The Neural Effects of Music on Anxiety:
A Rapid Review with Implications for Music Therapy Practice

by

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In Partial Fulfillment of the Requirements for the Degree of

MASTER OF SCIENCE

in

Music Therapy

State University of New York
New Paltz, New York 12561

May 2023

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A RAPID REVIEW WITH IMPLICATIONS FOR MUSIC THERAPY PRACTICE

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Submitted in partial fulfillment
of the requirements for the Master of Science degree
in Music Therapy
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Abstract

The use of music as a therapeutic tool for reducing anxiety has been extensively studied. This rapid review includes forty studies that provide neural evidence for the effects of music on anxiety-related brain structures, specifically the amygdala, hippocampus, and insula. The results indicate that to relieve anxiety, music therapists can tailor their musical selection to the client's preferences, focus on music with a steady rhythm to engage the clients, ensure musical continuity and integrity for each session, utilize instrumental improvisation to shift clients' perspectives, avoid dissonant and unexpected sounds when incorporating voices, and combine music with physical exercise.

Keywords: anxiety, music, amygdala, hippocampus, insula, neuroscience

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Anxiety

Anxiety is an emotion characterized by feelings of fear, dread, and uneasiness. It involves cognitive interpretations related to fear reactions and stress responses, makes people sweat, feel restless and consistently tense, and causes increased heart rate (American Psychological Association [APA], 2022a). For example, people may experience anxiety when confronted with a challenging situation at work or before making a major decision (MedlinePlus, 2020). It is worth noting that anxiety and fear are often used interchangeably; however, anxiety and fear are conceptually and physiologically distinct. Fear is viewed as an appropriate, in-the-moment, and fleeting response to a clearly discernible and precise threat, whereas anxiety is a future-oriented, long-acting response largely focused on a diffuse threat (APA, 2022a).

Moderate anxiety is common, and it can help people focus and cope, as well as provide energy to complete a task or project. However, for persons suffering from severe anxiety symptoms and diagnosed with anxiety disorders, their anxiety can be persistent and overwhelming, interfere with their daily life, and lead to health problems (Raskin, 2019). Anxiety as an emotion influencing various aspects of human lives has become an increasingly serious problem. According to World Health Organization (2022), in 2019, there were 301 million people with anxiety disorders, including 58 million children and adolescents. During Covid-19 pandemic, seventy-five studies with 147,435 participants in total reported an anxiety prevalence of 41.42% (95% CI: 36.17 – 46.54) (Mahmud et al., 2021).

Brain scans suggest that anxiety is the result of a constant exchange of information between several different brain areas. No one brain region can drive anxiety alone. Instead, interactions between different brain regions influence our experience of anxiety (Newman et al., 2013). Anxiety is related to the activity in brain regions associated with emotions (Martin et al., 2009). More specifically, anxiety is consistent with the hyperactivity of amygdala (Etkin & Wagner, 2007; Newman et al., 2013; Saviola et al., 2020), an important part of limbic system, a central structure in the brain's emotional processing circuit that, among other tasks, starts "fight-or-flight" reactions (Martin et al., 2009; Raskin, 2019). Anxiety is also related to excessive responsiveness of the insula (Etkin & Wagner, 2007; Saviola et al., 2020), a small area involved in basic emotions, self-consciousness, desire awareness, and awareness of body states (Raskin, 2019). Finally, anxiety is related to hyperactivity in the hippocampus (Ghasemi et al., 2022), an area located into temporal lobe, an important structure of limbic system, which regulates emotional behaviors, memory, spacial navigation, and learning (Anand & Dhikav, 2012).

Music Therapy and Anxiety

Lu et al. (2021) conducted a meta-analysis which examined the effects of music therapy on anxiety. Thirty-two randomized controlled trials (RCTs) with 1924 participants were included. Music therapy was reported to significantly reduce anxiety compared to the control groups during treatment. Only 8 of the studies included follow-up data on the effects of music therapy, and the duration to the follow up was inconsistent. Therefore, the authors recommended that further research is needed to determine long-term effects of music therapy post treatment (Lu et al., 2021).

State anxiety is a temporary psychological and physical response to unfavorable conditions at a particular time, while trait anxiety refers to the consistent tendency to pay close attention to, experience, and express negative emotions like fears, worries, and worry in various contexts (Saviola et al., 2020). High trait anxiety is a vulnerable factor of general anxiety disorder (Du et al., 2021). The State Trait Anxiety Inventory (STAI), developed by Spielberger et al. (1983), has been used clinically in order to diagnose anxiety and differentiate it from depression (APA, 2022b).

Several music therapy studies have used the STAI to measure the effects of group music therapy including active music making (Chen et al, 2016); group music therapy (typically including band rehearsal, instrumental tuition (teaching instrumental classes), music recording, improvisation, and songwriting) combined with individual visits (Gold et al., 2014); multimodal music therapy, a combination of active music making and cognitive-behavioral therapy (Goldbeck et al., 2012); and music listening and humming (Teckenberg-Jansson et al., 2019). According to Chen et al. (2016), group music therapy that focuses on music and imagery, improvisation, and songwriting was found to be more effective in reducing anxiety levels in prisoners than standard care. The study also revealed that younger prisoners exhibited greater improvement in trait anxiety, while participants with lower levels of education showed greater improvement in both trait and state anxiety. Likewise, Gold et al. (2014) also found that participation in group music therapy decreased state anxiety among people in prison, compared to the people receiving standard care.

In other settings, music therapy has also been found to play a role in relieving anxiety. For pregnant women, individual music therapy consisting of listening to live music and humming significantly reduced their general anxiety, but there was no difference between music therapy group and control group having rest practice (Teckenberg-Jansson et al., 2019). For children with anxiety disorder, multimodal music therapy was shown to be significantly superior to traditional cognitive-behavioral therapy in decreasing trait anxiety, and the effect lasted until four months after treatment (Goldbeck et al. 2012).

Description of the Condition

The present study is a rapid review, which is a method for producing timely and resource-efficient literature summaries, utilizing methods that expedite or simplify the traditional systematic review procedures (Moons et al., 2021). In addition, setting a time constraint can yield more cutting-edge results with the use of advanced technologies, providing a narrower scope for analyzing a policy or practice issue (Moons et al., 2021). The synthesis of results will typically be narrative and tabular to present clear findings, conclusions, and facilitate understanding.

For the purpose of this paper, anxiety is defined as a feeling of intense, excessive, and enduring worry and fear toward everyday life involving the changes in the activity of different brain regions (APA, 2022a). This paper will focus on the effect of music on the amygdala (e.g. Martin et al., 2009; Saviola et al., 2020), the insula (Etkin & Wagner, 2007; Saviola et al., 2020), and the hippocampus (Ghasemi et al., 2022).

Description of the Stimulus

Music is defined as any arrangement of sound and silence. Studies focusing on certain musical properties, such as pitch, timbre, rhythm, melody, and harmony, and music experience, such as receptive listening, music recreation, improvisation, and composing will be included in this review.

Objectives

The purposes of this rapid review are 1) to provide neural evidence that supports the use of music for anxiety reduction and 2) to offer recommendations for the use of music and music therapy methods in the treatment of anxiety.

Method

The search and analysis processes was consistent with those outlined by Sena Moore (2013). Studies included in this paper were published after 2012 and identified thorough search of the following electronic databases: MEDLINE, PsycINFO, CINAHL. The keyword phrases used for search were "music and amygdala", "music and insula", and "music and hippocampus."

The inclusion criteria were as follows: 1) the study was a primary research study; 2) participants were individuals who have typical development in terms of their physical, cognitive, emotional, and social abilities and do not have any diagnosed developmental disorders or condition, 3) the independent variables were musical properties, such as pitch, timbre, rhythm, melody, and interval, and music experiences, such as listening, music recreation, improvisation, and composing; 4) study results reported the effect of the music intervention on one or more of the following neural structures: amygdala, insula, or hippocampus, 5) published in English, and 6) published in peer reviewed journals. Studies published between the years of 2012 and 2022 are included in the rapid review.

The exclusion criteria were as follows: 1) theoretical papers or reviews; 2) studies that were not primary research studies; 3) participants were diagnosed with or had a reported history of a developmental/intellectual disability, mental disorder; congenital, acquired, or traumatic brain injury; 4) study was not published in English; 5) study was not published in a peer-reviewed journal. Studies focusing on the neural basis of emotions evoked by music were excluded, because the goal of this review is to provide neural evidence supporting the use of musical experience for anxiety treatment and therefore would focus on the neural mechanisms underlying the musical experience.

Results of the Search

The search within electronic database for “music and amygdala” resulted in 83 studies while 23 studies were duplicates. Thirty-six studies were excluded after title and abstract review. During the coding process, six studies did not meet the inclusion criteria, which led to the inclusion of 18 studies (See Figure 1). The search for “music and hippocampus” resulted in 69 studies with 28 duplicate papers. Twenty-four studies were excluded after title and abstract review. During the coding process, six studies did not meet the inclusion criteria, which led to the inclusion of 11 studies (See Figure 2). The search for “music and insula” resulted in 111. Thirty-eight of which were duplicates. After title and abstract review, and coding process, 11 studies met the inclusion criteria (See Figure 3). In total, 40 studies met inclusion criteria for this study.

Figure 1

Prisma Flow Chart: Research Related to the Effect of Music on the Amygdala

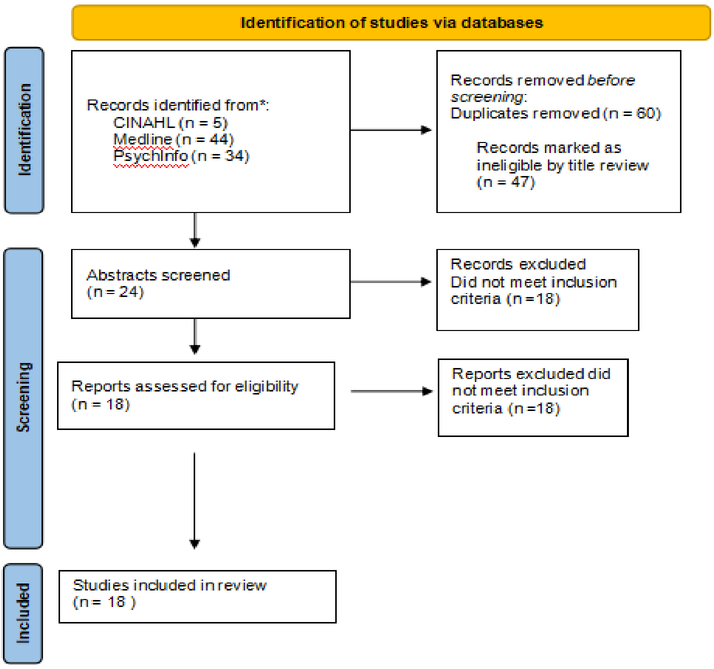


Figure 2

Prisma Flow Chart: Research Related to the Effect of Music on the Hippocampus

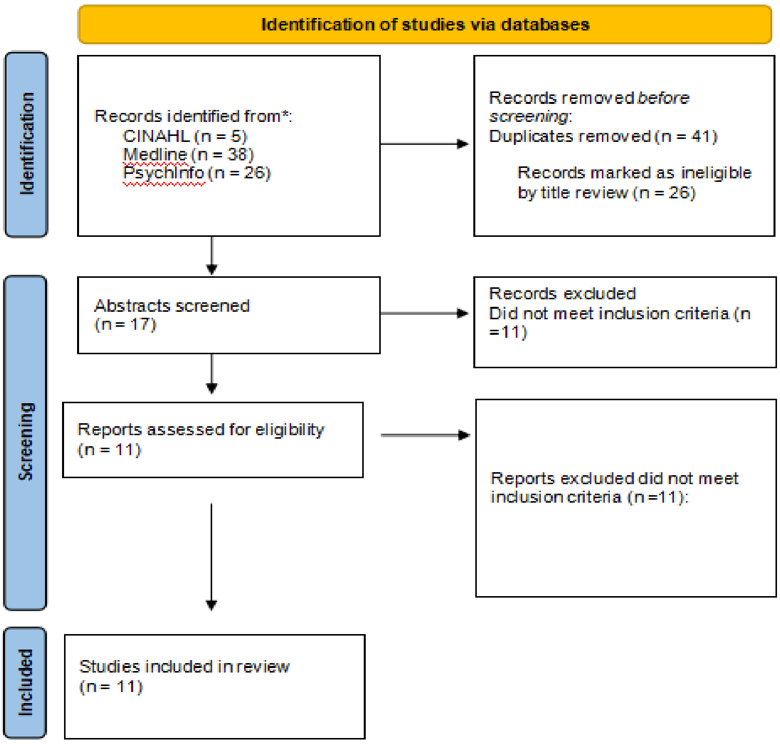
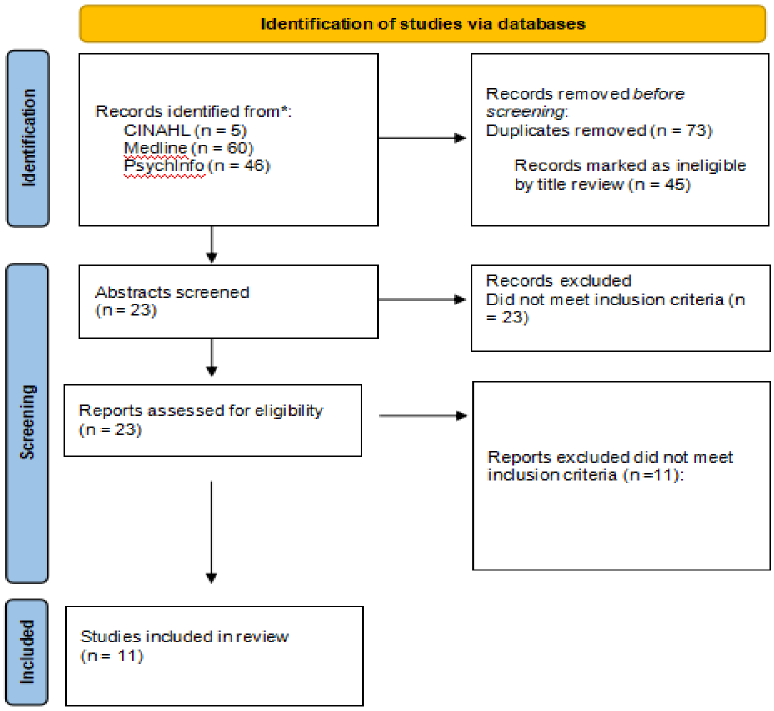


Figure 3

Prisma Flow Chart: Research Related to the Effect of Music on the Insula



Results

Characteristics of Included Studies

Participant characteristics. There were 1643 participants (range: 1-263 participants per study) across all 40 included studies. 750 participants were female (45.6%), 700 participants were male (42.6%), and gender information was not provided for 193 participants (11.7%). Half of the studies included "musicians only" or "both musicians and nonmusicians" as participants. 30% of the studies only included nonmusicians, while 20% of the studies did not report participants' music background (Table 1).

Characteristics of study design. Table 1 includes the music background of participants, types of music experiences used in the research, music characteristics, neural measurement tools, neural structures, music instruments, and music genres. The most common music experience researched was music listening (recorded) (67.4%), followed by improvisation (11.6%). Almost half of the studies did not specify a particular music characteristic (46.7%). Excluding these studies, rhythm (17.8%) and timbre (8.9%) were the most frequent music elements investigated. The most common neural measurement tool was functional Magnetic Resonance Imaging (fMRI), followed by Magnetic Resonance Imaging (MRI) and magnetoencephalography (MEG). In addition, event-related potentials (ERP), electroencephalography (EEG), and positron emission tomography (PET) were used. The most common music genre across included studies was Western tonal music (32.7%).

Table 1

Frequency of participants and Study Characteristics

Category	Number	Frequency
Music background of participants		
Nonmusicians only	12	30.0%
Musicians only	10	25.0%
Not specified	8	20.0%
Both musicians and nonmusicians	10	25.0%
Types of music experiences		
Music listening (recorded)	29	67.4%
Guided imagery and music (GIM)	1	2.3%
Imagination music performance	1	2.3%
Improvisation	5	11.6%
Composing	1	2.3%
Instrumental playing	3	7.0%
Singing	3	7.0%
Music characteristics studied		
Not specified	21	46.7%
Chord	2	4.4%
Rhythm	8	17.8%
Tonality	1	2.2%
Melody	2	4.4%

Category	Number	Frequency
Tone	1	2.2%
Pitch	1	2.2%
Timbre	4	8.9%
Interval	2	4.4%
Key	1	2.2%
Other	2	4.4%
Neural measurement tools		
fMRI	30	75.0%
MRI	5	12.5%
ERP	1	2.5%
MEG	2	5.0%
EEG	1	2.5%
PET	1	2.5%
Music instruments		
Not specified	12	27.9%
Piano/keyboard	8	18.6%
Flute	1	2.3%
Voice	6	14.0%
Cello	1	2.3%
Drum/percussion	3	7.0%
Instrumental (orchestral, accompaniment, synthesis, etc.)	10	23.3%
Various	2	4.7%
Genre of music		
Not specified	12	21.8%
Western tonal	18	32.7%
Tango	4	7.3%
Country	1	1.8%
Rock/metal	4	7.3%
Pop/Hip-Hop	4	7.3%
Jazz	2	3.6%
Folk	1	7.3%
Reggae	1	7.3%
Various	8	14.5%
Neural structures reported on		
Amygdala	19	37.3%
Hippocampus	9	17.6%
Insula	23	45.1%

Synthesis of Research Results

A summary of study characteristics and outcomes is presented in Table 2 and Table 3. Almost half of the studies focused on the effects of engagement in music on the insula (45.1%), followed by amygdala (37.3%) and hippocampus (17.6%). The results will be reported in terms of activation, functional connectivity, bilateralization, and volume change for each of these regions.

Amygdala

Several studies have investigated how engagement in music may activate the amygdala. Liu et al. (2012) reported that the amygdala was activated during lyrical improvisation, indicating emotional processing might be related to creative music activities. The amygdala played a role in tonal harmonic surprise and changes in musical tension: the interaction of musical surprise and uncertainty modulates bilateral amygdala activity (Cheung et al., 2019). Further it has been reported that when the musical tension increases (compared to decreasing tension), the right superficial amygdala is activated (Lehne et al., 2014). Increased activation of the amygdala was noted when singing dissonant intervals in comparison to consonant intervals (Gonzalez-Garcia et al., 2016). Unpleasant sounds activated the amygdala (Klepzig,et al., 2020). When listening to disliked music, the amygdala was activated when playing gambles with higher expected rewards, and correspondingly, the participants exhibited higher loss aversion and decreased financial risk-taking behavior (Halko et al., 2015). The imagined musical performance further increased the functional connectivity of the amygdala to the angular gyrus when compared with a resting state (Tanaka & Kirino, 2019). Music altered the connections between regions such as the insula, amygdala, and hippocampus before, during, and after receiving noxious stimuli (Powers et al., 2022). Musicians experience enhanced connectivity between the bilateral amygdala and the surrounding area during continuous music listening (Alluri et al., 2015).

Musical creativity, as reflected by improvisation and composition, was found to be positively correlated with the volume of the left amygdala (Bashwiner et al., 2016). Compared to the music-only listening, guided imagery and music (GIM) significantly activated brain regions associated with negative emotions, such as the left amygdala when listening to negative episodes (Lee et al., 2016). For unliked music, the right amygdala was more active than the left (Brattico et al., 2016). When listening to music with emotional attachment, the right amygdala was activated and showed increased interactions with bilateral insula (Karmonik et al., 2013). Rhythm also influenced amygdala activation--a more unclear rhythmic pulse was linked to increased activation in the left hemispheric amygdala (Alluri et al., 2012). Musicians were better at detecting deviant rhythm, showing increased activation in the right amygdala (James et al., 2012). Bilateral gray matter volume (GMV) of the amygdala was positively correlated with perceptual ability of pitch intervals, suggesting that interval perception is related to emotional experience. (Li et al., 2014). Expert pianists have larger gray matter volumes in the anterior amygdala than non-musicians (Vaquero et al., 2016).

Hippocampus

Toiviainen et al. (2014) demonstrated that the decoding of rhythm involves activation of the hippocampus. Similarly, Alluri et al. (2012) have further shown that an ambiguous rhythmic pulse enhances hippocampal activation. Additionally, Cheung et al. (2019) provided evidence for the involvement of the hippocampus in encoding surprise and uncertainty during chord progression. The hippocampus was activated during the listening of highly structured or memorized music, potentially contributing to the extraction and storage of musical information (Bonetti et al., 2021; Fernández-Rubio et al., 2022). The hippocampus was activated during script-driven imagery with music (Li et al., 2019) and selectively activated when listening to music with low arousal, such as peacefulness, nostalgia, and sadness (Trost et al., 2012). Musical expertise increased top-down excitatory regulation over the hippocampus when evaluating the level of familiarity of melodies (Gagnepain et al., 2017).

The imagined music performance further increased the functional connectivity of the hippocampus with the angular gyrus (Tanaka & Kirino, 2019). When listening to favorite music, the connectivity between hippocampus and other regions of Default Mode Network were enhanced (Wilkins et al., 2014). For musicians, the hippocampus displayed increased functional connectivity with the cerebellum as musical certainty increased (Burunat et al., 2018) and with several motor areas during continuous listening (Alluri et al., 2015).

The left hippocampus showed increased responses with more musical expertise during semantic access to familiar melodies (Gagnepain et al., 2017) and involved in the integration of neural activity when working memory recognized musical motifs (Burunat et al., 2014), possibly reflecting the formation of working memory and long-term memory. The right hippocampus demonstrated greater activity when only the melody was presented, indicating the role of combing the lyrics and melody during song listening (Alonso et al., 2016). Improvisational creativity was found to be negatively related to the gray matter volume of bilateral hippocampus (Arkin et al., 2019). Pianists have larger gray matter volumes in the anterior hippocampus compared to non-musicians (Vaquero et al., 2016).

Insula

Insula activation was observed during improvisation in both musicians and non-musicians (de Aquino et al., 2019) and positively associated with musical creativity (Villarreal et al., 2013). Moreover, the anterior insula is more activated in response to rhythm than verbal conditions during encoding and discrimination tasks (Hoddinott et al., 2021), and exhibits additional activation in response to irregular rhythm (Jungblut et al., 2012). Anterior insula activation was found when listening to music with empathy (Sachs et al., 2018), singing and cello playing, and positively associated with pitch accuracy (Segado et al., 2018). Disliked music elicited increased activation in the insula and reduced connectivity with the premotor cortex (Wallmark et al., 2018). Enhanced connectivity was observed in the insula when the cellist played contemporary music, compared to Baroque music (González et al., 2020). When the video was paired with either joyful or fearful music, the left insula exhibited enhanced activity (Plourde-Kelly et al., 2021). Melody produced activities in the right anterior insula while tempo processing alone activated the posterior insula (Thaut et al., 2014). Elderly people who exercised with music demonstrated significantly better visuospatial function and greater insular volume compared to those who exercised without music (Tabei et al., 2017).

Table 2.

Summary of Study Characteristics

Author	Description of study	Study characteristics: N	Participant musical ability	Type of experience	Music characteristic
Li et al., 2014	MRI study investigating the neural structures associated with the perception of melodic intervals	263 157F	Nonmusicians	Music listening (recorded)	Interval
Bashwiner et al., 2016	MRI study investigating the neural structures associated with the musical creativity	239 116F	Nonmusicians	Improvisation and composition	Not specified
Skouras et al., 2014	fMRI study exploring neural mechanisms during emotional music listening utilizing 3 T/ 1.5 T fMRI	32 18 F	Nonmusicians	Music listening (recorded)	Not specified
Halko et al., 2015	fMRI study investigating neural mechanisms in risky decisions and reward responses during liked or disliked music	22 8F	Nonmusicians	Music listening (recorded)	Not specified
Tanaka & Kirino, 2019	fMRI study investing the functional connectivity between neural structures during imagined music performance	41 41F	Musicians	Imagined music performance	Not specified

Author	Description of study	N	Participant musical ability	Type of experience	Music characteristic
Klepzig et al., 2020	fMRI study exploring the neural reactions to pleasant and unpleasant sounds	16 12F	Musicians and nonmusicians	Music listening (recorded)	Timbre
Vaquero et al., 2016	fMRI study exploring neural structural changes in expert pianists	53 26F	Musicians and nonmusicians	Instrument playing	Other (training years)
Alluri et al., 2015	fMRI study exploring changes in neural circuits of the limbic system during music listening	39 No GEN info	Musicians and nonmusicians	Music listening (recorded)	Not specified
Lee et al., 2016	fMRI study exploring the neural mechanisms of guided imagery and music when processing negative emotions	24 11F	Nonmusicians	Music listening (recorded)	Not specified
Brattico et al., 2016	fMRI study identifying the neural correlates of sadness or happiness in music rather than those associated with musical enjoyment	29 15F	Musicians and nonmusicians	Music listening (recorded)	Not specified

Author	Description of study	N	Participant musical ability	Type of experience	Music characteristic
Alluri et al., 2012	fMRI study exploring neural mechanisms when processing musical timbre, key and rhythm	11 5F	Musicians	Music listening (recorded)	Timbre, key and rhythm
James et al., 2012	ERP study exploring the neural activation when processing deviant endings	26 0F	Musicians and nonmusicians	Music listening (recorded)	Rhythm
Gonzalez-Garcia et al., 2016	fMRI study investigating neural activation when singing consonant and dissonant intervals	11 11F	Musicians	Singing	Interval
Powers et al., 2022	fMRI study investigating neural connectivity with or without music when presented with pain stimuli	20 10F	Not specified	Music listening (recorded)	Not specified
Cheung et al., 2019	fMRI study assessing neural activity related to uncertainty and surprise in music	40 21F	Not specified	Music listening (recorded)	Chord
Lehne et al., 2014	fMRI study exploring neural mechanisms underlying tension-related music listening	25 13F	Nonmusicians	Music listening (recorded)	Chord

Author	Description of study	N	Participant musical ability	Type of experience	Music characteristic
Liu et al., 2012	fMRI study exploring the neural activation while freestyle rap	12 0F	Musicians	Improvisation	Not specified
Karmonik et al., 2013	fMRI study comparing the neural activation when listening to music with/without emotional attachment	1 0F	Musician	Music listening (recorded)	Not specified
Gagnepain et al., 2017	fMRI study comparing neural activation between musicians and nonmusicians when evaluating the level of familiarity of melodies and proverbs	40 20F	Musicians and nonmusicians	Music listening (recorded)	Not specified
Toiviainen et al., 2014	fMRI study exploring neural mechanisms of processing musical features	15 5F	Nonmusicians	Music listening (recorded)	Timbre, rhythm, tonality
Alonso et al., 2016	fMRI study exploring the neural mechanisms of binding lyrics and melodies	22 11F	Nonmusicians	Music listening (recorded)	Melody

Author	Description of study	N	Participant musical ability	Type of experience	Music characteristic
Li et al., 2019	fMRI study exploring the neural mechanisms during imagined scenes with/without music	16 11F	Not specified	Music listening (recorded)	Not specified
Burunat et al., 2018	fMRI study comparing the functional connectivity of the cerebellum and hippocampus during music listening between musicians and non-musicians	36 19F	Musicians and nonmusicians	Music listening (recorded)	Not specified
Bonetti et al., 2021	MEG study exploring the functional connectivity when listening to highly structured music	68 33F	Musicians and nonmusicians	Music listening (recorded)	Tone
Burunat et al., 2014	fMRI study exploring the neural activation when working memory (WM) recognizing repetitive music motifs	26 11F	Musician	Music listening (recorded)	Not specified

Author	Description of study	N	Participant musical ability	Type of experience	Music characteristic
Wilkins et al., 2014	fMRI study exploring the neural network connectivity patterns associated with music listening and preference	21 13F	Musician	Music listening (recorded)	Genre
Trost et al., 2012	fMRI study investigating neural activation based on musical emotions in different level of intensity	15 7F	Nonmusicians	Music listening (recorded)	Not specified
Arkin et al., 2019	MRI study investigating how gray matter correlated with improvisational creativity evaluated by jazz experts	38 11F	Musicians	Improvisation	Not specified
Fernández-Rubio et al., 2022	MEG study comparing the neural activation in working memory and long-term recognition of music	71 33F	Not specified	Music listening (recorded)	Not specified
de Aquino et al., 2019	fMRI study examining neural activation during a controlled musical creativity task in both musicians and nonmusicians	40 26F	Musicians and nonmusicians	Improvisation	Rhythm

Author	Description of study	N	Participant musical ability	Type of experience	Music characteristic
González et al., 2020	fMRI study comparing different activation in cellist when playing contemporary and Baroque music	13 7F	Musicians	Instrumental playing	Not specified
Hoddinott et al., 2021	fMRI study comparing neural mechanisms underlying rhythm and verbal short-term memory	18 4F	Not specified	Music listening (recorded)	Rhythm
Plourde-Kelly et al., 2021	EEG study comparing neural activities when watching videos paired with joyful, fearful, or no music	27 13F	Not specified	Music listening (recorded)	Not specified
Sachs et al., 2018	fMRI study comparing neural responses to sounds and instruments when processing emotions	38 20F	Not specified	Music listening (recorded)	Not specified
Thaut et al., 2014	PET study exploring the neural mechanism underlying rhythm perception	10 No GEN info	Musicians and nonmusicians	Music listening (recorded)	Rhythm, melody

Author	Description of study	N	Participant musical ability	Type of experience	Music characteristic
Wallmark et al., 2018	fMRI study exploring neural activation related to timbre perceptions	15 8F	Nonmusicians	Music listening (recorded)	Timbre
Jungblut et al., 2012	fMRI study investigating neural areas underlying rhythm processing during singing	30 13F	Nonmusicians	Singing	Rhythm
Villarreal et al., 2013	fMRI study investigating the neural process of a music creative task Study characteristics	24 15F	Nonmusicians	Improvisation	Rhythm
Tabei et al., 2017	MRI study investigating the effects of physical exercise with musical accompaniment on structural changes in the brain of healthy elderly people	144 No GEN info	Not specified	Music listening (recorded)	Not specified
Segado et al., 2018	fMRI study exploring the overlaps of brain areas during singing and cello playing	12 6F	Musicians	Singing and instrumental playing	Pitch

Table 3.

Summary of Study Outcomes

	Outcomes	
Author	Neural structures	Related findings
Li et al., 2014	Amygdala	1) Interval perception was found to be related to daily emotional experiences, indicating that music and emotion are intimately connected. 2) A larger gray matter volume (GMV) of the bilateral amygdala was correlated with better interval perception, implying that the amygdala also participates in music processing.
Bashwiner et al., 2016	Amygdala	1) Domain-specific musical competence, default-mode cognitive processing style, and emotional intensity may all collaborate together to empower and facilitate the intention to create music. 2) Musical creativity is positively correlated with left amygdala volume.
Skouras et al., 2014	Amygdala hippocampus	1) The bilateral superficial amygdala was discovered as the neural center with the greatest increase in eigenvector centrality during joyful music when compared to fearful music. 2) When listening to happy music versus fearful music, the group scanned by 3T fMRI exhibited significant differences in activity in the bilateral superficial amygdala and bilateral hippocampus.
Halko et al., 2015	Amygdala	1) Loss aversion was lower and financial risk-taking was increased behaviorally when listening to preferred music. 2) When listening to disliked music, gambles with a high expected reward induced more activation in the amygdala than gambles with a low expected reward, whereas this activation pattern was altered when listening to liked music. 3) Music influenced value coding neurally.
Tanaka & Kirino, 2019	Amygdala, hippocampus	1) Compared to the resting state, the imagined music performance further increased the functional connectivity of the hippocampus with the angular gyrus and the amygdala with the angular gyrus.

Author	Neural structures	Related findings
Klepzig et al., 2020	Amygdala, insula	1) Both pleasant and unpleasant sounds could induce chill reactions characterized by a short increase in autonomic arousal and associated with emotions. 2) Chills caused by pleasant and unpleasant music activated anterior insula. 3) Amygdala responses were solely related with chills induced by unpleasant sounds.
Vaquero et al., 2016	Amygdala, hippocampus	1) Expert pianists have larger gray matter volumes in segments of the anterior hippocampus and amygdala than non-musicians, particularly the superficial and medial nuclei, central nucleus, and laterobasal amygdala, which indicated that music training is associated with increased gray matter volume in neural structures associated with reinforcement learning.
Alluri et al., 2015	Amygdala, hippocampus	1) The musicians' bilateral amygdalae showed increased connectivity to the primary motor area, the supplementary motor area, the cerebellum, visual area, during continuous music listening. 2) The hippocampus displayed greater connectivity with several motor areas, such as the supplementary motor area, the primary motor cortex, and the cerebellum in musicians during music listening. 3) For musicians, the right hippocampus was found to have greater connectivity to the olfactory cortex than for nonmusicians, implying that the hippocampus may facilitate continuous encoding of repetitive musical motifs.
Lee et al., 2016	Amygdala, insula	1) GIM could enhance neural activations associated with negative emotions and the processing of episodic memory. 2) Compared to the music-only condition, GIM significantly activated brain regions associated with negative emotions and episodic memory processing, such as the left amygdala, left anterior cingulate gyrus, and left insula.
Brattico et al., 2016	Amygdala	1) For unliked music, the right amygdala was more active than the left, however, listening to happy music (versus sad music) elicited activity in sensory areas, specifically the bilateral primary and non-primary auditory cortex.

Author	Neural structures	Related findings
Alluri et al., 2012	Amygdala, hippocampus insula	1) More unclear rhythmic pulse was linked to increased activation in the left hemispheric amygdala, hippocampus, bilateral insula, and other areas. 2) Lower key clarity was linked to increased activation in the left insula, and so on. 3) Generally, participants showed greater responses to timbral features than to rhythmic and tonal features.
James et al., 2012	Amygdala, insula	1) Musicians were better at detecting deviant rhythm, showing increased activation in the right amygdala and right insula, and so on in early stage. 2) Increased activation in motor and sensory related areas implied that rhythm elicits greater actions in musicians.
Gonzalez-Garcia et al., 2016	Amygdala, insula	1) The amygdala which is prone to musical stimuli, and the right posterior insula, etc. showed increased activation when singing dissonant intervals in comparison of consonant intervals. 2) The right anterior insula was activated when singing wide intervals rather than narrow intervals.
Powers et al., 2022	Amygdala, hippocampus insula	1) Familiar and pleasurable music significantly reduced the unpleasant emotions caused by pain and did not significantly alter the perception of pain. 2) Before, during, and after receiving noxious pain stimuli, music altered the connections of certain neural networks between regions such as the insula, amygdala, and hippocampus, which was influenced by individual pain sensitivity.
Cheung et al., 2019	Amygdala, hippocampus	1) When chords deviate from the listener's expectations (low uncertainty, high surprise), or when they fulfill expectations in the lack of information (high uncertainty, low surprise), participants found more pleasure. 2) The interaction of surprise and uncertainty significantly modulated activity in the bilateral amygdala and hippocampus.
Lehne et al., 2014	Amygdala	1) During an increase in musical tension (as compared to a decrease in tension), activation of the right superficial amygdala occurred. However, no activation of the amygdala was shown during successive rating of musical tension. 2) This research tended to attribute musical tension to affective processes.

Author	Neural structures	Related findings
Liu et al., 2012	Amygdala	1) In lyrical improvisation, the relationship between intention and action may be adapted and traditional executive control may be bypassed. 2) The amygdala was involved in the neural network associated with improvisation, indicating the affect is related to lyrical improvisation.
Karmonik et al., 2013	Amygdala, insula	1) Compared to listening to the music without emotional attachment, the right amygdala and bilateral insula were activated when listening to the music with emotional attachment. 2) When listening to music with emotional attachment, some subunits such as the right amygdala and bilateral insula showed greater interactions.
Gagnepain et al., 2017	Hippocampus	1) Musical proficiency improves access to familiar melodies but not to familiar proverbs. 2) During semantic access to familiar melodies but not familiar proverbs, the left hippocampus showed increased responses with musical expertise. 3) According to the analyses, musical expertise increased top-down excitatory regulation over the hippocampus when making familiarity decisions for melodies and proverbs.
Toiviainen et al., 2014	Hippocampus	1) Timbral features could be decoded more precisely than rhythmic and tonal components. 2) Hippocampus contributed to the decoding of rhythm.
Alonso et al., 2016	Hippocampus	1) Compared to presenting both lyrics and melody, the right hippocampus, as well as other regions, showed greater activity when only the melody sung with the syllable "la" was presented, suggesting that the right hippocampus plays a role in combining the lyrics and melody in the song

Author	Neural structures	Related findings
Li et al., 2019	Hippocampus	1) In the script-driven imagery, participants' emotions were enhanced by the music for both positive and negative conditions. 2) The insula, amygdala, hippocampus were commonly activated the positive and negative conditions with music in comparison to the baseline condition, suggesting that emotional music integrated in an imaginary scenario is an important social signal that stimulates audiences to prepare approach/avoidance actions and emotional responses. 3) With music, positive conditions are associated with greater activity in the insula compared to negative conditions.
Burunat et al., 2018	Hippocampus	1) When the predictability of music increased, the functional connectivity of the cerebellum to the hippocampus was enhanced. 2) Musicians show stronger enhancement compared to nonmusicians.
Bonetti et al., 2021	Hippocampus, insula	1) During active listening to highly structured music, the insula and hippocampus, were involved and these structures may contribute to extract and store music information. 2) The encoding process is preceded by a rapid transition of brain activity from primary auditory cortex to higher-order association areas (e.g., insula). 3) During encoding, participants with higher musical expertise show stronger centrality of the superior temporal gyrus and insula.
Burunat et al., 2014	Hippocampus, amygdala	1) The integration of neural activity distributed across cognitive, motor, and limbic subsystems were observed when working memory recognizing musical motifs, including the left hippocampus and the amygdala, which may reveal the formation of long-term memory. 2) Brain responses were primarily right-lateralized.

Author	Neural structures	Related findings
Wilkins et al., 2014	Hippocampus	1) Defaulted Mode Network (DMN) (including hippocampus) has the most connections when listening to favorite music. 2) Listening to favorite music separates the functional connections between the auditory cortex and the hippocampus, indicating the retrieving of episodic memory instead of encoding. 3) Listening to favorite music impacts the functional connectivity in regions related to self-referential thought and memory encoding. 4) Impairments and abnormal connections within the DMN were found to be linked to a variety of neurological problems, including autism, PTSD, schizophrenia, and depression, and client's preferred music may support the integration of functional connections within the DMN.
Trost et al., 2012	Hippocampus, insula	1) The insula was activated when experiencing positive emotions and high arousal (Wonder, Joy) during music listening. 2) Hippocampus, which related to memory, was selectively engaged in low arousal condition (Peacefulness, Nostalgia, and Sadness), suggesting the involvement of memory in calm and introspective feeling states.
Arkin et al., 2019	Hippocampus	1) The most predictable factor of improvisational creativity was the duration of improvisational training. 2) Creativity ratings were discovered to be negatively related to gray matter volume in bilateral hippocampus.
Fernández-Rubio et al., 2022	Hippocampus, insula	1) An overall positive relationship exists between working memory abilities and brain activity that reflects the recognition of previously learned musical sequences. 2) The hippocampus and insula were involved in the recognition of previously memorized versus novel auditory sequences. 3) During the third, fourth, and fifth tones of the auditory sequence (in five-tone sequences), the insula and hippocampus were most active.
de Aquino et al., 2019	Insula	1) In rhythmic improvisation, the musician's insula shows greater activation. 2) In non-musicians, the duration of improvisation is associated with activation of the insula. 3) Since the anterior insula plays a central role in the correlation network,

		activation of the insula may mark a shift from a traditional way of thinking to a new perspective in non-musicians.
González et al., 2020	Insula	1) Some exclusive seed-regions appeared in contemporary or Baroque styles due to different cognitive, sensory and motor demands in different music styles. 2) Insula was involved when playing contemporary style music.
Hoddinott et al., 2021	Insula	1) When comparing working memory for rhythmic and verbal conditions, rhythm activates areas such as the anterior insula more than letter sequences during encoding and discrimination. 2) Rhythm perception is not simply a chunking of auditory information, despite the large overlap between rhythmic and verbal short-term memory networks.
Plourde-Kelly et al., 2021	Insula	1) Self-reported happiness increased after watching a video paired with joyful music. 2) Activity in the left insula was enhanced when the video was paired with fearful and joyful music. 3) Mean gamma activity in the insula was lower the more anxious the self-report was.
Sachs et al., 2018	Insula	1) Brain areas hold emotion-specific patterns that apply to a variety of acoustical sounds, including voice, violin, and clarinet. 2) Relationships between behavioral measures of empathy and classification accuracy within the anterior insula were positive.
Thaut et al., 2014	Insula	1) Several brain regions showed common activities to rhythmic fundamental elements: pattern, meter, and tempo. 2) Tempo processing by itself activated mechanisms that function somatosensory and premotor information, including the posterior insula. 3) Different from rhythm perceptions, melody produced activities in the right anterior insula and various other regions.
Wallmark et al., 2018	Insula	1) There may be motor perception in timbre processing, especially for the “noisy” timbre. 2) The more disliked timbre, the more activities in the somatomotor area, insula and limbic system, and the less functional connectivity between the premotor cortex and insula relay.
Jungblut et al., 2012	Insula	1) For irregular rhythmic groupings of vowel changes, participants exhibited additional activation of the insula and it was more pronounced in the left hemisphere. 2) The insula is associated with the

		processing of complex rhythms.
Villarreal et al., 2013	Insula	1) Participants with higher creativity improvised their own music with little reliance on the original rhythm, and their right insula was activated. 2) The activation of the insula was related to the levels of musical creativity, which could be contributed to an integral network of cognition, motivation, and emotional processes.
Tabei et al., 2017	Insula	1) Participants who exercised with music had significantly better visuospatial function and showed greater volume of the insula compared to those who only exercised and/or those who did not exercise. 2) Exercise with music had a greater positive effect on cognitive function in older adults and may delay cognitive decline.
Segado et al., 2018	Insula	1) In many areas of the auditory-vocal network, such as the anterior insula, brain activity during cello playing overlaps with that during singing, and the brain activity is positively correlated with pitch accuracy in singing and cello playing. 2) Vocal areas may be closely included during cello playing.

Clinical Implications

This study investigated the emotional processing circuit which relates to anxiety, namely amygdala, hippocampus, and insula, to provide neurological evidence for how music characteristics, musical experiences and music therapy methods might help alleviate anxiety. However, it should be noted that the fact that music modulates neural activity in neural structures associated with anxiety is not the same as music altering anxiety states clinically. When assessing the effectiveness of music therapy in improving anxiety, the therapists should not refer only to changes in neural activity but should see the client as a whole and evaluate the changes thoroughly.

Anxiety is consistent with the hyperactivity of the amygdala (Newman et al., 2013; Saviola et al., 2020). Music characteristics and musical experiences can impact the activity of the amygdala. Singing dissonant intervals (Gonzalez-Garcia et al., 2016) and listening to unpleasant sounds (Klepzig, et al., 2020) enhanced the overall amygdala activity. More unambiguous rhythm was associated with increased activation of the left amygdala (Alluri et al., 2012). Smaller left amygdala was found to be associated with higher neuroticism and trait anxiety (Hu et al., 2020). Musicians showed increased activation of the right amygdala when detecting deviant rhythms (James et al., 2012). Studies have found that musical ability and musical training are positively correlated with amygdala volume (Li et al., 2014; Vaquero et al., 2016). Musicians showed increased connectivity in the bilateral amygdala and motor-related areas when listening to music continuously (Alluri et al., 2015), meanwhile, these pathways might be related to psychiatric disease (Toschi et al., 2017) and can influence their social behavior and coping skills (Grèzes et al., 2014). Imagined musical performances further increased the functional connectivity of the amygdala with the angular gyrus (Tanaka & Kirino, 2019). Therefore, to improve anxiety, the therapist can provide a diverse musical experience; trying to ensure the continuity and integrity of the music within a session. Besides, music therapists may use music that the client feels is pleasant and has a steady rhythm. When incorporating voices, dissonant and unexpected sounds should be avoided.

Anxiety was found to relate to hyperactivity in hippocampus (Ghasemi et al., 2022) and General Anxiety Disorder was found to be positively associated with the volume of hippocampus (Baksh et al., 2021). However, the hippocampus also reflected the processing of learning and memory (Anand & Dhikav, 2012), which might be involved in music experiences. Therefore, changes in the activity of the hippocampus do not completely respond to changes in anxiety or emotions. When listening to favorite music, connections between the hippocampus and other areas of the default mode network are enhanced (Wilkins et al., 2014). The enhanced DMN connections are similar to the effects of mindful meditation (Bremer et al., 2022), reflecting a decrease in anxiety levels (Scult et al., 2019). For musicians, with increased musical certainty, the hippocampus shows increased functional connectivity with the cerebellum (Burunat et al., 2018) and with several motor areas during continuous listening (Alluri et al., 2015). Jazz improvisation is negatively correlated with gray matter volume in the bilateral hippocampus (Arkin et al., 2019). To reduce anxiety, the therapist can include the client's favorite music and ensure that the listening experience is complete (e.g., play the entire piece and listen to the music without interruptions). Music-based instrumental improvisations with defined musical elements (e.g., steady rhythms, regular chord changes, etc.) can also be utilized.

The insula plays an important role in limbic-autonomic integration and is involved in circadian rhythms (Nagai et al, 2009). There are several studies exploring the insula and rhythm. In encoding and discrimination tasks, the anterior insula is more active in response to rhythm than in response to verbal conditioning (Hoddinott et al., 2021) and shows more activation in response to irregular rhythms (Jungblut et al., 2012). Besides, anxiety is related to excessive responsiveness of the insula (Etkin & Wagner, 2007; Saviola et al., 2020). Disliked music elicited increased activation of the insula and decreased connectivity with the premotor cortex (Wallmark et al., 2018). de Aquino et al. (2019) observed activation of the insula during rhythmic improvisation in both musicians and non-musicians and suggested that non-musicians improvising may reflect a shift from a traditional to a new perspective. Older adults who listened to music during movement had larger insula volumes and showed better visuospatial functioning (Tabei et al., 2017). To decrease anxiety, the therapists could use rhythm to engage the clients and encourage the clients to do rhythm-based improvisation. Involving the client's favorite music could also be helpful. Sometimes, experiences that do not focus entirely on music can still be beneficial, such as combining music with exercise or other multimodal implications.

Discussion

The purpose of this rapid review was to investigate the effects of music on neural structures underlying anxiety and to offer clinical recommendations for the use of music and music therapy methods in the treatment of anxiety. Some of the implications we summarized were consistent with the findings of previous studies offering clinical recommendations. For example, music therapists can use music that is familiar, enjoyable and feels pleasant to the client, engage the clients in musical experiences that have identifiable musical elements by providing stable chords and steady rhythm, and try to avoid dissonant and unexpected melodies or chord changes (Sena Moore, 2013).

However, there are some new considerations that have emerged. Specifically, ensuring musical continuity is important for clinical practice because participants showed enhanced functional connections between amygdala and motor-related areas as well as hippocampus and motor-related areas during continuous music experience (Alluri et al., 2015), and these pathways can be related to psychiatric disease (Toschi et al., 2017), executive functions (Burman, 2019), and impact social behavior (Grèzes et al., 2014). Therefore, the music therapists should be mindful when editing music for practice use, especially if they choose not to use a whole song. Moreover, providing clear beginnings and endings for each musical experience is a crucial aspect of music therapy.

Furthermore, creating some casual music experiences without fully focusing on the music can also be beneficial for clients. The music therapists can combine music with physical movements to improve the visuospatial functions of the clients (Tabei et al., 2017). Playing games with music and drawing with music can also be alternative ways to engage clients and assist with anxiety management.

Conclusion

This rapid review indicates that music characteristics and music experiences might help with anxiety and provides neurological evidence on how music influences the anxiety-related structures, specifically amygdala, hippocampus, and insula. Some clinical considerations are formed based on these studies. To reduce anxiety, the music therapist can play music that the client enjoys, feels happy with and has a steady rhythm. The music therapist can provide a variety of musical experiences and ensure musical continuity and integrity for each session. Music-based instrumental improvisation can also be utilized to help the clients shift their perspectives and therapists should provide grounding and clear musical characteristics (e.g., steady dynamics, regular chord progressions, etc.). Therapists can use rhythm to engage clients and encourage them to do rhythm-based improvisation. When incorporating voices, such as song recreation and singing improvisation, dissonant and unexpected sounds should be avoided. Sometimes it is beneficial to have casual music experiences without focusing on the music, such as combining music with physical exercise.

Limitations

There are some limitations of the review. First of all, many studies did not provide detailed descriptions of the elements of music or types of instruments that were used. Second, most studies included in this review focused on music listening, and there is limited research on other music therapy methods. Third, participants in the studies that met the inclusion criteria were fully developed individuals without any diagnosed developmental disorders or conditions, therefore, people suffering from anxiety disorders were not sufficiently studied and their needs and neurological changes were not sufficiently explored.

Future Research

For future studies, further attention can be paid to neural structures related to the prefrontal cortex, anterior cingulate cortex (ACC), as increased studies have found that anxiety can also be associated with these structures related to cognitive function (Hwang & Hashimoto-Torii, 2022; Kenwood et al, 2022). Research related to music and musical experience calls for detailed descriptions of musical traits and characteristics, such as, genres and instruments being used. Also, neuroscience research related to music therapy experiences has focused on music listening, and improvisation, music recreation, and composition have not been adequately studied.

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