


# The Neurobiological Foundation of Neurologic Music Therapy

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## Abstract

Neurologic music therapy (NMT) is a specific methodology of music therapy that is based on neuroscience models of music perception and production. Codified NMT techniques are developed out of basic and applied research on the unique effects of music on the brain. The distributed nature of neuronal networks for music processing in the brain, combined with the precise temporal processing ability of the auditory system, makes music a valuable tool for rehabilitation of sensorimotor, communication, and cognitive functions. A large number of clinical studies have demonstrated that music stimuli applied systematically can yield functional outcomes in persons with stroke, Parkinson disease, multiple sclerosis, and other conditions. The purpose of this article is to explain the neurobiological foundation of NMT and explore relevant research in clinical populations.

## Keywords

neurologic music therapy, neurorehabilitation, cortical plasticity, entrainment

Since the early 1990s, the study of music and its effect on brain function has increased, providing insights into the neural mechanisms involved in music engagement. A greater understanding of music neuroscience led to the development of a new approach to music therapy particularly in rehabilitative clinical practice, neurologic music therapy (NMT). Neurologic music therapy is defined as the therapeutic application of music to cognitive, sensory, and motor dysfunctions due to neurological disease of the human nervous system.<sup>1</sup> As an evidence-based treatment methodology, the foundation of NMT is in neuroscience models of music perception and production. Research findings in basic and applied music neuroscience have led to the development of codified therapeutic techniques that address sensorimotor, speech and language, and cognitive functioning.<sup>2</sup>

Neurologic music therapy clinicians have opportunities to receive continuing education and training in music neuroscience, clinical assessment, and NMT techniques and application. Since the techniques are based on models of music perception and production, a basic understating of music neuroscience is essential to the understanding and selection of NMT techniques and their potentially therapeutic application. Research has demonstrated a rich physiological basis for the influence of the auditory system on nonmusical functions, which may be utilized for the rehabilitation of functional nonmusical skills.<sup>1</sup> The purpose of this article is to describe the neurobiological basis of NMT, with particular emphasis on its critical elements and foundations including rhythmic entrainment.

## Music in the Brain

Although the precise mechanisms involved in the perception of music and production are not entirely understood, music neuroscience studies have provided some insights about how music is processed. Performing, listening, and moving to music engages regions throughout the cortex, subcortex, and cerebellum.<sup>3</sup> These activations are not specific to music processing; rather, music shares supramodal networks that are also utilized for communication, cognitive, and sensorimotor functioning. These shared networks allow for musical stimuli to engage cortical networks that are utilized in similar nonmusical tasks, allowing these networks to be targeted in music therapy treatment.

Another important finding that is critical to the use and application of music in therapy is evidence of extended networks. Engagement with music stimuli activates cortical areas that extend beyond the typical areas utilized in an equivalent nonmusical task. For example, in most people speech production is primarily left lateralized to the left inferior frontal gyrus; however, singing activates the right and left inferior frontal gyrus.<sup>4</sup> This is the proposed reason that a person who has lost

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the ability to speak due to a left cerebral vascular accident often demonstrates unimpaired ability to sing. The shared and extended networks of music processing and production allow music stimuli to access multiple cortical areas utilized in musical and nonmusical tasks, providing a means for rehabilitating nonmusical functioning when disease or damage occurs.

Music not only accesses shared and extended networks but can also facilitate cortical plasticity. When compared to nonmusicians, adult musicians have differences in the cortex, including sensorimotor areas, auditory areas, and areas involved in multi-sensory integration.<sup>5-8</sup> Cortical changes are not limited to gray matter, as researchers have documented differences in the superior longitudinal fasciculus of adult musicians.<sup>8</sup> Cortical changes have also been demonstrated in children and adult nonmusicians who undergo musical training. Hyde and colleagues<sup>9</sup> demonstrated that children who underwent 15 weeks of training on the piano showed anatomical changes in the motor and auditory cortex as well as the corpus callosum. After a few weeks of training on the piano, adult nonmusicians have shown more connectivity of the hand area of the sensorimotor cortex<sup>10</sup> and preparatory activation of the motor area when learned piano melodies are played.<sup>11</sup> This research demonstrates that the brain that engages with musical stimuli undergoes changes in structure and functional connectivity.

Musical engagement provides a means for optimal learning and rehabilitative experiences. Due to the sequential and spectrally complex nature of auditory information, the auditory system is proposed to be particularly sensitive to temporal information.<sup>12</sup> The auditory system may naturally provide a scaffold for the encoding and processing of temporal information, which may be further enhanced by a highly anticipatory musical structure. Music stimuli may be rapidly encoded by the auditory system and directly projected to subcortical and cortical regions involved in motor planning, cognition, or communication. This may be observed in the tendency to use mnemonics to encode new information, such as learning the ABCs in childhood. Collectively, this evidence on the unique nature of how music is processed in the brain provides a rationale for the use of music in therapy, which is further supported by research demonstrating a rich connectivity between the auditory system and brain regions involved in cognitive, motor, and speech/language functions.

### **Rhythmic Entrainment**

Similar to other musical elements, rhythm activates numerous brain areas, including several that are utilized in motor functioning including the dorsal premotor cortex (PMC), supplementary motor areas, presupplementary motor area, lateral cerebellum,<sup>13</sup> and the basal ganglia.<sup>14</sup> Furthermore, sound can prime and time spinal motor neuron excitability via reticulospinal pathways.<sup>15</sup> Not only does rhythm activate motor areas of the brain, but the oscillatory neuronal firing patterns associated with rhythm processing also directly project into the motor system, entraining motor neuron discharge.<sup>16</sup> This entrainment phenomenon, resulting in closely frequency-locked auditory-

motor synchronization patterns, has been shown to be an effective means for altering or influencing the timing of movement due to the strong physiological attractor function between auditory rhythmic cues and motor response.<sup>16</sup>

Motor entrainment to an external auditory stimulus is quickly achieved and maintained despite perturbations in the stimulus period.<sup>17</sup> Small changes in the stimulus period below the conscious level of perception result in rapid correction of the period errors (time difference between auditory stimulus interval and response interval), followed by a gradual adjustment of synchronization error (time difference between tap and onset of auditory stimuli). With perturbations over a 5% change in period, there is a notable temporary overcorrection, followed by resynchronization.<sup>17</sup> This evidence suggests that the auditory system communicates precise interval-based temporal information to the brain, which directly influences the organization and timing of motor output. Furthermore, due to the cyclic periodicity inherent in rhythm stimuli motor entrainment appears to be anticipatory in nature.

Motor response to a rhythmic auditory stimulus precedes the occurrence of the stimulus (termed negative asynchrony), indicating that motor entrainment occurs through anticipation of the duration of the stimulus period. Although motor responses appear to occur as coincidental with the stimulus, the actual response fluctuates within milliseconds. However, despite the “slack” in the individual response times, the response period is tightly coupled to the stimulus period. Therefore, motor entrainment is thought to be a self-correcting system, with random fluctuations in motor response that occur within a tightly coupled period.<sup>18</sup>

Although studies indicate that many areas of the cortex, sub-cortex, and cerebellum are involved in rhythmic entrainment, the exact process involved in auditory-motor entrainment remains unclear. A rich connectivity between the auditory and motor areas has been documented since early studies. Studies by Paltsev and Elnor<sup>19</sup> and Rossignol and Melvill Jones<sup>15</sup> demonstrated that motor responses entrained to rhythmic auditory cues in adults. These researchers observed a tight coupling between the stimulus and motor response, indicating auditory-spinal facilitation. Subsequent studies demonstrated muscle activation changes as a direct result of auditory cueing,<sup>20</sup> with suggested activation via reticulospinal connections, projections to the cerebellum via the inferior colliculus and pontine nuclei, and projections to the basal ganglia via thalamic projections from the inferior colliculus.<sup>21</sup>

Auditory-spinal facilitation is further supported by evidence that entrainment occurs despite an interruption of neural impulses from motor areas of the brain. Malcolm et al<sup>22</sup> applied repetitive transcranial magnetic stimulation (rTMS) to the left ventral PMC (vPMC) and the left superior temporal-parietal area (STP), inhibiting neural impulses. The period error (difference between response interval and stimulus interval) was not affected by the rTMS; however, there was significant increase in phase synchronization (difference between auditory stimulus and motor response). These results indicate that although the vPMC and the STP areas are involved in motor synchronization, the absolute period synchronization is achieved through other mechanisms.<sup>22</sup>

Additional evidence that entrainment occurs via direct projections to the motor system comes from research demonstrating that persons with neurological disease and disability maintain the ability to entrain to an external auditory stimulus. Clinical studies have demonstrated that persons with Parkinson disease (basal ganglia deficit) respond to auditory rhythmic stimulation utilized in the treatment of gait and speech.<sup>23</sup> Persons who have had a cerebral vascular accident damaging the sensorimotor cortex have intact synchronization abilities, which have been utilized to improve in measures of gait and volitional movements.<sup>24</sup> Entrainment despite cortical damage is a key element that allows for rehabilitative goals to be met through the employment of rhythmic stimuli.

### Sensorimotor Rehabilitation

The largest body of research in NMT involves the use of external rhythmic cueing for gait entrainment and rehabilitation. This technique, called rhythmic auditory stimulation (RAS), involves the specific application of external auditory cues to quickly and precisely influence gait. Rhythmic auditory stimulation is designed to improve temporal and spatial parameters of gait, as the rhythmic cue provides time-based information aimed at reestablishing functional gait patterns.<sup>25</sup> Research over the past 15 years has indicated that RAS can be used to improve gait parameters including step cadence, stride length, velocity, symmetry of stride length,<sup>23,24,26,27</sup> and center of mass.<sup>28</sup>

Rhythmic auditory stimulation has been successful in improving gait parameters of adults with Parkinson disease,<sup>20,28-33</sup> traumatic brain injury,<sup>34,35</sup> spinal cord injury,<sup>36</sup> stroke,<sup>24,26,37-39</sup> multiple sclerosis,<sup>40</sup> and Huntington disease.<sup>41</sup> Although these neurological disorders are comprised of different areas of cortical damage or disease, the use of rhythmic cueing is an effective treatment method due to priming of the auditory-motor pathway and cueing of the movement period (gait cycle).<sup>25</sup> These studies indicate that auditory-motor entrainment has direct and measurable effects in gait rehabilitation. Furthermore, researchers have demonstrated that RAS can surpass outcomes achieved in traditional Bobath/neurodevelopmental therapy<sup>26</sup> and can facilitate functional therapeutic outcomes for weeks after training.<sup>42</sup>

Rhythmic auditory cueing has also been utilized in upper extremity studies and full body coordination<sup>43</sup> where the movement period is facilitated by the auditory cue period. Techniques in NMT directed toward these goals are called auditory patterned sensory enhancement (PSE) and therapeutic instrumental playing (TIMP) when functional movement patterns are translated to exercises that involve actively playing music instruments (keyboard, percussion). Persons with a hemiparetic arm benefited from auditory rhythmic cueing, demonstrating decreased movement variability, increased speed of movement, and a smoothing of the movement trajectory.<sup>44-46</sup> Rhythmic cueing treatment also facilitated a significant decrease in compensatory trunk movements while increasing contribution of the shoulder.<sup>47</sup>

One application of PSE to upper extremity exercises utilizes rhythmic auditory cues matched with the movement of handles

in a transverse plane (see Whitall et al<sup>48</sup> for description). This method, called bilateral arm training with rhythmic auditory cueing (BATRAC), has resulted in improved scores on functional motor tests,<sup>48</sup> movement time, peak acceleration, and hand path accuracy.<sup>49</sup> Although not as broadly researched as RAS in applications related to gait, emerging evidence provides good indication that rhythmic cueing can also be used to facilitate movements of the upper body and full body coordination.

### Speech Rehabilitation

Speech communication is a complex skill that involves precisely timed motor sequences including the coordination of laryngeal, bronchial, and oral motor structures. Research findings have revealed several shared neural correlates between speech and singing including the processing of pitch, melody, and temporal aspects.<sup>3</sup> When comparing singing to speech, several distinct activations have been documented, namely, greater activation of the right hemisphere, indicative of greater bihemispheric organization for singing.<sup>4</sup> Shared networks involved in singing and speech, combined with the extended networks documented in singing, allow treatment techniques utilizing singing to facilitate speech rehabilitation.

One such researched application of music for speech rehabilitation is the use of melodic intonation therapy (MIT) for persons with acquired nonfluent aphasia. Melodic intonation therapy utilizes a person's unimpaired ability to sing in order to retrain speaking ability. This technique utilizes both rhythmic and melodic cues, creating a predictable structure to practice sung speech phrases. Melodic intonation therapy has been shown to improve dominant hemisphere<sup>50</sup> and nondominant hemisphere pathways.<sup>51,52</sup> These results indicate that music intervention can drive cortical plasticity for speech function, with therapeutic outcomes documented in patients more than 1 year poststroke.<sup>51</sup>

Rhythmic speech cueing (RSC) is another NMT technique that researchers have shown to be successful in improving fluency in stuttering<sup>53</sup> and speech production and intelligibility in persons with dysarthria (for a review see Wan et al<sup>54</sup>). Rhythmic cueing can be used to modulate speech tempo, providing a predictable template for intelligible speech production. Researchers demonstrated that rhythmic cueing was most successful in improving speech intelligibility in patients with severe dysarthria due to traumatic brain injury.<sup>55</sup> Rhythmic cueing has also been used to increase intelligibility in patients with Parkinson disease, showing that the greatest benefit was in persons with more severely affected speech.<sup>23</sup> Additional studies have investigated singing for overall improvements in speech production in persons with dysarthria, with results indicating positive outcomes in speech intelligibility, vocal control, and speech volume.<sup>56,57</sup> Other evidence-based techniques in NMT address articulatory control and respiratory function (oral motor and respiratory exercise [OMREX]), voice disorders (vocal intonation therapy [VIT]), nonpropositional speech stimulation in aphasia (musical speech stimulation [MUSTIM]), developmental speech and language delays (developmental

speech and language training through music [DSLMM]), symbolic nonverbal communication training (symbolic communication training through music [SYCOM]), and global facilitation of speech production through therapeutic singing (TS).

### Cognitive Rehabilitation

A clinical area of NMT that has emerging evidence in the past 10 years is in cognitive rehabilitation. A growing body of evidence has begun to demonstrate that the temporal organization of music can be effectively utilized for rehabilitation of attention control, memory, psychosocial, and executive function.<sup>1</sup> Neurologic music therapy techniques have been designed to address these areas.<sup>1</sup> The use of music and rhythm for cognitive tasks is proposed to facilitate increased neuronal network synchronization, which may result in faster encoding and learning of cognitive functions. This theory has emerging evidence, as electroencephalogram (EEG) measures of brain wave activity indicate that musical stimuli evokes more synchronized firings in alpha and gamma bandwidths.<sup>58,59</sup> Furthermore, persons with multiple sclerosis showed increased frontal network synchronization paired with more successful word recall in a music/sung word recall task.<sup>59</sup>

Music engagement and listening may aid in the rehabilitation of attention due to the activation of cortical areas involved in attention, for example, in music neglect training (MNT).<sup>60,61</sup> One study investigated music listening in the early stage of recovery following a middle cerebrovascular accident. Results indicated that music listening increased verbal memory and focused attention skills.<sup>62</sup> Memory skills have further been documented to increase when information is paired with a rhythmic pattern. Silverman<sup>63-65</sup> demonstrated that adults better recalled randomly ordered numbers when they were paired with simple rhythms. Silverman<sup>65</sup> suggested that rhythm aided in recall by promoting bihemispheric activation and/or the increase in neural connectivity promoting working memory. Preliminary studies indicate success when memory tasks are paired with music in persons with Alzheimer disease<sup>66</sup> and multiple sclerosis.<sup>67</sup> Furthermore, a study comparing musicians to nonmusicians demonstrated that musicians have improved auditory and visual working memory.<sup>68</sup> There are several memory training techniques in NMT including music mnemonics training (MMT) and associative mood and memory training (AMMT). Each technique is employed based on the needs of the client and the type of music stimuli being utilized.

Another area with emerging evidence supporting the use of music for cognitive functioning is in executive functioning skills. Music executive function training (MEFT) is a technique that involves the use of rhythmic and music exercises to provide opportunities for tasks of executive functioning including sequencing, decision making, problem solving, organizing, and planning. Thaut and colleagues<sup>69</sup> utilized MEFT with a group of persons who had traumatic brain injury. Results indicated that there were improvements in mood and emotional adjustment. Participants in the MEFT group also reported decreased anxiety. Collectively, the aforementioned studies indicate that

rhythm and music can be effective in facilitating or enhancing cognitive outcomes.

Neurologic music therapy for cognition is an area of treatment that will continue to expand as more research is conducted in this important area of functioning. Basic science and initial clinical evidence supports techniques utilized to address other cognitive functions including music attention control training (MACT)<sup>70</sup> and music sensory orientation training (MSOT).<sup>71,72</sup> Neurologic music therapy techniques also address psychosocial and emotional needs through music psychosocial training and counseling (MPC), where music experiences are employed to work on social competence, cognitive reorientation, affective behavior training, and mood induction. Music has long been utilized for psychosocial behavior training; however, this is an area where more systematic research is needed to guide practice in music therapy.

### Conclusion

Scientific evidence in music neuroscience has better informed the field of music therapy and led to the development of NMT. Neurologic music therapy is based on models of music perception and production, and trained practitioners can utilize knowledge of music neuroscience to better inform therapeutic practice. With evidence-based techniques, the NMT model promotes standardized application, whereby communication of techniques might lead to enhanced clinical outcomes. Advances in research will continue to drive the development and refinement of NMT techniques, thus improving therapeutic outcomes in patients in need of rehabilitation. Furthermore, a greater knowledge of NMT will evolve as more studies are conducted in this important area of music therapy.

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