Narrative Review Article

Music and the Brain: Therapeutic Applications for Neurodivergent Individuals

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ABSTRACT

This paper explores music's complex and comprehensive impact on the brain and the practical applications of music therapy for treating conditions that arise from differences in brain structure and function. Brain imaging shows how music activates nearly every area of the brain and helps promote brain development through several complex processes. Board Certified Music Therapists use evidence-based music interventions to meet their patients' varied and wide-ranging therapeutic goals. In particular, music therapy is uniquely positioned to address the concurrent needs of neurodivergent individuals, including challenges with language processing and speech, emotional regulation, social cognition, and fine and gross motor skills. These interventions often disguise the hard work of therapy with non-confrontational, dopamine-inducing engagements, nurturing a safe space for growth, healing, and essential skill development. The purpose of this paper is to raise awareness of the unique relationship between music and the brain. Furthermore, it discusses the potential for music therapy to bring about profound and life-changing impacts for neurodivergent individuals, as well as suggests future research needs to bridge gaps in interest and innovation within the field.

Keywords: Music therapy; neurologic music therapy; neurodivergence; autism spectrum disorder (ASD); neuroplasticity; bilateral connectivity; social and cognitive development; language and communication skills

INTRODUCTION

"Thank you for your guidance; As only music can touch; Thank you for reaching our William, Because it means so much (1)". These are the last four lines of a poem written by a grateful mother, Tamera Norris, after a decade of music therapy provided her non-verbal, autistic son, William, a chance at an independent life. Like many autistic individuals, William's communication challenges led to feelings of social isolation and emotional frustration (1). From ages four to sixteen, William attended weekly sessions at The Music Settlement, a music school in Cleveland, Ohio. There, his therapy team used both live and recorded music to manage William's unpredictable emotions while teaching him how to play instruments, aiding in his development of important life skills (1).

Through individual and group sessions, William learned how to follow musical and social rhythms, such as taking turns and following directions (1). The school became a safe space, allowing William to express himself in ways he had never been able to previously. Music gave William an escape from a life of "involuntary silence,"

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giving him the tools to engage with others, ask questions, and communicate verbally (1).

While William's experience may initially appear to be merely anecdotal, the result of a mother's wishful thinking, his story is far from the first. Techniques of musical healing appear among the oldest forms of medicine, recorded in the most ancient civilizations on Earth; India, China, Arabia, and Greece all have archeological evidence of sound healing the soul (2). The ancient Greeks believed that music could heal both physical and neurological ailments. In Athens, physicians would prescribe "different tonalities" and "specific scales" to treat patients suffering from everything from "colds, aches, depression, or injuries" (3). National best-selling author, neuroscientist, and lifelong musician, Daniel J. Levitin, describes some of these methods in his seminal book *I Heard There was a Secret Chord: Music as Medicine*: Dorian mode was considered suitable for mourning; Phryian mode was used to control digestive problems; Lydian imparted good cheer, optimism, friendliness, and tendency to laughter, love, and song when it was well-executed, but could lead to weeping and sadness when not (3). The Greek god Apollo was the god of both music and medicine (4). Apollo's and the Athenians' techniques are found in other cultures as well, including Ancient Israel. David's treatment of King Saul's depression and agitation at the end of his life, as depicted in 1 Samuel of the New International Version, during the 11th century BCE, was based in music: "David would take the lyre and play it; Saul would find relief and feel better, and the evil spirit would leave him" (5).

This connection between the neurological condition and music is a concept that predates both the Greeks and the Israelites, to the very beginning of human life. Neurological researchers Michael Trimble and Dale Hesdorffer suggest that music is actually a part of human evolutionary anatomy, ingrained into man's psyche (6). The first instrument, the voice, is theorized to have predated sophisticated human language, due to early humans having primitive linguistic abilities but advanced emotional expression, leading to the formation of song as a prehistoric way of communicating emotion. The human ears are constantly open and alert, naturally attuned to more sounds than are necessary purely for speech, like music. But humans differ from other animals, even those that are highly evolved such as gorillas and chimpanzees, in the sheer size of their auditory cortexes (6). This evolution suggests that the human brain is 'hardwired' for enjoyment of aesthetically pleasing sounds and emotional connection with others, rather than solely for survival. From these evolutionary origins of music creation and enjoyment, the ability to soothe the soul with music was subsequently connected with healing.

Not only does music foster emotional connection via the evolution of the auditory cortex, it also has a greater widespread neurological impact. When looking at functional MRIs–a type of MRI that tracks the brain's activity based on blood flow–music has been found to increase blood flow to almost every area of the brain, enhancing everything from fine motor skills to imagination to pro-social feelings (7, 8). Today, scientists know that there are no specific tonalities or certain rhythms that heal the brain and body. Music as a whole, however, can induce relaxation, sometimes to the point of reaching "flow state," motivate people through hardship, improve the body's physiological and autonomic functions, and govern human thoughts, emotions, and behavior (3). These varied and impressive functions of the brain are based in the unique and intricate structures and processes of the brain, and the ways that music affects these structures and processes are complex.

ANATOMY OF THE BRAIN

Emerson Pugh, American physicist and professor, once said, "If the human brain was so simple to understand that we could understand it, we would be so simple that we couldn't" (9). The brain is the most complex organ of the body. It is a deeply complicated system composed of billions of neurons–nerve cells–that carry out quadrillions of synapses–connections between these neurons that send ions from neuron to neuron to ensure rapid signaling–throughout a person's lifetime (9). There are hundreds of different types of neurons and synapses that work seamlessly and simultaneously to think, feel, move, and respond to the environment (9).

Despite this interconnectedness, many areas of the brain work separately to accomplish specific, regional goals, compartmentalizing to improve efficiency and accuracy. Neurologists, doctors who study and treat the nervous system, began separating the brain into lobes as early as the 17th century, having observed that certain areas of the brain were responsible for certain behaviors and activities (10). The story of Phineas Gage is infamous in the neuroscience field as an example of this separation. Gage was involved in a serious accident on a railroad construction site in 1848, where an iron rod entered the top of his head and exited out of his jaw, in the process destroying almost his entire prefrontal cortex (11). Shockingly, Gage made a full recovery and went on to live 13 more years, except his personality was completely changed. It was this incident that suggested to neuroscientists that certain areas of the brain–the prefrontal cortex in this instance–have specific functions. In the years since, neuroscientists have dedicated their entire lives to dividing up the brain, and greater nervous system, into lobes.

The front of the brain, the cerebrum, is typically divided into two parts, the cortex and the inner layer (12). The cortex consists of gray matter that processes and interprets the information the brain takes in. The inner layer consists of white matter that communicates the information throughout the brain. The cortex is made up of four key lobes, each with their own specific functions: the frontal lobe, the parietal lobe, the temporal lobe, and the occipital lobe. The primary functions of these brain regions and their potential relevance to music-based interventions are summarized in Table 1. The largest lobe is the frontal lobe. It contains the prefrontal cortex and is involved in memory, personality, speech and language, and emotional regulation. It also contains the motor cortex, the area of the brain responsible for fine and gross motor skills (12). In contrast, the parietal lobe controls the sensorimotor experience, interpreting sensory information and coordinating it with movement, while also managing spatial abilities that allow the brain to perceive and navigate the physical world around it (12). Similarly, the temporal lobe is located beneath the frontal and parietal lobes. It contains the primary auditory cortex, which is responsible for the processing and interpretation of sound during both passive and active listening (12). However, research suggests that this region is not exclusively auditory. Studies have shown that, in individuals who are deaf, areas typically associated with auditory processing may be reorganized to support sign-language processing, demonstrating that this region is involved in both communication and auditory processing (3). Finally, the occipital lobe, located at the back of the brain, is primarily responsible for visual processing and the interpretation of visual information (12).

Table 1. *Summary of neurologic structures, neurological processes, and proposed effects of music-based interventions. The table summarizes the major brain structures and neurological processes discussed in this review, their primary functions, reported associations with music and music-based interventions, and the potential cognitive, social, communicative, motor, and developmental outcomes described in the literature. Proposed mechanisms and outcomes are based on findings reported in the cited studies and should not necessarily be interpreted as established causal relationships.*

Neurologic Structure	**Function**	**Music Impact**	**Skill Development**
Frontal Lobe	Memory recall, personality, speech and language, and emotional processing	Invokes nostalgia, emotional response, and is a dual-system interaction	Builds emotional regulation skills, strengthens memory recall (for short-term memory), and encourages speech development
Parietal Lobe	Motor-sensory processing, movement, and spatial awareness	Awareness of location of instrument and self, moves as required	Improves attention and focus, spatial-awareness, and multi-sensory processing
Temporal Lobe	Translation and interpretation of sound, and memory recall	Invokes nostalgia and an emotional response	Improves memory recall (for long-term memory) and speech development
Occipital Lobe	Visual interpretation	Dual awareness of music notation and physical action	Develops pattern recognition and spatial understanding
Neurologic Process	**Function**	**Music Impact**	**Skill Development**
Neuroplasticity	Learning and adaptation from repeated experiences, stimuli, and environment	Full brain activation by processing of music content and subsequent interpretation, gray matter growth	Develops essential motor, social, emotional, and cognitive skills

Continued Table 1. *Summary of neurologic structures, neurological processes, and proposed effects of music-based interventions. The table summarizes the major brain structures and neurological processes discussed in this review, their primary functions, reported associations with music and music-based interventions, and the potential cognitive, social, communicative, motor, and developmental outcomes described in the literature. Proposed mechanisms and outcomes are based on findings reported in the cited studies and should not necessarily be interpreted as established causal relationships.*

Neurologic Process	Function	Music Impact	Skill Development
Bilateral Connectivity	Communication between the left and right hemispheres	Processing and interpretation of music's structural elements in tandem with interpretation of abstract, emotional elements	Develops fine and gross motor skills
Mesolimbic Reward Pathway	Dopamine management to control motivation and feelings of pleasure and reward	Induces pleasure, increases motivation and desire for reward	Reinforces skill development, associates learned skills with pleasure and reward

HOW MUSIC INTERACTS WITH THE BRAIN

Despite the incredibly varied goals of the different parts of the brain, music affects nearly all of them. In fact, music is one of few stimuli that can activate widespread neural networks throughout the brain simultaneously (13). The exact sequence by which music is processed in the brain is not fully understood, complicated by how many systems music can engage. Music enters the brain through the cochlea in the inner ear and then is processed by the auditory cortex. Different aspects of the music are interpreted in the temporal lobe. Foundational elements of music like pitch, harmony, and beat are typically processed in the right hemisphere of the temporal lobe, while more abstract parts like lyrics, tempo, and pacing are processed in the left hemisphere of the temporal lobe. Where brain activity goes next depends largely on the feelings the listener has toward the music and/or their past experiences with it. For example, while speech cannot be "off-pitch," music absolutely can, often leading to feelings of unease or discomfort in the listener when disharmony is present. These feelings are processed in the temporal lobe as the brain tries to decode the music within the primary auditory cortex. But when music generates feelings of pleasure in a person, music can be observed activating the limbic system in the frontal lobe instead (13). If music evokes nostalgia or calls back vivid memories, it can also activate the visual cortex, amygdala, and hippocampus, located in the temporal lobe (14). These areas of the brain are associated with short- and long-term memory and the emotions associated with these memories (13).

Memories impact the brain heavily in the short term, allowing for humans' remarkable ability to learn new skills quickly and absorb new information. But long-term memory is even more valuable to the brain due to a process known as "neuroplasticity" (15).

Neuroplasticity is the brain's ability to form new neural pathways, strengthen or weaken existing pathways, and/or reorganize its functions through reordering or remapping these pathways (15). These neural pathways are the way the brain "grows." Neuroplasticity is a lifelong process, causing the brain to learn by taking in stimuli, repeated experiences, and environmental interactions and restructuring the brain accordingly (15). The majority of functional brain development happens in early childhood, slowing down in the teen years and concluding by age 30, but persists throughout adult life in a more regulated manner, allowing the brain to continue to develop despite age (15).

Playing a musical instrument is a neuroplasticity-inducing experience, research suggests. One study conducted in 2000 at the Wellcome Center of Human Neuroimaging's Department of Cognitive Neurology compared the gray matter volume of musicians and non-musicians (16). Results found that musicians had increased amounts of gray matter, which corroborated some studies' observations of an average higher intelligence and cognitive functioning skills, possibly fostering some select skill development (16, 17). This formation of new gray matter correlates with observed changes in brain structure that form through widespread brain activation from music production (17). Although this evidence does suggest that music can help induce neuroplasticity, it is difficult to tell the degree of brain development that is directly caused by music practice and playing. However, these findings still suggest that music can induce neuroplasticity, making it a potential way of training the brain new skills as well as possibly reteaching it skills after enduring a traumatic brain injury.

Music also fosters connectivity between the left and right hemispheres of the brain. Separated by the longitudinal fissure, the two hemispheres, much like the lobes of the brain, carry out different functions (18). Contrary to popular pseudoscience perpetuated in the 1970s and '80s, however, claims that musicians and artists are "right-brained" are scientifically unfounded (19). Musicians do not have a more dominant right hemisphere, just as people who are more "quantitative and analytical" do not have a more dominant left hemisphere (19). Like the rest of the brain, the left and right hemispheres also rely on one another to carry out cognitive and autonomic functions, making a certain amount of connection critical to survival (18).

A study conducted by the Institute of Psychology at the University of Zurich found that structural changes suggesting increased connectivity between the left planum temporale and the right planum temporale, regions of the temporal lobe that are "involved in auditory comprehension and possibly phonological processing," are more commonly observed in musicians than in non-musicians (20). While this study may suggest that stronger connectivity between these regions, known as bilateral connectivity, is due to musicianship, and therefore links it to speech processing and long-term structural changes in the brain, the exact relationship between this neurologic process and subsequent neurologic development continues to be researched.

MUSIC THERAPY: BRAIN ENGAGEMENT

While still an active field of research, music's potential ability to induce neuroplasticity, bilateral connectivity, and widespread synapse activity simultaneously across large areas within the brain is a vital part of the music therapy movement, with therapists attempting to induce brain development and encourage subsequent skill development. Kristen Scaplen, an assistant professor of Neuroscience at Bryant University, explains the significance of the brain's activation by music: "Very few experiences activate the entire brain at once. Because music uniquely engages the entire brain, it has become a powerful tool to support rehabilitation, memory, mood, reduce anxiety, and even help reduce pain" (21).

Music therapy, as defined by the American Music Therapy Association, is a "clinical and evidence-based use of music interventions to accomplish individualized goals within a therapeutic relationship." To become a Board Certified Music Therapist, one has to complete at least a Bachelor's Degree in Music Therapy, work 1200 clinical hours, and earn certification from Certification Board of Music Therapists, resulting in a professional highly trained in music, medicine, and psychology (22, 23). Many music therapists also pursue higher education in the cognitive sciences, clinical psychology, and neurobiology (24). Because music therapists often work with easily portable instruments like the voice and guitars, they can work almost anywhere–and they do, practicing in hospitals, clinics, schools, retirement homes, in-patient therapy wards, and more (23). This makes music therapy a "cradle-to-grave" therapy, because it can encourage development in the NICU, manage pain in hospice care, and benefit the countless steps in between (23). The variety of applications of music therapy, treating everything from communicative to social to sensorimotor needs, lends itself to effective intervention for individuals dealing with a variety of needs, including neurodivergent individuals.

MUSIC THERAPY: APPLICATIONS FOR THE NEURODIVERGENT BRAIN

Neurodivergent people can suffer from an array of conditions, each with varying degrees of severity of those conditions. Neurodiversity, per Northwestern Medicine in Chicago, is defined as a range of "cognitive differences between how people think, learn, and behave" (25). These differences can present in numerous ways, from learning disabilities to social deficits, in a variety of conditions, including attention deficit hyperactivity disorder (ADHD/ADD), autism spectrum disorder (ASD), dyslexia, dyscalculia, and more (25).

Neurodiverse conditions often arise due to structural or functional changes in the brain that alter behavior and/or cognition. For example, a study at Trinity College in Dublin observed structural differences between the amygdalas of children with ADHD and ASD and neurotypical children–who process information in a more "standard or typical" manner (26). The amygdala, located within the temporal lobe, is responsible for emotional processing and social interpretation, making it a crucial part of social cognition (14). In children with ADHD and ASD, researchers found a "lower volume" in this region of the brain, correlating with deficits in emotional regulation and typical social behavior often observed in these individuals (26). These deficits can lead to struggles with emotional understanding, higher amounts of stress, and social isolation as barriers form between neurotypical and neurodivergent individuals. This makes the development of effective coping skills all the more vital to neurodivergent people, allowing them to traverse a society that their brain is not hard-wired to fit into, potentially improving quality of life.

Because neurodivergent conditions can affect neurodivergent individuals so deeply and in such a variety of ways, meaningful therapy must be adaptable. A key part of the music therapy process is careful music and activity selection (23). Music therapists choose pieces of music based on patient preference, familiarity, and sensory tolerance, making sessions feel accessible rather than overstimulating. Because music is chordally and stylistically predictable, it can produce results without inducing overstimulation, a common struggle for the neurodivergent (24). Like psychotherapists and occupational therapists, music therapists track progress clinically and make adjustments accordingly. Music therapists are able not just to adapt to their patient and their specific conditions–whether that be motor difficulties, speech delays, communication barriers, emotional regulation, stress, or even physical pain–but also to their patient's environment (27). This allows therapists to make their patients comfortable, decreasing the stress level of an already stressful environment. Lower stress levels not only make patients more comfortable working with their therapist, but also make their brains more receptive to the therapy, improving the music therapist's ability to reach their patients.

Additionally, music therapy can help develop a wide range of essential skills. A common indicator that a person may be on the autistic spectrum is deficits in speech and language functioning skills, often from a young age (28). These issues can appear as deficits in language articulation and speech syntax processing, putting up barriers that inhibit self-expression and typical communication (28). The origins of these deficits are not fully understood, but a common theory of causation is atypical functionality in Broca's area of the brain (28). This area of the frontal lobe interprets language, making impairments often appear as an inability to understand language or respond verbally (28). Some evidence proposes that music-based therapeutic interventions engage areas of the brain involved with both syntax processing (understanding speech) and tonal harmonic syntax processing (responding to widely accepted chord progressions), possibly including Broca's area (29). In creating a "dual-system" interaction, this research suggests that this brain engagement may contribute to stronger speech skills, although the exact mechanism of this development continues to be studied (29).

For autistic individuals, the isolation associated with neurologically originating communication barriers is often devastating, making the efforts to enhance speech and language all the more vital.

Speech and language barriers also impact the development of social and emotional skills in neurodivergent individuals. Understanding and correctly interpreting emotion is a difficult concept to grasp for many individuals with differing neurological functions (30). People with ASD, for example, often struggle with emotional processing and regulation due to atypical functioning of their limbic system, contained deep within the temporal lobe (28). This dysregulation affects their ability to interpret not only their own emotions but the emotions of the people around them, leading to a failure to provide socially acceptable responses (30).

But music can help them get there. In a study by music therapist June Katagiri at Florida State University, children with ASD were tested on their ability to interpret and understand four key emotions: happiness, fear, sadness, and anger. In a control group of autistic individuals, emotions were verbally explained. In an experimental group, background music was played. Results found understanding of emotions increased significantly in the experimental group compared to the control group, demonstrating how music can develop emotional awareness and can sometimes be more effective at developing this skill than spoken word, although these results continue to be researched (31).

Greater emotional understanding aids in the development of social cognition. Types of music therapy that teach unspoken social rules are group music therapy and improvisation, among others; these methods teach patients not just how to make music, but how to interact with other people (32). These deficits in social understanding often manifest as difficulty picking up on social cues or interpreting the tone of voice of others and regulating one's own tone and volume in response (32). Oftentimes, group music making can be combined with improvisation, a skill that helps hone independent movement and confidence while also decreasing impulsivity and increasing awareness of the feelings of others because actions affect not only the individual but the group as well (17). This method, like the "dual-system" interaction with Broca's area, can also develop multiple skills at once, making it an effective and potentially less overwhelming way to develop coping mechanisms that impact patients in the real world, often in non-musical ways.

Finally, music therapy can also be used to address motor difficulties, increasing the brain's control over the motor cortex (33). Defined by the *Handbook of Neurologic Music Therapy*, therapeutic instrumental music performance (TIMP) is a common neurologic music therapy technique that teaches patients how to play musical instruments as a non-invasive way to "exercise and stimulate functional movement patterns," acting as yet another "dual-system model" (34, 30). Affected movement patterns include range of motion, endurance, strength, functional hand movements, and limb coordination, musical training engaging both fine and gross motor skills. Several studies suggest that neurologic music therapies like TIMP may enhance enjoyment of music in autistic children, as well as help them hone strength and coordination skills, allowing them to more accurately move their limbs and body, both in response to music and continuing in the absence of it, although results vary study to study (35). Despite this, strengthening these skills further promotes independence, physical confidence, and long-term functional resilience.

However, despite its efficacy in bridging communication barriers, encouraging social and emotional growth, facilitating greater motor control, and more, music therapy is often not the first therapy that families turn to for treating neurodivergent disorders like ASD and ADHD, more often relying on speech and language therapy or physical therapy to help cope with speech delays and motor control difficulties (36). Music therapy is an underrepresented field in many clinical spaces, with approximately 9,000 authorized MT-BCs in the United States, and struggles with many of the same problems as other therapy fields, most notably accessibility, diversity, and career interest (37, 24). But for people like William, it is the form of therapy that made all the difference. Evidence suggests that many music-based interventions may support the development of social, emotional, and communication skills, coping mechanisms, as well as tune motor skills, potentially through functional and structural changes in the brain. However, the direct cause of the brain and/or skill development, as well as the actual magnitude of these effects is still being researched. Still, Waverly Noble, a practicing music therapist, considers music therapy to be an "easy therapy" as well as an effective one (27).

Music is also an inherently rewarding activity, both in the short and long term. Perhaps one secret to music therapy's success is that it is actually fun. Music engages the mesolimbic dopamine pathway, located within the limbic system, blending pleasurable emotions with memory (38). Within this process, dopamine–the primary neurotransmitter controlled by the prefrontal cortex–binds to receptor neurons, leading to neural changes that cause "feelings of pleasure and reward" (39). This dopamine release is generally believed to act in feedback loops that cause positive emotions to form new neural pathways, potentially leading to the development of crucial "reinforcement learning and behavior regulation" (38). It is these pleasure-reinforcing cycles that are likely motivating the brain to repeat activities in a more informed way, often with the goal of inducing the same pleasurable stimulus that was previously experienced.

Music therapy capitalizes on the dopamine reward cycle to teach the brain coping skills, new communication styles, and motor functions through music without inducing exhaustion, stress, or unpredictable variables–in fact, these conditions are actually often decreased by music (32). Just like the brain releasing dopamine in response to the aesthetically pleasing musical stimulus, it has also been observed releasing serotonin, a "feel-good" neurotransmitter that causes the body to relax (32). Because of music's ability to engage the brain in multiple areas at once, simultaneously relaxing the body and inducing a sense of safety, music therapy is a highly effective way to connect with a variety of patients, making therapy feel less like a chore and more pleasurable and relaxing.

CONCLUSION

William Norris, like many other autistic individuals, struggled his entire life with the communication barrier and emotional dysregulation common to people with ASD. Music transformed William's trajectory, the development of crucial life-skills and coping mechanisms for his communication barriers leading to not only the formation of tangible emotional connections and social resilience, but also fostering a confidence in himself that William's mother claims he could not have found any other way (1). Quoting philosopher Ralph Waldo Emerson, his mother claimed it allowed him to "go where there is no path and leave his trail." With his newfound confidence, William auditioned for a drum group at his school. He earned a regular position on the team, performing in front of a crowd with the noisy, unpredictable atmosphere rolling off of him (1). William's ability to take his skills beyond the therapy space changed his life. Because Tamera Norris believed in music's ability to reach her son where other interventions had failed, William and his therapy team were able to end his involuntary silence and progress his coping by leaps and bounds, changing his life forever.

However, despite William's success, a lack of accessibility in this field and to this field continues to restrict career growth and patient accessibility. Continued research into which therapies work best in conjunction with music therapy, what makes a patient well-suited for music therapy, and what barriers restrict music therapy's impact, growth, and accessibility to patients would improve these deficits in the field. Increased access to music therapy would innovate music therapy techniques and spaces, opening doors for neurodivergent individuals, potentially changing lives.

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CONFLICT OF INTEREST

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