

Neuro Musicology: Unraveling the Effects of Music on the Brain and Nervous System

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ABSTRACT Music is a universal human experience that transcends language and culture, engaging intricate networks within the brain. The processing of music involves multiple interconnected brain regions, including the auditory cortex, limbic system, motor cortex, prefrontal cortex, and cerebellum. These regions work synergistically to decode rhythm, pitch, harmony, and emotional content, transforming acoustic stimuli into meaningful experiences. Recent neuroscientific studies reveal that music is not only a passive auditory experience but also it actively influences brain chemistry. Listening to or creating music modulates the release of key neurotransmitters such as dopamine, serotonin, endorphins, and oxytocin, which are associated with pleasure, motivation, mood regulation, and social bonding. These neurochemical changes contribute to music's therapeutic potential. Moreover, music has emerged as a promising non-pharmacological intervention in various neurological disorders. In conditions such as Parkinson's disease, Alzheimer's disease, stroke, depression, autism spectrum disorder, and schizophrenia, music therapy has shown benefits in enhancing motor coordination, memory, emotion regulation, and social interaction. This review aims to explore the neural mechanisms involved in music processing, highlight the impact of music on neurotransmitter activity, and discuss its potential applications in managing neurological disorders. Understanding these interactions not only deepens our knowledge of brain function but also opens new avenues for therapeutic interventions using music.

KEY WORDS Auditory cortex, Cerebellum, Amygdala, Neurotransmitters, Synaptic plasticity, Dementia

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INTRODUCTION

Music plays an important role in daily life. It is a tool to assist people in transmitting their thoughts and feelings to one another, and a medium to help people express their inner feelings. Furthermore, the effects of music on healing can be profound on all levels – physical, mental, emotional, and spiritual (Steckler, 1998). Nowadays, the focus on the role of music in the healing arts has intensified, and musical experiences can direct people towards health and well-being. Music therapy is based on the associative and cognitive powers of the mind. It is one of the expressive therapies that are of late interpreted as a complementary or integrative

medicine (Sairam, 2006). The therapeutic effects of music on physical and emotional disorders caused by stress, anxiety, or some other associated psychological disorders have been documented by many studies. Music, a structured form of auditory stimulation, has been increasingly studied for its neuromodulatory effects across various species, including rodents. In mice, exposure to music has been found to influence a wide range of neurological functions, encompassing brain development, neurotransmitter regulation, synaptic plasticity, and behavior (Chikahisa *et al.*, 2006). Studies have shown that classical music can enhance spatial learning and memory in mice, potentially by promoting hippocampal neurogenesis and increasing brain-derived neurotrophic factor (BDNF) levels (Angelucci *et al.*, 2007).

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Music is one of the oldest and most basic socio-cognitive domains of the human species. It is assumed by some those human musical abilities played a key phylogenetical role in the evolution of language, and that music-making behavior covered important evolutionary functions such as communication, cooperation, social cohesion, and group coordination (Zatorre and Peretz, 2001). The process of deciphering sound involves several brain areas working in concert to grant the perception of a sound along with the emotional valence for a specific melody. The music perception occurs through a series of events, starting with sound waves transforming into an electric signal, which then progresses through the auditory nerve to the brainstem and activates cortical areas, allowing the perception of a specific sound (Moreno and Bidelman, 2014). In a spontaneous and effortless way, music can trigger memories, awake emotions, and intensify social bonding (Molnar-Szakacs and Overy, 2006). Music perception is associated with numerous beneficial effects on sensorimotor, cognitive, and emotional processing. Individuals may associate “good” music with “musical chills,” which are characterized by stimulation of the responses of the autonomic nervous system, often associated with enhanced heart rate, decreased temperature, and blood volume pulse (Colverson *et al.*, 2022). Such musical chills are associated with dopaminergic reward response regions of the hypothalamus and amygdala, activation of which signifies intense emotions and pleasure (Quintin, 2019). Improved attention and communication were observed in children with severe neurological impairments (Bringas *et al.*, 2015), and a task-dependent cortical reorganization in stroke patients occurs after piano and electronic drum pad lessons (Amengual *et al.*, 2013). Music interventions are also promising therapies for mood, vigilance, and the overall quality of life in patients with Parkinson’s disease (Park and Kim, 2021; Pohl *et al.*, 2020), Alzheimer’s disease, and other nervous system injuries (Gómez Gallego and Gómez García, 2017; Martínez-Molina *et al.*, 2021; Paprad *et al.*, 2021; Pezzin *et al.*, 2018).

This literature review seeks to look into the ways the nervous system interprets music, its effects on the functioning of the brain, and its role in neurotransmitter secretion. Understanding how music is applied to rehabilitate damaged brain circuitry through music therapies for various neurological conditions helps shed light on the use of music.

BRAIN REGIONS INVOLVED IN MUSIC PERCEPTION AND RESPONSE

The auditory cortex is a part of the brain located in the temporal lobe, primarily responsible for processing auditory information, as shown in Fig. 1. It is a critical component of the auditory system and plays a central role in interpreting sounds, including speech and music. The auditory cortex plays a crucial role in music perception, influencing both the processing of musical elements and the emotional responses elicited by music. Research indicates that the auditory cortex not only emphasizes the perceived beat of music but also engages in complex emotional processing, linking auditory stimuli to affective experiences.

The auditory cortex plays a crucial role in music perception, influencing both the processing of musical elements and the emotional responses elicited by music (Rajendran *et al.*, 2020). Janata (2015) indicates that the auditory cortex not only emphasizes the perceived beat of music but also engages in complex emotional processing, linking auditory stimuli to affective experiences. The auditory cortex is interconnected with limbic structures, facilitating the processing of emotions evoked by music. This connectivity allows for the differentiation of emotional responses, such as joy and fear, based on musical cues. Studies show that music can elicit distinct emotional responses, with specific neural signatures identified in the auditory cortex corresponding to different emotional categories (Putkinen *et al.*, 2021).

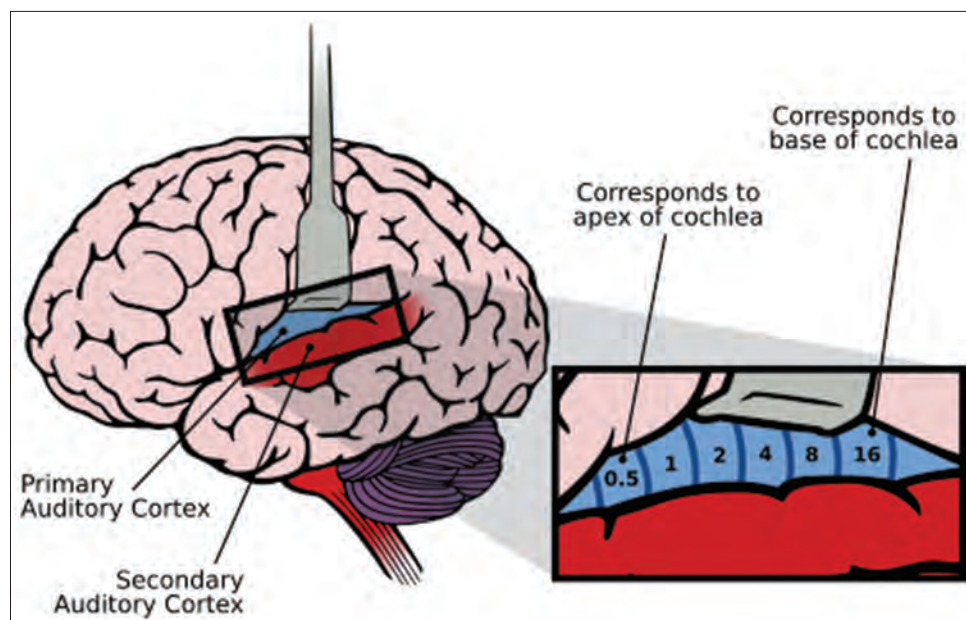


Fig. 1: Auditory cortex in the human brain.

PRIMARY AUDITORY CORTEX (A1)

- Temporal processing: A1 exhibits a transient response to musical sounds, processing them as single events, akin to language processing (Izumi *et al.*, 2011).
- Neuronal sensitivity: Neurons in A1 show sensitivity to tonal contour, responding differently to various frequency sequences, which is crucial for distinguishing musical elements (Weinberger and McKenna, 1988).

SECONDARY AUDITORY CORTEX (A2)

- Complex integration: A2 neurons demonstrate unique integration patterns, allowing for the processing of concurrent multifrequency sounds, essential for understanding complex musical structures (Kline *et al.*, 2023).
- Cognitive processing: A2 is also involved in higher-level cognitive functions, such as predicting melodic errors, particularly in musically trained individuals (Bonetti *et al.*, 2022).

The motor cortex and basal ganglia play key roles in how the brain processes music, particularly in relation to rhythm, timing, and movement. The motor cortex is involved not only in executing voluntary movements but also in predicting and synchronizing to musical beats, even during passive listening. This reflects the brain's intrinsic tendency to connect sound with movement (Zatorre *et al.*, 2007). Meanwhile, the basal ganglia, a group of subcortical nuclei involved in motor control and reward, are crucial for beat perception and internal timekeeping. They help in detecting temporal regularities in music and in maintaining rhythm over time (Grahn and Brett, 2007). Moreover, the basal ganglia interact with the dopaminergic system, contributing to the pleasurable and motivational aspects of musical engagement (Salimpoor *et al.*, 2011). Together, the motor cortex and basal ganglia form part of a broader auditory–motor network that enables humans to

move in synchrony with music, learn rhythmic patterns, and experience musical reward.

The cerebellum, conventionally known for its role in motor coordination and balance, also plays a significant part in music processing, particularly in rhythm perception, timing, and motor learning. It helps in the precise timing of auditory and motor events, allowing for accurate synchronization with musical beats and sequences (Ivry and Keele, 1989). During music listening or performance, the cerebellum is activated when tracking tempo, predicting beat timing, and coordinating fine motor movements such as playing an instrument or dancing (Stoodley and Schmahmann, 2009). In addition, it contributes to the internal generation of rhythmic patterns even without external cues, highlighting its role in temporal prediction. Its involvement in both motor and cognitive aspects of music illustrates the cerebellum's broader function in sensorimotor integration and auditory–motor coupling.

The prefrontal cortex plays a vital role in the cognitive and emotional processing of music. It is involved in functions such as musical memory, attention, expectation, and the evaluation of musical structure and meaning. This region helps integrate past experiences with current musical input, allowing listeners to anticipate melodies or harmonies and derive emotional responses. The dorsolateral prefrontal cortex is particularly active during tasks involving musical working memory and decision-making, while the ventromedial prefrontal cortex is associated with the pleasurable and rewarding aspects of music (Blood and Zatorre, 2001). The prefrontal cortex also modulates how music affects mood and social cognition, making it essential for interpreting music's expressive qualities and for emotional regulation during music listening.

The limbic system, particularly the amygdala and nucleus accumbens shown in Fig. 2, plays a central role in the emotional and reward processing of music. The amygdala is involved in detecting and processing the emotional content of music, such as fear, sadness, or joy, and is especially responsive to emotionally intense or arousing music (Koelsch *et al.*, 2006).

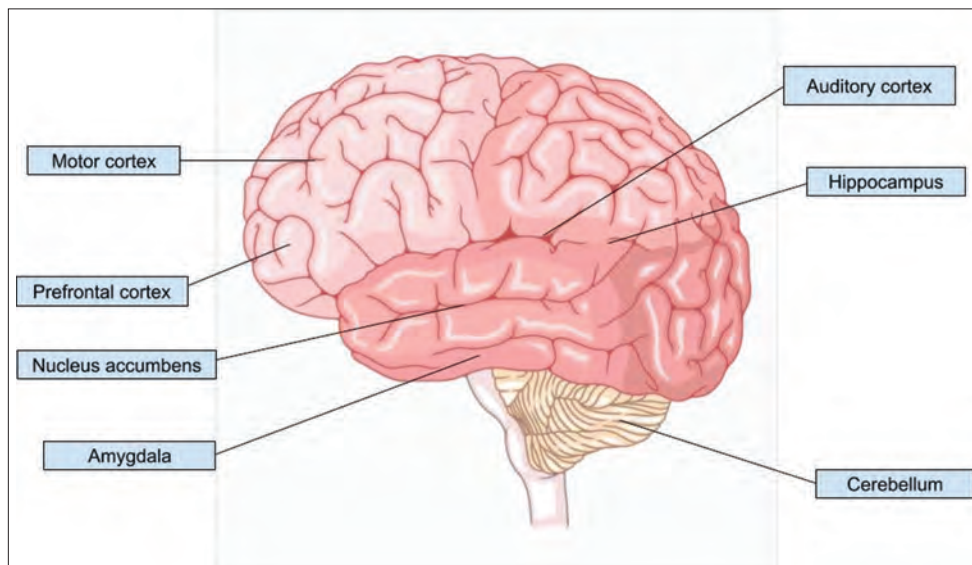


Fig. 2: Lateral view of the human brain highlighting brain region-specific effects of exposure to music.

The nucleus accumbens, part of the brain's dopaminergic reward circuitry, is activated during peak emotional moments in music listening, contributing to the feeling of pleasure or "chills" often experienced with favorite songs (Salimpoor *et al.*, 2011). This region helps link auditory stimuli with emotional and motivational responses, explaining why music can powerfully affect mood and behavior. Together, these structures explain why music is not only heard but felt on a deep, emotional level.

MUSIC AND NEUROTRANSMITTERS

Music has a profound impact on the production and regulation of neurotransmitters, which are crucial for various brain functions and emotional responses. Listening to pleasurable music activates the brain's reward system, primarily involving the mesolimbic pathway, which leads to the release of dopamine, a neurotransmitter linked with feelings of pleasure and motivation. A study by Salimpoor *et al.* (2011) used PET scans to show that dopamine is released in the striatum when individuals listen to music they find emotionally engaging. In addition, music can influence serotonin levels, which play a crucial role in mood stability and emotional well-being. This effect is particularly evident in music therapy interventions for depression and anxiety, where participants show improved mood and reduced symptoms,

potentially linked to enhanced serotonin transmission (Chanda and Levitin, 2013).

Moreover, music affects the release of endorphins, the body's natural painkillers, which are also implicated in the experience of pleasure and euphoria. This is often observed in group singing or rhythmic musical activities, where synchronized movement and vocalization can lead to elevated endorphin levels (Dunbar *et al.*, 2012). Furthermore, oxytocin, often called the "bonding hormone," has been shown to increase following music listening, particularly in social or group settings, enhancing feelings of trust and connection (Nilsson, 2009). Norepinephrine, associated with arousal and alertness, increases during dynamic or rhythmically intense music, enhancing attentional focus and physiological arousal (Thoma *et al.*, 2013). In addition to emotional neurotransmitters, inhibitory systems are also activated. Gamma-aminobutyric acid, the brain's main inhibitory neurotransmitter, contributes to the calming effects of slow, soothing music by reducing neural excitability and anxiety (Koelsch, 2010). In contrast, glutamate, the primary excitatory neurotransmitter, facilitates cognitive and auditory processing essential for decoding rhythm, pitch, and harmony, particularly in the auditory cortex and hippocampus (Zatorre *et al.*, 2007). Finally, acetylcholine, important for attention and learning, supports the brain's ability to recognize musical patterns and sustain focus, particularly during complex or unfamiliar music (Snyder and Alain, 2007).

Table 1: Effects of music and music therapy on mood and brain, and neurons in neurological patients

Neurological condition	Music intervention	Effect on mood	Key findings	Brain region/ neuronal effect	Reference
Stroke	Receptive music listening (daily for 2 months)	Reduced depression, improved mood	Music listening enhanced cognitive and emotional recovery	Increased activation in frontolimbic circuits, enhanced dopaminergic activity	Särkämö <i>et al.</i> , 2008
Parkinson's disease	Dual-task drum playing with rhythmic cueing	Enhanced attention, emotional engagement	Improved motor-attention coordination and mood	Involves motor cortex, prefrontal cortex (PFC), cerebellum	Park and Kim, 2021
Alzheimer's disease	Structured music therapy programs	Improved mood, reduced aggression and anxiety	Reduced depression and behavioral symptoms	Stimulates temporal lobe, amygdala, hippocampus	Gómez Gallego and Gómez García, 2017
Multiple sclerosis	Group music therapy (improvisation, listening, movement)	Reduced anxiety and depressive symptoms	Improved emotional state and energy levels	Modulation of the limbic system, increased serotonergic activity	Aldridge <i>et al.</i> , 2005
Traumatic brain injury	Music therapy and guided listening sessions	Enhanced emotional regulation, reduced distress	Music enhanced neuroplasticity and resting-state connectivity	Increased default mode network, PFC, temporal cortex	Martínez-Molina <i>et al.</i> , 2021
Dementia	Singing and music listening	Enhanced positive mood, reduced agitation	Better social behavior and calmness	Activation of the temporal lobe, amygdala, and nucleus accumbens	Vink <i>et al.</i> , 2013
Autism (ASD)	Music therapy with improvisation and rhythm training	Reduced irritability, improved emotional connection	Facilitated social interaction, emotional expression	Enhances connectivity in temporal lobe, mirror neuron system, insula	Geretsegger <i>et al.</i> , 2014
Attention-deficit hyperactivity disorder	Background music+sound-based time processing tasks	Improved emotional control, reduced frustration	Music helped time estimation, self-regulation, and task orientation	Modulates dopaminergic and frontostriatal pathways, increased PFC activity	Carrer, 2015
Post-traumatic stress disorder (PTSD)	Music instruction intervention (guitar, drumming)	Lowered PTSD symptoms, emotional expression	Music supported emotional healing and self-expression	Engages limbic system, hippocampus, supports cortical reorganization	Pezzin <i>et al.</i> , 2018
Schizophrenia	Adjunct group music therapy (systematic review)	Reduced negative symptoms, enhanced mood	Group music therapy improved emotional regulation, social interaction, and reduced psychiatric symptoms	Alters limbic system, prefrontal cortex, stabilizes dopaminergic activity	Lam <i>et al.</i> , 2023

MUSIC AND SYNAPTIC PLASTICITY

Music has been shown to enhance synaptic plasticity, the brain's ability to strengthen or weaken synaptic connections in response to activity, which is crucial for learning and memory. Listening to or practicing music stimulates multiple brain regions, especially the hippocampus, which is central to memory consolidation. Musical training increases long-term potentiation, a key mechanism underlying synaptic plasticity, and promotes the release of BDNF, a protein that supports neuron growth and synaptic modulation (Herholz and Zatorre, 2012). Studies also show that early and sustained musical engagement leads to structural and functional changes in the auditory and motor cortices, reflecting enhanced neuroplastic responses (Wan and Schlaug, 2010). These effects suggest that music not only enriches cognitive function but also supports brain resilience across the lifespan.

MUSIC IMPACT ON NEUROLOGICAL PATIENTS

Music has emerged as a significant form of complementary and alternative medicine for various neurological disorders, including Alzheimer's disease, Parkinson's disease, and anxiety disorders, as shown in Table 1. The therapeutic use of music can enhance cognitive function, improve mood, and foster emotional well-being among individuals with neurological impairments. Research indicates that music engages multiple brain regions, including those involved in emotion, memory, and motor control. For instance, (Colverson *et al.*, 2022) highlight that music can stimulate preserved brain areas in individuals with neurodegenerative diseases, facilitating memory recall, and emotional responses.

CONCLUSION

The intricate relationship between music and the brain reveals a compelling narrative of how auditory experiences can shape neural function and structure. Music processing engages a widespread network in the brain, including the auditory cortex for sound perception, the limbic system for emotional response, the motor cortex for rhythmic synchronization, the prefrontal cortex for attention and decision-making, and the cerebellum for coordination. These regions work in concert, highlighting music's multisensory and cognitive impact. A vital concept that underpins these effects is neuroplasticity—the brain's ability to reorganize and form new neural connections in response to stimuli. Music acts as a catalyst for neuroplastic changes, fostering cognitive recovery and emotional resilience.

Furthermore, music modulates key neurotransmitters such as dopamine, serotonin, and endorphins, which play critical roles in mood regulation, motivation, and stress reduction. This biochemical response lays the foundation for music therapy as a potent tool for addressing a range of neurological disorders, including Parkinson's disease, Alzheimer's disease, stroke, and depression. Music therapy not only alleviates

symptoms but also promotes rehabilitation and improves quality of life.

In conclusion, the interdisciplinary field of neuromusicology offers promising insights into how music can be harnessed not merely for entertainment but as a transformative therapeutic modality. As scientific understanding deepens, music may emerge as an integral component of holistic, brain-based healthcare strategies.

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