International Journal of
Life Sciences
International Peer Reviewed Open Access Refereed Journal

Int. J. of Life Sciences, 2024; 12 (3): 257-268
ISSN:2320-7817(p) | 2320-964X(o)

Review Article Open Access

The Neuroscience of Music: How Music Can Influence Brain Health and Functioning

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Manuscript details:
Received: 03.08.2024
Accepted: 28.09.2024
Published: 30.09.2024

Cite this article as:
Sanvi Gupta (2024) The Neuroscience of Music : How Music Can Influence Brain Health And Functioning, *Int. J. of Life Sciences*, 12 (3): 257-268.

Available online on http://www.ijlsci.in
ISSN: 2320-964X (Online)
ISSN: 2320-7817 (Print)

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ABSTRACT

Music is a form of entertainment that has been instrumental in human culture. This literature review aims to highlight the additional aspects music impacts in modern-day life from its biological effects on brain health and functioning. Many studies cite music's wide range of effects to promote mental well-being for various ailments and induce neuroplasticity in individuals who are musically trained. These discoveries have brought about the fields of music medicine and music therapy for individuals with Alzheimer's disease and depression. These interventions can additionally work with neurodivergent populations to improve abilities, such as verbal communication for individuals with autism. Medical imaging studies have revealed neuroplastic changes in musically trained individuals, providing them with enhanced auditory and speech processing. Future studies are encouraged to examine the greater relationship between music and human productivity and vitalize the integration of music into various societal sectors to bring positive change to them. Music is truly an asset to human functioning, one that is yet to be fully explored and used for its full value.

Keywords: neuroscience, audition, musical processing, musical interventions, neuroplasticity.

INTRODUCTION

Music is organized sound that consists of a rule-based framework. As an abstract art form, its overall purpose and use can vary from person to person. Throughout history, music has been a unique art form that individuals can take part in, as musicians, or enjoy as listeners. In today's world, a large music industry allows listeners everywhere to have their unique musical interests for their entertainment.

This review aims to study music's role in brain health and development and its consequent connection to applicable fields. Musical sound waves first pass through the ear and the auditory system before reaching specific brain areas, allowing for the interpretation of essential musical components including pitch, timbre, and rhythm (Warren, 2008). The advanced cognitive processing of music supports brain health and functioning, in the form of musical interventions. Interventions like Music therapy and Music Medicine have been used for various disorders, including Alzheimer's Disease, depression, autism, and various pediatric illnesses (Matziorinis and Koelsch, 2022; Stegemann *et al*., 2019). Musical training also impacts cognition (Moossavi and Gohari, 2019; Wang *et al*., 2022) and neuroplasticity (Olszewska *et al*., 2021). These biological changes and psychological changes observed in musicians lead to higher cognitive functionality, compared to non-musicians (Wu and Shih, 2019).

The purpose of this review is to explain music's greater role in society, encouraging additional music studies in important fields such as medicine and education. Exploring music's ability to heal ailments and foster greater cognitive skills, could bring necessary change across diverse therapeutic and educational disciplines.

The Neuroscience of The Auditory System

Our ability to hear music comes from the process of audition. This is governed by the auditory system which is made of the ears, (the sensory organs through which sound waves arrive at our awareness), the auditory nerve (responsible for transmitting auditory signals to the brain), and certain areas of the brain. The ear is divided into 3 different sections– outer ear, middle ear, and inner ear– and each section of the ear has unique anatomical characteristics, as shown in *Figure 1*.

Musical vibrations are classified as sound waves, longitudinal waves that transmit sound energy from the source of the sound to a listener. Sound waves are first funneled to the auditory canal by the outer ear and they travel until they hit the eardrum, located outside the middle ear. The bones of the middle ear (stirrup, anvil, and hammer) vibrate in response to the sound waves, and the vibrations are transmitted to the inner ear, which contains the semicircular canals and the cochlea. The cochlea is a coiled, bony, fluid-filled tube, containing more than 20,000 hair cells on its membrane (McCollum, 2019), and reacts to the different tones and pitches of incoming sound waves. The incoming vibrations from the middle ear prompt the hair cells on the cochlear membrane to bend. This triggers impulses to the adjacent nerve cells of the auditory nerve. Finally, the auditory nerve sends the neural message of the sound waves to the auditory cortex of the auditory cortex in the temporal lobe of the brain for further processing. Specific sections of the cortex process specific musical elements, which will be discussed in the following section.

Music Perception in The Brain

Once in the brain, music is processed in various association areas in the auditory cortex. In the auditory cortex, the Heschl's gyrus (located superior to the temporal lobe), Superior Temporal Gyrus (also located superior to the temporal lobe, and the Insular Cortex (located deep to the lateral sulcus) assist in this processing, so do areas of the frontal and parietal lobes (Moossavi and Gohari, 2019). This review will exclusively examine musical perception in the human mind and extend this understanding to other fields in the later sections.

Music perception is the ability to organize and identify musical information to interpret its meaning (Pando-Naude *et al.* 2021). The brain engages this processing through top-down and bottom-up processing, a

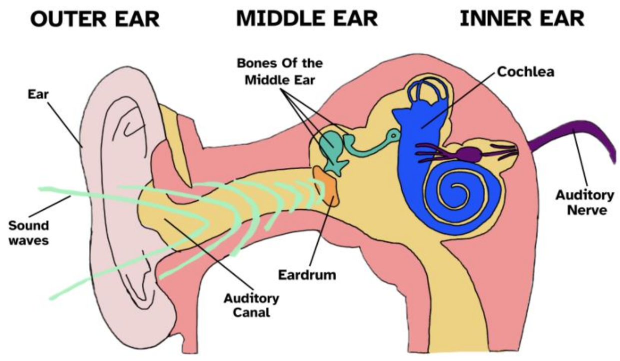

Figure 1: Anatomical characteristics of Human Ear

feedback loop that integrates the external stimuli, or the current sound, with previous experiences to make sense of the created sound (Pando-Naude *et al*., 2021). In music perception, different key elements of music like pitch, rhythm, timbre, meaning, and emotion are processed individually.

Pitch is the perceptual correlation of the repetition rate of sound waves. It is a defining element in music, being used to construct almost all melodies, chords, and harmonies in music. The lateral Heschl's gyrus perceives pitch (Warren, 2008). More intricate details of pitch, such as pitch anticipation, and violation of harmony involve the right hemisphere section of Broca's area, which processes auditory information from communication. In the superior temporal lobe, both the anterior and posterior sections analyze pitch in melodies (Warren, 2008). Studies have also shown that there is greater activation in the right hemisphere for pitch contour (the rise & fall of pitch over time in the melody) and that the left hemisphere instead uses this pitch counter to fill in the specific pitch intervals from the right hemisphere.

Rhythm is defined as a repetitive pattern of sound and is important for the understanding and appreciation of music. The belt and parabelt, subregions of the right auditory cortex, process rhythm in songs (McCollum, 2019). Rhythm prediction increases activity in the lateral area of the cerebellum and the basal ganglia and putamen of the reward system. Additionally, premotor cortex activity increases when perceiving rhythm in the preferred tempo (Brodal *et al*., 2017).

Timbre is the ability to distinguish between sound production from different musical instruments. People with the condition of amusia are unable to process timbre and pitch. Amusia studies have found that the right section of the superior temporal lobe was damaged, and therefore responsible for correct timbre perception (Warren, 2008).

Listening to music additionally involves understanding the music's meaning and emotional content. Studies have shown that the inability to recognize familiar tunes comes from damage to the anterior superior temporal gyrus and the insular cortex, a multimodal area that is essential for perpetual, cognitive, and emotional processing (Pando-Naude, *et al*., 2021). The limbic system, which consists of the hippocampus, the amygdala, and their cortical connections, is a circuit that mediates the human emotional response. Researchers have hypothesized that the same system analyzing the emotional content of music has similar limbic system activity to basic biological situations that require emotion such as excitement or fear (Warren, 2008).

As shown here, musical perception, which comes from listening and interacting with music, can activate a variety of brain areas. Because of this, music can target the areas of the brain that are negatively impacted by various ailments as discussed in the next section.

Understanding Music Interventions

Recently, the idea of using music as a healthcare intervention has become popular for certain diseases and conditions. The two main types of music interventions include Music Therapy (MT) and Music Medicine (MM), and this review will focus on the role of interventions in the medical context. These interventions can be applied to community, developmental, and educational contexts as well, as well as delivered in a group or individual setting.

Music Therapy.

The American Music Therapists Association defines music therapy as a clinical and evidence-based use of music interventions to support individualized goals in therapeutic relationships by a credentialed professional (AMTA, 1998). Professional music therapists have the specific knowledge to select, construct, and combine specific stimuli for creating controlled music experiences (Leubner and Hinterberger, 2017). To strengthen the therapist-patient relationship, music therapists must understand a patient's musical preferences and needs while addressing their physical, emotional, cognitive, and social needs, similar to general therapists (Stegemann *et al*., 2019). MT is classified as active music intervention, where the client actively and directly participates in music through improvisation, listening, recreating, and composing with musical devices (Stegemann *et al*., 2019). Improvisation is the spontaneous creation of music through instrumental playing, vocalizing, or creating sounds that stimulate the unconscious mind, facilitating communication and emotional expression (Stegemann *et al*., 2019). Music listening is largely practiced in music medicine, although this receptive method is used in MT to evoke bodily responses and relax patients (Stegemann *et al*., 2019). Recreation allows clients to interact with precomposed or live music by playing instruments in the music or singing along (Stegemann *et al*., 2019). Composition lets clients formally record and perform music like instrumental pieces, lyrics, and songs to help them generate their own opinions and ideas in a workable structure. (Stegemann *et al*., 2019; Aalbers *et al*., 2017). The component of active intervention can activate the brain networks involved with auditory processing, motor control, and emotional regulation, therefore having a greater impact on the patient's cognitive and emotional processes (Bleiel *et al*., 2023). The patient can meet their emotional needs from MT by using skills like organization, problem-solving, and communication to reduce anxiety and stress. MT is a versatile therapeutic method, using psychodynamic, behavioral, and humanistic approaches, and complements activities such as writing and drawing (Aalbers *et al*., 2017).

Overall, the principles of music therapy and its multifaceted approach serve to be a useful intervention for various dysfunctional cases, and its effectiveness for specific diseases will be discussed in a later section.

Music Medicine.

MM allows patients to experience music through pre-recorded playlists tailored to their preferences (Tang *et al*., 2020). Unlike MT, the music therapist has a passive role; any medical professional can create the patient's playlist and consult a music therapist (Leubner and Hinterberger, 2017). MM is classified as receptive music intervention, where music is listened to and responded to passively, without active creation (Bleiel *et al*., 2023). Studies have shown that listening to music allows brain cells to process information more efficiently, facilitating the brain's adaptability and neuroplasticity. (Fink, (n.d.)). MM also shifts consciousness, allowing patients to focus and practice self-reflection, introspection, and motivation (Aalbers *et al*., 2017). The receptive nature of music medicine also induces physical changes in patients by changing heart rate and breathing, reducing stress, and improving patients' sleep (Aalbers *et al*., 2017). Memory formation, verbalization, and other cognitive functions are also improved in patients who undergo extensive MM (Bleiel *et al*., 2023). MM also uses psychodynamic, cognitive-behavioral, and humanistic approaches and can be performed with activities like meditation and drawing. (Aalbers *et al*., 2017).

MM is more reflective compared to music therapy, yet it can encourage a sense of well-being in patients. Greater studies into this intervention can discern its relaxing effect on physical and mental health.

Use of Music Interventions in Medical Applications

Both music therapy and music medicine can impact the psychological and physiological aspects of the human body. Therefore, these interventions are imperative for treating various physical and mental diseases in medicine today.

Music Interventions for Alzheimer's Disease.

Alzheimer's Disease (AD) is a progressive neurodegenerative disease among older populations associated with memory loss and cognitive decline (Breijyeh and Karaman, 2020). The disease is currently incurable and is projected to grow to 153 million cases worldwide by 2050 as the global population ages (Matziorinis and Koelsch, 2022). Clinical symptoms of AD include a decline in memory formation, cognitive ability, visuospatial abilities, executive function, language processing, and speech production, while psychological symptoms include agitation, depression, anxiety, emotional imbalance, and sleep disorders. (Matziorinis and Koelsch, 2022). Studies have indicated that while neurodegeneration is widespread, it spares the sensorimotor, auditory, and motor areas, which could be the reason that music benefits AD patients (Matriorinis and Koelsch, 2022).

Humans store memories and emotions from musical events, memories can be retrieved when triggered by the same kind of music. Interacting with music in a therapeutic context or listening to music allows patients to recall those memories and elicit emotions, as shown by activity changes in the anterior hippocampal formation (an area associated with memory) (Matziorinis and Koelsch, 2022). This is why AD patients can recall musical memories with emotional aspects, like singing familiar melodies, rather than autobiological memories. However, music-evoked autobiographical memories (MEAMS) can spark emotional reactions once evoked from musical cues; studies have shown that they are preserved in AD patients. A study by El Haj *et al*. (2012), compared MEAMS in adults and patients with AD with a silent or music condition and saw that MEAMS were retrieved faster and had a more detailed emotional content rather than memories evoked simultaneously. An additional study by Cuddy *et al*. (2015) observed

MEAMS in healthy older adults compared to moderate AD patients, finding that familiar instrumental music sparked more episode memories in both groups (Matriorinis and Koelsch, 2022). Both studies highlight music's ability to promote cognitive ability and social communication by allowing for memory stimulation in AD patients. Studies have examined that AD patients can retain musical memories due to neural encoding of music in the anterior cingulate cortex and the pre-supplementary motor area (SMA), which go through neurodegeneration last (Matriorinis and Koelsch, 2022). A study by King *et al*. (2019) investigated music listening in AD patients which included the patient's favorite songs. The authors then measured brain connectivity during a musical task using functional magnetic resonance imaging (fMRI) and saw activity in the SMA. This matched with reports that the SMA was activated upon listening to familiar music. A study by Lyu *et al*. (2018) implemented MT for AD patients, assigning them to 3 groups: active singing, lyric reading, and a control group. After 6 months, researchers found that the active MT singing group was more effective than the lyric reading group in improving the lives of AD patients. In the MT group, mild AD patients had improved language abilities, severe and moderate AD patients had fewer psychiatric symptoms than usual, and all AD patients had high recall on an auditory verbal learning test (Lyu *et al*., 2018). With these results, the authors concluded that MT was useful for AD patients.

Overall, musical interventions for AD patients show great promise through their ability to change the neurophysiology of the brain. This ranges from potentially improving memory and cognitive decline to facilitating the emotional responses and communication of these patients with their loved ones. A variety of theories have been proposed to understand the mechanism behind music's effects on AD patients, but more research is required to find out the best way to approach music interventions for this population.

Music Interventions for Depression.

Depression is a psychological mood disorder, which affects more than 300 million people worldwide (WHO, 2023). Common symptoms of depression include a persistent lowered mood, a loss of pleasure and excitement, a loss of interest and energy in day-to-day activities, sleep disturbances, diet, and weight fluctuations, consistent feelings of guilt, lowered esteem, and worthlessness (Aalbers *et al*., 2017). Depression can also lead to greater future health problems, create severely dysfunctional relationships, and if untreated, can lead to extreme impairment in individual day-to-day functionality.

Because of music's ability to modulate moods and emotions in daily life, music interventions are gaining greater popularity as a non-pharmacological intervention to treat depression (Aalbers *et al*., 2017). A 2020 meta-analysis explored the effectiveness of MT and MM in treating depression and found that MT had a greater impact on reducing patient's depression rather than MM in various studies (Tang *et al*., 2020). Generally, methods involved in MT such as music recreation, and guided imagery specificity yielded superior effects than the music listening methods, which are heavily involved in MM. However, this analysis has its limitations, such as the variety of patient types from each study and the exclusive use of MT and not MM in some cases. (Tang *et al*., 2020).

MT has been compared to regular treatment for depression, which generally includes medications and psychotherapy. A 2017 meta-analysis found a significant short-term effect of music therapy combined with treatment as usual for depression rather than treatment alone (Aalbers *et al*., 2017). For example, there was a significant reduction in anxiety symptoms for patients who had music therapy plus treatment rather than just treatment (Aalbers *et al*., 2017). When the effects of MT were compared against the effects of psychological therapy on the severity of depressive symptoms, no significant differences were found, and levels of anxiety and levels of functioning were not measured in the studies of the meta-analysis (Aalbers *et al*., 2017).

Overall, current research presents that MT is effective in treating depressive symptoms. More research in this field can provide medical personnel with a better understanding of how to integrate this intervention into treatment for additional psychological and behavioral disorders.

Music Interventions for Autism.

Autism Spectrum Disorder (ASD) is a neurodevelopmental condition that affects social interaction, communication, learning, and behavior. ASD may be accompanied by co-occurring conditions including anxiety disorders, depression, intellectual disabilities, language impairments, and additional neurodevelopmental, mental, and behavioral disorders (APA, 2013). The prevalence of the condition among the population has started to rise in the last decade, as the diagnostic criteria, serviceability, and awareness of the condition have increased; the CDC has reported that one in 54 children in the US may be on the autism spectrum (Maenner, 2020). Previously, ASD was understood as a set of social deficits with an inability to communicate with others and therapy forced behavioral and cognitive correction (Milton, 2019). The medical paradigm for autism today focuses on improving social communication and interaction, but still tries to remove outward signs of autism (Geretsegger *et al*., 2022).

MT, however, uses a social model following the strengths of ASD individuals. As an "open-minded" therapy it works with autistic individuals to understand their abilities and encourage their participation in activities to begin developing social interaction. Generally, MT facilitates the shift between non-verbal and verbal communication, allowing individuals with autism, especially children, to engage their senses and process emotions. Each specific activity in MT has its benefits as well. For example, active music creation in MT fosters communicative behaviors like eye contact, turn-taking, and joint attention helping autistic individuals gain social responsiveness (Geretsegger *et al*., 2022). Improvisation in MT allows individuals to create a structure with measured flexibility, teaching them to cope with challenging and unpredictable situations in the real world. (Geretsegger *et al*., 2022). Finally, listening to music in MT stimulates verbal reflection and verbal capabilities in individuals with ASD (Wigram, 2002).

MT improves conditions for autistic individuals by leveraging their abilities to advance their learning, rather than forcing neurotypical behaviors. Further research could uncover innovative approaches to widely integrate MT for ASD individuals and their families.

Music Interventions for Pediatric Care.

MT was first used with children and teens after World War II in the US and introduced to Europe in the 1950s as part of a greater movement to help treat mentally ill patients (Davis, 2008). Today, these interventions play a larger role in pediatric care. In a 2017 survey among members of the World Federation of Music Therapists, more than half (50.6%) of music therapists reported working with children/preteens, 45.7% reported working with teens, and 38.2% reported working with infants/children (Stegemann *et al*., 2019). These music therapists also work in mental health facilities, schools, and private practice. This can be in the form of individual, group, and now family-based settings, an approach that has increased in recent years.

MT is unique in its ability to be used in various psychological approaches. The behaviorist approach uses music therapy for relaxation and behavioral modification. The humanist approach uses musical improvisation as a tool to engage creativity and develop better relationships with others. In both approaches, music provides a versatile medium that can be used in various therapeutic ways to treat a variety of ailments and needs.

Epilepsy. Music interventions are an effective addition to epilepsy treatment in children and adults. This is due to music's ability to reduce seizure activity by modulating the hyperactivity of the dopaminergic circuitry, or by modifying ictogenesis, the process that leads to seizures from a relaxed state (Maguire, 2017). The idea of the "Mozart Effect"- that music from W.A. Mozart can influence the activity of seizures in children–has been studied in recent publications, but the claim generally holds doubt in the scientific community. Researchers Brackney and Brooks (2018) claimed "The evidence for the efficacy of the Mozart Effect on seizure activity in children is promising but not conclusive" (Stegemann *et al*., 2019).

Disabilities. Music therapy has been effective in helping children and adolescents with various mental and physical disabilities. MT can foster social and emotional regulation, and promote motor skills for disabled individuals. Previous studies have indicated how children with ASD, Rett syndrome, Williams syndrome, and trisomy 21 or Down Syndrome are especially responsive to various kinds of musical activities and music listening (Stegemann *et al*., 2019). A longitudinal study by Jellison and Draper (2015) investigated music in a preschool setting from 1975 to 2013, and their evidence pointed to the positive effects of music-based interventions on literacy and reading skills among kids with disabilities. Although the study highlighted promising results, it cannot make definitive claims on this topic as it was rated low on the AMSTAR 2 appraisal tool (Stegemann *et al*., 2019).

Therefore, additional research in this area is required to justify the positive effects of music interventions for individuals with disabilities.

Neonatal Care. Music interventions, especially MT, are becoming more important in neonatal ICU units (NICU). Premature infants, (infants born much earlier than expected), are underdeveloped and more vulnerable at birth. A 2016 study suggested meaningful "auditory stimulation" like music can manage the neurodevelopment of premature infants (Van der Heijden *et al*., 2016). Since then, studies on MT and music-based interventions have been shown to reduce infant heart and respiratory rates, improve infant food intake and sleeping habits, and reduce mothers' anxiety levels (Bieleninik *et al*., 2016). Currently in NICUs, MT is strictly regulated to ensure musical performances do not compromise the safety of infants with sensitive hearing. These regulations include having reduced numbers of instruments, shorter duration of musical performances, and ensuring that the music itself has minimal changes in volume, harmony, rhythm, dynamics, pitch, and melody (Stegemann *et al*., 2019). MT for this vulnerable population is therefore useful in moderation.

Pain, Anxiety, and Stress.

Music interventions are effective in reducing pain, anxiety, and stress for medical procedures done on children and adolescents. A literature review by Kim and Stegemann (2016) studied the use of MM for pediatric patients going through a needle insertion, measuring the effect of the intervention on the factors of pain, anxiety, and stress on the patients. Regarding pain perception, 9 of the 12 studies found that patients in the music group experienced significantly less pain than in the non-music and control groups (Stegemann *et al*., 2019). Another study by Nguyen *et al*. (2010) explored MM in reducing pain and anxiety among pediatric cancer patients undergoing lumbar surgery. Findings from the study highlighted how heart and respiratory rates were significantly reduced in the group listening to music during and after the procedure rather than in the group(s) without music (Stegemann *et al*., 2019). A study by Kristjánsdóttir *et al*. (2011) looked at the "music distraction strategy," or a music medicine intervention in teens receiving an immunization shot. Results showed that young patients who listened to music during the procedure were 2.8 times more likely to believe they weren't experiencing pain than patients who didn't listen to music. Music listening/MM is therefore an impactful intervention to reduce pain symptoms, but the effect of MT needs exploration.

Overall, the use of musical interventions as a therapeutic device has benefited various diseases and disorders discussed in this review. Additional studies can prompt the greater integration of music into medical institutions to increase the quality of care for patients.

Impact of Musical Training on Brain Function Throughout the Life Span

Musical training is the formal study of musical techniques in instrumental or vocal music. From a neurobiological perspective, music-making activates multiple systems in the human brain such as sensory adaptation and multisensory input (tactile, auditory, visual, and proprioceptive) (Olszewska *et al*., 2021). It also involves motor output, cognitive functions (memory, attention, emotion), and the reward system, which drives brain plasticity by promoting future learning (Olszewska *et al*., 2021). Because of the complex stimulation that musical training provides, musical training greatly impacts neuroplasticity and neurodevelopment in musicians.

Understanding the Process of Neuroplasticity

Neuroplasticity is the ability of the human brain to adapt and perform novel tasks through new processes (Strong *et al*., 2022). This process continually occurs across the lifespan and is essential for learning and memory experiences. Neuroplasticity also includes neurobiological processes such as myelination, neurogenesis, synaptic remodeling, and the reconfiguration of neural connections (Olszewska *et al*., 2021). Because musical training involves the interaction of various systems in the brain, changes in brain structure and function are easily seen in musicians.

Biological Changes in Musician vs. Non-Musician Brain

Cross-sectional studies on this topic can compare musician-trained and untrained individuals at a single point in time, rather than showing their development over a period. In contrast, longitudinal studies can track the changes in brain development among a group during a learning period but are more costly and difficult to handle. Both kinds of studies, however, have presented structural and functional changes in musicians' brains.

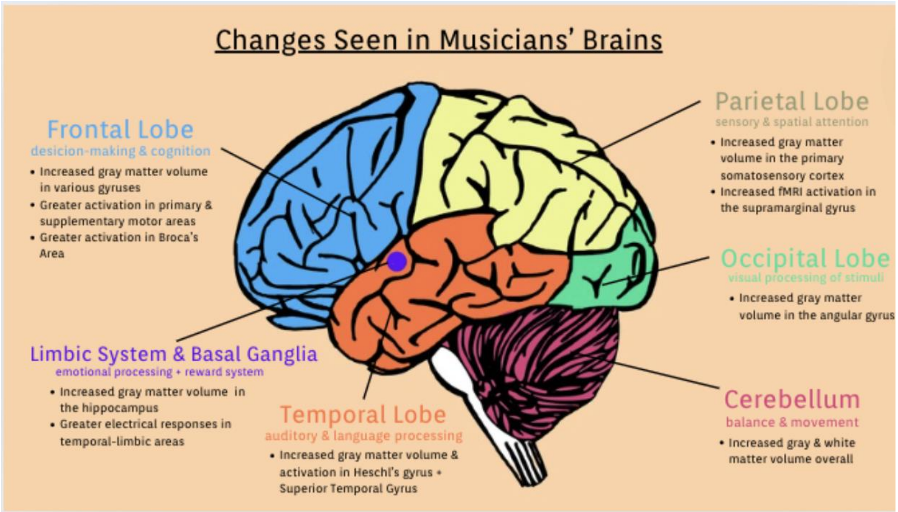

Figure 2: Changes in various brain areas as seen in musicians

The differences seen in the major distinctions of the brain and associating areas can be summarized in *Figure 2*. The areas of the brain that undergo neuroplastic changes include the four main lobes of the brain (frontal, temporal, parietal, occipital), the cerebellum, the limbic system, and the basal ganglia. All areas are made of white and gray matter. White matter consists of nerve fibers while gray matter consists of neurons (brain cells).

The frontal lobe (located at the front of the brain), is responsible for decision-making, as well as cognitive, motor, and social skills. Studies have shown that musicians have increased gray matter in various gyruses, or curves in this lobe which allows for greater executive function, like the maintenance, retrieval, and processing of musical information (Olszewska *et al*., 2021). Additionally, there is greater activation in the primary and supplementary motor areas in musicians when comparing musicians' and nonmusicians' brains with fMRI imaging, allowing musicians to have greater motor execution (Olszewska *et al*., 2021). Finally, musicians have greater fMRI activation in Broca's area, which is responsible for speech production in humans, and therefore have greater speech execution (Olszewska *et al*., 2021).

The temporal lobe (located under the frontal lobe) is responsible for auditory and language processing, as well as memory retrieval. Musicians show an increased gray matter volume and activation at Heschl's gyrus (used in pitch perception) and the superior temporal gyrus (used in auditory processing) (Olszewska *et al*., 2021). Increased gray matter volume means both vocalists and instrumentalists have a greater ability to analyze and match various pitches and sounds than non-musicians.

The occipital lobe (located towards the back of the brain) is responsible for the visual processing of stimuli. Musicians have an increased gray matter volume in the angular gyrus, which is involved in spatial attention, and aids with their ability to read complex scores of works and play music simultaneously (Olszewska *et al*., 2021).

The parietal lobe (located above the temporal & occipital lobes) is responsible for the sensory and spatial processing of stimuli. Increased gray matter in the primary somatosensory cortex, (responsible for touch perception), gives musicians advanced tactical skills to play their instruments (Olszewska *et al*., 2021). Additionally, musicians show increased fMRI activation in the supramarginal gyrus (responsible for syntax processing & attention), which enhances their touch processing and sustained focus while playing instruments with precision.

The cerebellum (located underneath all the brain lobes) is responsible for balance and movement. Musicians have increased gray and white matter volume in these areas allowing them to have enhanced motor and movement skills to play instruments that require precise hand-eye coordination (Olszewska *et al*., 2021).

The basal ganglia (involved in reward cognition and learning) and limbic system are essential brain areas that lie between the frontal and temporal lobes. Musicians exhibit increased gray matter volume in the hippocampus, which controls memory, enabling musicians to memorize and recall long pieces. Heightened electrical responses in the musicians' temporal-limbic areas, which regulate emotions and memory, facilitating the expressive performance of emotionally complex pieces (Olszewska *et al*., 2021).

Overall, these studies provide evidence that musical training can promote neuroplasticity. The variety of structural and functional changes in the brains of musicians are what provide them with the specialized skills to create music effectively as individuals.

Auditory and Speech Processing in Musicians.

Auditory processing is the process where the brain interprets and perceives sound information (Riggs, 2009). Speech processing, in contrast, is the process of understanding, representing, and analyzing speech as individuals (Abhang *et al*., 2016). Musical training can enhance both kinds of processing by testing these skills in musicians. The auditory system is essential to musical training and there is evidence of alterations in the auditory pathway of expert musicians, compared to non-musicians (Moossavi and Gohari, 2019). Studies have indicated that musical training & listening induce functional and structural plasticity in various areas of the auditory pathway, including pathways from the cochlea to the auditory and non-auditory cortexes. That plasticity has led to changes in the brainstem, primary cortex, and other auditory processing centers (Moossavi and Gohari, 2019). Research shows that musicians have enhanced feedback in the internal medial olivocochlear bundle of the cochlea, which improves signal response in noise detection and speech in noise perception (Micheyl *et al*., 1997). In contrast, damage to this area leads to auditory processing disorder (Muchnik *et al*., 2004). The frequency-following response (FFR) is an electrical response generated by the brain stem and reflects the brain's ability to respond to auditory stimuli. Studies show that musical training enhances FFR and triggers neuroplastic changes, allowing musicians to process these complex sounds(Moossavi and Gohari, 2019). Finally, the primary auditory cortex undergoes neuroplastic changes in the rhythmic and pitch processes with musical training. This is seen in the larger amplitude of the middle latency response, which sends signals from the thalamus to the auditory cortex (Moossavi and Gohari, 2019).

Many studies indicate how the skills learned through musical training improve speech perception and production. Firstly, musicians show stronger neural responses to the complex tones of resolved and unresolved harmonies than non-musicians. This arises from increased activation in the right hemisphere in musicians, an area that plays an important role in speech perception (Jantzen *et al*., 2014). Therefore, areas like the insular cortex, Heschel's gyrus, inferior frontal gyrus, and the colliculus inferior have higher activation in musicians (Moossavi and Gohari, 2018). Additionally, musicians are highly involved in neural responses for the preservation and comparison of pitch information, which is used in speech processing (Moossavi and Gohari, 2018). Various studies have indicated that musicians have an optimized auditory system, allowing them to respond to various musical elements and discriminate sounds. On auditory perception tests, musicians can process acoustic features like the pitch of F0, (the first step in music) allowing them to perform better than non-musicians on tasks. (Moossavi and Gohari, 2018). Another important part of speech processing is the ability to perceive speech amid distractions. For example, the average listener has difficulty differentiating between various voices at a noisy party. However, musicians have an enhanced capability to segregate concurrent sounds because of their pitch discrimination and selective attention skills (Moossavi and Gohari, 2018). Because research findings have suggested music's ability to enhance speech processing, musical training with a special focus on rhythm is being utilized for children with dyslexia, a learning disability that impairs language skills. A 2016 study looked at musical intonation training for children with stroke and dyslexia in Broca's area and found that the musical training facilitated continuous speech and accuracy in creating sentences, (Flaugnacco *et al*., 2016).

Musical training has proven instrumental to the neurodevelopment of musicians; neuroplastic changes in brain structure have enhanced the processing of information, auditory stimuli, and language in musicians. Additional studies can apply the benefits of musical training for those with learning challenges, auditory disorders, and speech deficits.

CONCLUSION

Research in the last two decades has provided abundant information regarding music and its subsequent impact on the human brain, enabling its applications to the fields of medicine, learning, industry, and more. Scientists, researchers, and clinicians have the potential to implement music in various sectors more frequently. In the medical context, it could mean making music therapy an essential part of patient care by implementing it in hospitals and post-operational care centers. In the teaching and learning sector, understanding how musical training promotes neuroplastic changes and greater processing skills can be emphasized to fund music programs for youth in schools, communities, and cities. The applications of music in human culture, aside from the entertainment industry, are limitless. Yet many questions remain unanswered such as understanding how training in certain instruments facilitates a different skill set or whether the use of background music for certain tasks in the workplace can produce efficient workers. Therefore, we encourage the utilization and greater study of this resource of music to bring about greater societal advancements.

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Conflict of interest: The authors declare that they have no conflict of interest.

Acknowledgements:
I would like to thank Mr.Sean Gay (Ph.D candidate at UNC-Chapel) and Ms. Daphne Schmid (Ph.D) candidate at the University of Georgia) for guiding me with the writing and finalization of this manuscript. .

Publisher's Note
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