discrete emotions, are typically slow, and require listening to the entire musical work.

When listeners or performers enjoy such intense aesthetic emotions, they sometimes experience certain bodily changes, such as chills. The intensity of chills is positively correlated with activity in extensive brain regions including the ventral striatum, orbitofrontal cortex, insula, anterior cingulate cortex, and supplementary motor area, and negatively correlated with activation of the hippocampus, amygdala, precuneus, and medial frontal cortex (Panksepp, 2009).

Aesthetic emotions integrate early emotional responses, as well as the perception, induction, and recognition of discrete emotions, leading to longer and more intense emotional and bodily responses, and ultimately forming conscious preferences.

Brattico et al. (2010) found that, compared to correctness judgments, the electrophysiological response corresponding to preference judgment (late positive potential, LPP) peaks at approximately 1200 milliseconds, likely occurring after aesthetic judgment.

Stable musical preferences are often related to personality traits, social factors, and professional knowledge, ultimately forming each individual's unique musical taste.

In summary, musical aesthetics is a process that includes sensory input, emotional arousal, aesthetic judgment, and interaction between emotions and feelings, ultimately forming preferences. In this process, the orbitofrontal cortex, amygdala, striatum, anterior cingulate cortex, and motor cortex play important roles.

3.1 Influences of Aesthetic Subject Factors

Aesthetic responses in music are influenced by aesthetic subject factors, mainly including familiarity, individual factors, and contextual factors.

Familiarity, also called repeated listening, refers to the anticipation resulting from having heard or repeatedly encountering the same or similar music previously. Familiarity is an important factor influencing aesthetic judgment in musical experience.

There are two different viewpoints regarding the influence of familiarity on musical aesthetic experience. One viewpoint holds that familiarity can increase musical preference. As participants listen to music more frequently, they can unconsciously learn the statistical regularities of music, generating expectations that influence emotional experiences, with enjoyment and liking subsequently increasing—a phenomenon researchers call the mere exposure effect (Zajonc, 1968). The alternative viewpoint suggests that as exposure to music increases, enjoyment and liking may decline due to overexposure—a phenomenon researchers call the tedium effect (Cantor, 1968).

Both viewpoints have received support from empirical studies (Cui, Collett, Troje, & Cuddy, 2015; Ward, Goodman, & Irwin, 2014). Subsequently, researchers have proposed that the effect of familiarity on musical preference is not linear but follows an inverted U-shaped relationship (Berlyne, 1974), and this inverted U-shaped relationship is moderated by other factors, such as the complexity of musical works and listeners' attentional states.

When participants are attentively focused, their preferences show an inverted U-shaped change as listening frequency to musical works increases; whereas when participants listen casually, their preferences show a linear increase with repeated exposure (Schellenberg, Peretz, & Vieillard, 2008).

Researchers using fMRI technology have discovered that familiarity plays an important role in musical aesthetics. Pereira et al. (2011) found that, compared to unfamiliar music, familiar music significantly activated limbic regions and paralimbic gyri of the brain, including reward circuits—brain regions considered relevant to musical aesthetics. Correspondingly, compared to disliked musical works, listening to liked musical works only activated small portions of the cingulate gyrus and prefrontal cortex, suggesting that familiarity may play a more important role in music appreciation.

Satoh et al. (2006) found that familiarity judgments of piano pieces activated bilateral anterior temporal lobes, posterior superior temporal gyri, anterior and posterior medial frontal lobes, bilateral cingulate gyri, left inferior frontal gyrus, and left superior temporal gyrus. This may be because the valence of aesthetic responses is determined by the fluency and speed of stimuli: the more fluent the processing, the more pleasant the experience (Reber, Wurtz, & Zimmermann, 2004).

In other words, musical training can enhance auditory processing abilities, which explains why musicians show preferences for more complex musical styles (Brattico et al., 2009).

Additionally, the chills response, unique to musical aesthetics, is also significantly influenced by familiarity, which is why people rarely experience chills with unfamiliar music (Grewe, Kopiez, & Altenmüüller, 2009).

As a subjective emotional experience, musical aesthetics is inevitably influenced by individual and contextual factors. Researchers have found that listeners' professional knowledge, attentional state, and personality traits can all influence musical aesthetics (Hargreaves & North, 2010).

For example, compared to cognitive judgments, aesthetic judgments by non-musicians enhance emotion-related neural processing, whereas musicians do not show such enhancement, indicating that the latter rely less on emotion and more on other strategies for aesthetic judgment (Müller et al., 2010).

The chills response, unique to musical aesthetics, is also influenced by individual differences. Individuals scoring higher on openness are more likely to experience chills in music (Nusbaum & Silvia, 2011), while age, gender, and musical education have no effect on chills experience (Grewe et al., 2009).

Recent research has found that whether chills can be experienced in musical aesthetics may be related to individual differences in music reward sensitivity, with the neural basis of this difference being the activity of white matter connectivity between the sensory processing region of the superior temporal gyrus and the emotional and social processing regions of the insula and middle prefrontal cortex (Sachs et al., 2016).

Another comparative study on children with autism and typically developing children found that children with autism may have stronger musical aesthetic judgment abilities, primarily benefiting from their often stronger absolute pitch and the exceptional musical memory abilities present in some autistic children (Masataka, 2017).

Additionally, attentional state is also an important factor influencing musical aesthetic experience, as listeners must focus on music to appreciate the emotions and memories it evokes and to judge its aesthetic value.

Some neuroimaging studies of music listening have found that the superior parietal lobe, precuneus, and attention-driven parietal structures are involved during listening (Fan, McCandliss, Fossella, Flombaum, & Posner, 2005), and that the default network continuously monitors and integrates the external environment during music listening (Raichle & Snyder, 2007).

3.2 Influences of Aesthetic Object Factors

Musical aesthetics is also influenced by the aesthetic object of music itself (i.e., musical features). Musical features refer to all elements that constitute music and their organizational patterns, such as tempo, rhythm, tonality, melody, harmony, volume, timbre, and genre.

Research has found that musical structural features also influence listeners' musical aesthetics (Karno & Konečni, 1992; Williams, 2017).

LeBlanc et al. (1988) compared preferences for four tempo levels of musical works across six age groups and found that listeners at every age stage showed significant preference for faster tempo music.

In terms of rhythm, researchers have found that musical excerpts with clear, regular, and steady rhythms typically have higher preference ratings (Fernández-Sotos, Fernández-Caballero, & Latorre, 2016).

Recent research has found that the complexity of musical rhythm is strongly correlated with musical emotional arousal and shows an inverted U-shaped relationship with musical aesthetic experience, with moderately complex rhythms being most preferred by listeners (Marin, Lampatz, Wandl, & Leder, 2016).

Costa et al. (2004) found that musical aesthetic judgment can be predicted by the distribution of single-interval steps and pitch height in musical works.

Regarding timbre, instrumental music in both classical and non-classical genres is relatively preferred, but in popular music, vocal music is more preferred instead. Moreover, disliked timbres can activate motor regions, the insula, and the limbic system, and reduce connectivity between the premotor cortex and insula (Wallmark, Iacoboni, Deblieck, & Kendall, 2018).

In terms of harmony, researchers have found that listeners significantly prefer consonant intervals, with both special populations and normal populations showing greater preference for music with higher degrees of consonance (Williams, 2017).

Ferri et al. (2014) used fMRI research to find that, compared to consonant musical works, dissonant works received lower aesthetic judgments and activated the medial temporal lobe, including the parahippocampal gyrus, which may suggest that dissonant music increases memory load.

Additionally, the titles of musical works and musicians' names also influence aesthetic judgments. People consider works by musicians with fluent names to have higher aesthetic value compared to those with disfluent names, and they express higher aesthetic preference for musical works with positive-valence titles compared to those with negative-valence titles (Anglada-Tort, Steffens, & Müllensiefen, 2018).

4 Implications and Future Directions

Musical aesthetics is an important branch of current neuroaesthetics research, with numerous studies conducted abroad; however, domestic research remains relatively scarce. Previous studies on the theoretical framework, research content, and neural mechanisms of this field still contain many uncertainties, leaving much to be explored and investigated in the future.

First, the neuroaesthetics of music must have a set of agreed-upon central questions. Considering the uniqueness of musical neuroaesthetics, we believe its core question concerns how music possesses emotional and aesthetic impacts.

Since its establishment by Zeki (1999) in the 1990s, neuroaesthetics has matured as a field, with its core question being to understand how and why the human brain has the capacity to appreciate and create artificial products. The neuroaesthetics of music will explore this question through auditory modalities rather than other sensory modalities (such as visual).

Second, frameworks and methods for addressing core questions in the field of musical aesthetics must be established. Some researchers have begun to develop such frameworks, such as Brattico et al. (2013) and Juslin et al. (2016), though this work has only just begun.

The methodology of musical neuroaesthetics largely borrows from related disciplines, particularly cognitive neuroscience and experimental psychology. However, the uniqueness of musical neuroaesthetics determines an important methodological issue: how to simulate real-world musical samples in experimental contexts to effectively elicit aesthetic experiences.

For example, Alluri et al. (2012) applied a non-traditional analysis attempting to mimic more ecologically valid contexts by correlating continuous fMRI signals with acoustic components extracted from an 8-minute musical piece. Using this approach, they could confirm that large-scale brain networks are involved in processing timbre, tonality, and melodic features during online music listening.

Finally, specific research paradigms and suitable research subjects must be explored. Musical neuroaesthetics originates from music psychology and neuroaesthetics but has its own characteristics. Musical neuroaesthetics focuses on emotion and aesthetics rather than cognitive representation and processing, and focuses on temporally extended, multidimensional auditory signals rather than visual stimuli.

Therefore, it cannot be viewed as a static entity but rather as something that unfolds over time and possesses unique neural pathways.

Regarding research subjects, musical neuroaesthetics should identify what its specific research objects are, rather than traditional topics in psychology or aesthetics.

For example, how do musical events generate positive experiences such as chills, awe, and joy, and what are their neural mechanisms? During which period in early childhood do musical aesthetic emotions, preferences, and aesthetic judgments emerge in the mature brain, and what is their developmental trajectory?

Additionally, musical aesthetics depends on listeners and context. Only through in-depth exploration of its various aspects can musical neuroaesthetics develop a profound understanding of its essence and thereby have significant practical impact.

Music is widely used to evoke emotions and regulate atmosphere (Särkämö et al., 2008), and music therapy is striving to integrate treatment for emotional and psychiatric disorders (Erkkilä et al., 2011).

Researchers believe that musical aesthetic experience is sometimes associated with immersion, intense enjoyment, or peak experiences. When combined with music therapy, these experiences can effectively help clients or patients (Konieczna-Nowak & Trzęsiok, 2018).

By having therapists set up music and context, activating clients' or patients' knowledge, experience, and preferences, and guiding them to immerse in musical aesthetic experiences, clinical symptoms in psychiatric and addiction treatment patients can be effectively alleviated (Silverman, Baker, & MacDonald, 2016).

Future in-depth understanding of the neural mechanisms of musical neuroaesthetics will promote the development of these clinical applications on a solid scientific foundation.

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Note: Figure translations are in progress. See original paper for figures.