Effects of Music Education on Brain Development and Behavior Across the Lifespan

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Abstract

Music education is a wide field of study that encompasses learning musical theory, instrument playing techniques, and learning to appreciate musical composition and styles. The field equips individuals with crucial skills, which activate and grow various areas of the brain. This review paper provides an in-depth perspective on how music influences brain development. First, we review how the sound of music is processed in the brain and what brain regions are involved when listening to or playing music. Next, we explore the benefits of music on various behaviors during childhood and adolescence, including academic performance. Additionally, we summarize literature involving the benefits of music therapy for neurodegenerative diseases. Overall, music education has been shown to be a powerful tool in influencing brain development and function as indicated by the structural changes in different areas of the brain, excelled performance in academics, and positive impacts on mood and cognition.

Introduction

Music has existed for tens of thousands of years with the first instruments dating back to the Paleolithic era. From its uses as means of social bonding, expression of emotion, and entertainment, it is undeniable that music has been an essential aspect of daily life throughout human history (Bellis, 2025). This review paper will answer the question regarding the influence of music on brain development and what the positive effects that music has on specific behaviors across the lifespan. More specifically, this paper will summarize how music is processed by the brain, discuss the impact of music on neurodevelopment, and evaluate potential benefits of music on academic performance, mood, and cognition within a variety of nonclinical and clinical populations. This work has the potential to improve the current understanding of how music shapes the world today and inspire innovative ways for music to be implemented in society.

How Music is Interpreted by the Brain

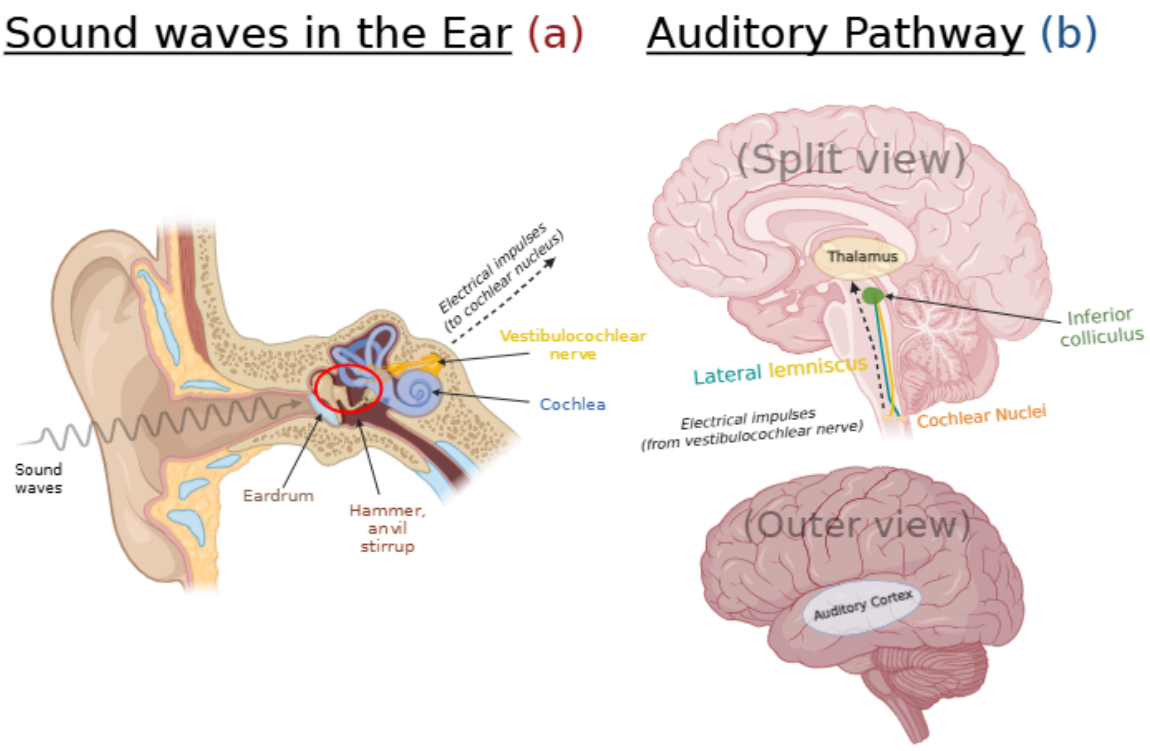

Figure 1: Auditory Processing in the Ear and Brain. (A) How sound waves are processed in the ear and (B) How auditory information reaches the brain. Figure 1 was created in BioRender.

Auditory Processing from Ear to Brain

When a note is played on an instrument, vibrations in the air known as sound waves are produced. The sound waves travel through the ear canal to the eardrum, which causes it to vibrate. The eardrum then passes these vibrations to three small bones: the hammer, anvil, and stirrup, which send the vibrations to the inner ear or cochlea. The cochlea is a spiral-shaped tube located in the inner ear, which translates these vibrations into electrical impulses through the movement of miniscule hairs. Next, the cochlear component of the vestibulocochlear nerve carries these impulses to be further processed in the brainstem (Figure 1A; T. Zaatar et al., 2023).

The primary auditory pathway is responsible for relaying the auditory information from the ear to the brain. After reaching the cochlear nuclei, the vestibulocochlear nerve separates into two: the cochlear and vestibular nerve. This process is important because the cochlear nerve is associated with carrying the auditory information while the vestibular nerve is responsible for balance. Both travel up the brainstem in a fiber bundle known as the lateral lemniscus. Once the fibers reach the inferior colliculus, they converge and connect to the thalamus, specifically the medial geniculate body. (Figure 1B; Davies and Sugano, 2020). After further signal processing in the thalamus, auditory information is relayed to the primary auditory cortex (Toader et al., 2023).

Regions of the Brain Involved in Music Processing and Music Playing

The brain can be divided into four main regions: the frontal, temporal, parietal, and occipital lobes. These regions, as well as the cerebellum, are all responsible for specialized functions such as movement, vision, cognitive function, and more. The temporal lobe is the region of the brain responsible for processing auditory information. This region of the brain contains the primary auditory cortex. In the

primary auditory cortex, signals are interpreted as pitches, volume, and timbres (Davies & Sugano, 2020; Toader et al., 2023). The functions of the temporal lobe aid in processing music while the functions of the frontal lobe and cerebellum aid in tasks required to play musical instruments.

A major part of being able to play an instrument is timing and coordination. The prefrontal cortex, which is located in the frontal lobe, identifies structural patterns in music and plans out the executive functions accordingly. The function of the prefrontal cortex is necessary when playing music since it allows for adaptations to be made from complex sequences of motor movements (Bianco et al., 2022). Furthermore, the cerebellum, which is located at the posterior and inferior aspect of the brain, helps maintain balance and fine-tune motor functions through a trial-and-error process. (Jimsheleishvili & Dididze, 2025). When practicing an instrument, the cerebellum helps the musician adapt to the specific motor movements needed to produce specific sounds, which leads to higher proficiency when playing a song.

Memory is also needed while learning an instrument. As discussed previously, the prefrontal cortex stores auditory working memory while actively playing a song, which is useful for recognizing melodies and planning out the next movements (Bianco et al., 2022). The hippocampus, which is located in the temporal lobe, is responsible for forming memories based on experiences (Lisman et al., 2017). Memory formation is integral to playing music because it is required for muscle memory in the fingers and ability to remember entire songs without sheet music.

In addition to developing motor skills, playing expressively is also an important aspect of learning a new instrument. When the hippocampus creates memories involving emotions, the amygdala, which is located in the temporal lobe, processes and regulates these emotions when stimulated (Šimić et al., 2021). Interpreting music beyond the notes can positively impact one's memory since associating music with certain emotions that induce dopamine signaling. Since dopamine is the neurotransmitter associated with

pleasure, motivation, and reward, it could reinforce these memories (Ferreri & Rodriguez-Fornells, 2017). This idea has been tested with a study done which evaluated the relationship between arousal levels and episodic recollection. Thirty university students listened to 24 excerpts and ranked them based on how pleased they felt during each excerpt . A day later, the participants listened to the 24 old excerpts as well as 24 new ones and were asked how much they knew about the excerpt. Results showed that the excerpts that were ranked higher, indicating more satisfying experiences, were generally remembered clearer (Ferreri & Rodriguez-Fornells, 2017). Memory retrieval is a major component of cognitive functionality. Thus, the positive connection between the emotional experiences from songs and the ability to recall them may support the integrity of brain structures and functions that are involved in these mental processes, which are the hippocampus and amygdala.

Music and Neuroplasticity

Neuroplasticity is defined as the ability of the brain to change its structure, function, and connections (Puderbaugh & Emmady, 2025). This is a key factor regarding how the brain develops throughout life. Multiple studies have concluded that playing music is associated with increased volume of white and gray matter in the brain and the strengthening of neural connections (Butcher, 2002; Olszewska et al., 2021; T. Zaatar et al., 2023). There are several processes of neuroplasticity including synaptic and myelin plasticity.

Synaptic Plasticity

One of these processes, synaptic plasticity, involves the enhancement in strength and efficacy of synapses, the small space in between neurons through which neurotransmitters are carried. New information builds stronger connections between neurons and enhances cognitive functions (Johnston et al., 2009). Practicing an instrument is one way of positively influencing synaptic plasticity. Repetition of specific motor movements, like the placement of fingers on the fingerboard of a violin, strengthens the connections between the neurons involved.

Myelin Plasticity

Myelin plasticity is another process of neuroplasticity. It determines the speed at which signals are transmitted between neurons in the brain. Myelination is the process involving the wrapping of membranes, called myelin, on the part of the neuron that transmits electrical signals to other neurons known as axons. Since myelin significantly improves the speed at which neurons conduct electrical signals, myelin plasticity is a major part of neuroplasticity. It is also important to know that the properties of myelin, such as thickness and length, continuously change throughout all stages of life (Almeida & Lyons, 2017; Bonetto et al., 2021). Brain tissue that contains myelin-covered axons is known as white matter. White matter is crucial for brain development by connecting various brain regions for information processing and the facilitation of learning. In addition, activity-based myelination is correlated with the regulation of white matter and neuronal circuits, which means that greater myelin plasticity results in more efficient organization of information and the enhancement of learning through experiences (Almeida & Lyons, 2017). The impact of practicing an instrument on structural white matter plasticity was demonstrated by an increase in white matter integrity over several regions of the brain in trained musicians when compared to non-musicians (Alves-Pinto, 2016). Since white matter integrity is connected to myelin plasticity, this evidence reveals that, when practicing an instrument, the repetitive actions involved enhance myelination of the neurons that connect brain regions responsible for motor movement.

Music-Evoked Structural Changes in the Brain

Learning a musical instrument is a unique and intricate experience, and neuroplasticity enables this process to occur. In fact, musical training can lead to quicker adaptation and stronger neural connections in the associated areas (Olszewska et al., 2021). These music-evoked structural changes have been found through cross-sectional neuroimaging studies that measured the volume of gray matter, or brain matter with higher concentrations of unmyelinated neurons, in professional musicians versus

non-musicians. The studies have found that professional musicians tend to have higher gray matter volume in brain structures such as the primary auditory cortex, the frontal lobes (specifically areas responsible for executive tasks including maintenance, monitoring, and musical information retrieval), and the hippocampus when compared to non-musicians (Olszewska et al., 2021; T. Zaatar et al., 2023). In addition, Butcher conducted research to investigate the relationship between musicality and grey matter volume in Heschl's gyrus, a region of the auditory cortex, in professional musicians as compared to non-musicians (2002). Musicality was measured through the degree of neural activity in Heschl's gyrus, and the experiment involved participants listening to several musical sounds. The results showed that twice as much neural activity was present in the Heschl's gyrus of musicians compared to the non-musicians. Additionally, there was a 130% increase in grey matter in the Heschl's gyrus of the professional musicians. The increased gray matter in Heschl's gyrus of the musicians signified that there were more neural adaptations (Butcher, 2002). In summary, multiple studies comparing musicians vs. non-musicians show that musical experience leads to increased grey matter volume in several regions of the brain.

Furthermore, neuroimaging studies have found that greater white matter organization and structure, as shown by high fractional anisotropy, was present in tracts like the corpus callosum, the collection of nerve fibers connecting the brain's hemispheres. (T. Zaatar et al., 2023). As mentioned in the previous section, white matter increases the brain's efficiency to transport information between different regions. This is especially relevant for the corpus callosum since information would be able to be transferred between both hemispheres more efficiently, allowing them to coordinate with each other. Communication between hemispheres is essential for complex tasks like playing an instrument, as it involves both understanding music notation and being expressive since the left hemisphere is associated with analytical thinking while the right hemisphere is associated with emotional processing and creativity (Corballis, 2014).

Heightened Neuroplasticity During Childhood

Being immersed in music during childhood positively affects neurodevelopment. For example, by around 12 months of age, Western infants become familiarized with the musical structure of Western music (Trainor et al., 2012). Musical experiences during childhood have a greater impact on how the brain develops than during adulthood due to heightened neuroplasticity. The higher levels of plasticity during childhood allow for important structural changes in the brain (Olszewska et al., 2021). This could explain why in general, professional musicians start learning an instrument during childhood.

Effects of Music on Academic Performance

Learning an instrument has advantages outside of alterations in brain structure. Practicing an instrument teaches students important life skills such as time management, motivation, and perseverance. These skills are important in an academic setting since students are expected to complete work on time, are encouraged to take rigorous classes, and are encouraged to set goals for themselves. One meta-analysis of studies indicated that there was a 57.3% probability that a person who participated in musical training demonstrated higher cognitive abilities and academic achievement than a person who did not (Román-Caballero et al., 2022). In another study, the composite academic achievement score of six subjects were collected from music and non-music students in 7th grade and 9th grade. The results showed that students with musical experience performed higher academically and received higher marks (dos Santos-Luiz et al., 2016**).** Taken together, music education has proven to reinforce crucial behaviors including time management and perseverance and foster motivation in academics during the formative years.

Time Management

Practicing an instrument teaches students the importance of effective time management since they need to balance their schoolwork and practice time. The relationship between playing music and time management were analyzed from the survey results of 2,323 parents regarding improved behavior of their

child, ages 7 to 17, after participating in music lessons for more than a year. 60% of the parents observed that their child more frequently self-monitored and limited their screen time. Furthermore, 68% of the parents reported that their child completed more tasks on time and kept track of what they needed to accomplish (Box, 2019). Together, this indicates that involving children in music lessons may help them develop better time management skills.

The benefits of managing time in order to fit daily practice result in improvement in students' academic success. Students not only complete their schoolwork on time, but also learn the importance of responsibility. For example, middle schoolers' time management abilities were assessed in a longitudinal study that analyzed their effects on homework completion and academic achievement over two time points (T1 and T2) spanning eight months. It was observed that good time management at the start of the study was related to higher academic achievement at the end. Another noteworthy finding showed that good time management at the first time point prompted teachers to promote self-regulated learning for students (Xu, 2025). The independent approach to learning encouraged students in the study to think critically, which allowed them to more easily understand new information.

Motivation

The willingness to develop skill in playing an instrument and practice on a daily basis depends on motivation. When there is a lack of motivation, students usually stop practicing since they do not find the importance in doing so. There are a variety of motives for someone to continue learning an instrument, which include enjoyment of the activity, improvement, or self-pressure (dos Santos-Luiz et al., 2016). Moreover, parents and teachers play a crucial role in a student's determination by setting the learning environment and influencing their feelings. Strict mentors could cause students to practice out of the fear of being punished, which results in a negative viewpoint and extrinsic motivation, or external causes for practicing like the fear of being punished. On the other hand, mentors that give students freedom encourage them to practice from intrinsic motivation, or internal reasons to practice (Miendlarzewska &

Trost, 2014). In a survey that evaluated participants' reasons for persisting to play an instrument, they stated that support from parents and teachers was a major motivator. Around 80% of students that took the survey said that their parents attend their performances and, according to 96% of students, teachers would assist them when they needed help improving at their instrument. (Földi et al., 2024).

Music training teaches students that having goals, whether internal or external, are effective in starting and continuing to play an instrument. In music class, students are internally motivated to learn an instrument and develop confidence in their ability to complete difficult tasks, or high self-efficacy, subsequently increasing their academic motivation (Jing, 2023). These skills that are developed through music translate to academic success as well. Students with higher confidence and desire to succeed are more likely to perform well in school since they have goals that they strive for. They dedicate more time to studying, and as a result, the likelihood of excelled academic performance increases.

Perseverance

Learning how to play an instrument comes with many challenges. It takes many hours of practice in order to overcome those challenges. These hurdles are a testament to one's ability to persist in practice even when progress seems slow. Rebecca MacLeod, the professor of music education at the University of North Carolina, provides an example that demonstrates how learning an instrument teaches kids perseverance. Fourteen students in the fourth grade who were interested were enrolled in an orchestra program that had 40 minute rehearsals twice each week for a total of sixty times. During the rehearsals, students were challenged to play their instrument by themselves for two minutes, and were rewarded for not giving up rather than accomplishing a goal. At the end of the year, the students were asked to reflect on lessons they learned while in the program. The students wrote about how orchestra improved their confidence in their own ability, made them feel special, and taught them to keep trying (MacLeod, 2014). This insight from MacLeod demonstrates the impact of continuously working hard in face of challenges as seen by the experiences gained from learning how to play an instrument.

The skill of perseverance learned through playing an instrument can be applied to academics. Students' behavior towards challenges faced in school play a major role in determining their academic success. Maintaining the same amount of academic engagement no matter their current performance and preventing emotions from affecting focus are examples of perseverance that show the strive to achieve more (Datu, 2021).

Music as Medicine

Music education has been shown as beneficial in building stronger connections in multiple regions of the brain. Musical experience has also been linked to improved academic performance for students. In addition to academic benefits, new research suggests that music has the potential ability to improve mental well-being and as treatment for a wide range of neurological disorders including Parkinson's disease, Alzheimer's disease, and Autism Spectrum disorder. Music therapy uses elements of music, like melodies and rhythm, to strengthen motor and emotional functions in patients.

Music Listening

One means of engaging in music therapy is through music listening. The regions of the brain involved in playing an instrument differ from those involved in listening to music. For example, there are no physical movements such as the intricate placement of fingers on a fingerboard or the controlling of air required to listen to music. However, there are still physical benefits of listening to music. Entrainment is the phenomenon defined as a state where biological functions, like heartbeats and breathing, synchronize with the rhythms of a song (Toader et al., 2023). People may also synchronize their body movements to the tempo of the music. These precisely coordinated movements are tied to areas of the brain that control motor functions, such as the cerebellum, and the stimulation of these regions forms new connections between neurons. Regulating motor timing is an essential mechanism of musical therapy that can rehabilitate lost or damaged neurological functions. In a research study of patients with Parkinson's

disease who had difficulty striding equally with each step, they were given instruction to walk for 30 minutes a day with music. The rhythmic stimulation improved both stride symmetry and stride length symmetry (Galińska, 2015). In summary, music rhythms provide biological cues that can aid in strengthening and coordinating motor movements. Future applications of therapeutic methods involving rhythmic stimulation may hold the potential to benefit other motor skills, for instance, coordination and balance.

In addition to the physical responses, listening to music associated with one's memories activates areas of the brain that process emotions. The ability to select personal music has been shown to positively affect functions such as attention, memory, and behavior regulation (Galińska, 2015). Several studies revealed that patients diagnosed with dementia showed decreased severity of depression symptoms as a result of simple instrument playing, like percussion, and song listening (Raglio et al., 2015). The benefits of music listening, including physical rehabilitation and its ability to enhance memories and mood, show the positive impact of music therapy.

Interactive Music Therapy

In addition to music listening, music therapy can be interactive between the music therapist and client through active music making. These activities, such as singing, improvising, or playing an instrument, allow patients to express their emotions and improve social skills. Every instrument requires unique movements in order to produce sound. The numerous motor skills involved, such as finger dexterity and strength, can be a useful tool for patients with certain neurological disorders. For example, learning how to improve intonation on string instruments trains the fingers about precise placement. Consistent musical training could be used to treat individuals who have difficulty performing specific movements. In addition, wind instruments teach breath control and increase lung capacity, which can be beneficial for patients dealing with respiratory problems. In musical improvisation, where the music therapist and client create music on the spot and build off each other's ideas, creativity is developed and

social interactional skills are trained. A collection of five studies were compared to demonstrate the benefits of music intervention for clients with neurological disorders affecting motor control such as multiple sclerosis and motor neuron diseases (Horne-Thompson & Bolger, 2010; Pacchetti et al., 2000; Schmid & Aldridge, 2004; Tamplin et al., 2013; Thaut et al., 2009). The majority of the studies reported an increase in mood and improvements in depression, with only two of the five studies indicating no significant differences in depression and anxiety (Raglio et al., 2015).

In one long-term study, several young adults with severe autism spectrum disorder engaged in musical therapy sessions to examine the impact on their social and behavioral skills (Boso et al., 2007). During each one-hour weekly session, they engaged in live musical activities with instruments including a piano, electrical keyboards, and drums in addition to singing. Clinical and musical ratings were recorded before the therapy started, 26 weeks into the study, and 52 weeks into the study. Clinical Global Impressions-Severity (CGI-S) was used to measure the patients' symptoms prior to the sessions, and the Clinical Global Impressions-Improvement (CGI-I) was used after the 26th and 52nd week. Also, the Brief Psychiatric Rating Scale (BPRS) score was used to identify symptoms and their severity. The results concluded that the patients exhibited less severe symptoms of autism spectrum disorder including abnormal behavior, hyperactivity, and asociality. The participants also demonstrated improvement in their social skills. Furthermore, musical skills such as singing short or long melodies and the ability to play the C-scale on the keyboard were improved (Boso et al., 2007). Interestingly, most musical improvement happened over the 26 weeks, whereas only a small amount of progress was observed from the 26 week mark to the 52 week mark. This may suggest that the clients absorbed a lot from the interactions quickly.

Overall, music therapy is an important tool in the medical field that helps a wide range of people through emotional regulation and physical rehabilitation. More experimentation with a broad range of disorders is the necessary next step in understanding the potential of music therapy in the field of medicine.

Conclusion

There is ample evidence showing the effects of music education on enhancing learning environments and improving academic performance. Furthermore, music has shown to be beneficial in treating neurodegenerative diseases such as Alzheimer's and Parkinson’s. Further research is necessary to develop a better understanding of the impact of music education on academic performance and the effectiveness of music rehabilitation through additional longitudinal studies with larger cohorts.

In the future, music therapy could be implemented more frequently in educational facilities to promote relaxation in students and help them persevere through stressful days. There may be benefits seen in their academic performance, indicating music education is just as valued as other forms of academic education. As a final takeaway, the next time you listen to a song or play an instrument, take a moment to appreciate that the brain is growing stronger and more resilient in the process.

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