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Neurologic Music Therapy: A Scientific Paradigm for Clinical Practice

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Abstract

Neurologic Music Therapy (NMT) is an evidence-based approach to research and clinical practice that is based in neuroscience models of treatment and rehabilitation (Thaut, 2005a). The ability to perceive music and to engage in musical experiences is often still intact even when the central nervous system is damaged by injury or disease. Thus, NMT techniques produce specific and functional outcomes for patients with neurologically based deficits. To give a comprehensive description of the entire NMT clinical taxonomy in one article is not possible. Rather, the descriptions that follow are intended to clarify the underlying neurologic mechanisms and functional outcomes for certain techniques that may be most useful as part of neurorehabilitation. These techniques include Rhythmic Auditory Stimulation in gait training, Vocal Intonation Therapy to enhance speech production, and Musical Neglect Training for redirection of spatial awareness.

Keywords

gait, music therapy, neglect, neurorehabilitation, voice disorders

The connection between music and health can be traced back to prehistoric times, during which songs and musical rituals were used to communicate with the gods and to access supernatural powers needed for healing (Merriam, 1964; Nettl, 1956). As it is recognized today, the music therapy profession grew out of a movement following World War II in which musicians were brought into veterans' hospitals as a way to boost the morale of soldiers requiring long-term stays (Davis & Gfeller, 2008). Although not considered music therapy per se, these performances not only lifted soldiers' spirits but also made significant contributions to their physical and mental rehabilitation. With input from faculty members in music, music education, nursing, and psychology, universities began to develop academic programs to prepare musicians for this specialized field (de l'Etoile, 2000).

Even while academic programs were teaching therapeutic techniques, the basic science was lacking to explain how the techniques worked. Music therapy research conducted in the years following World War II tended to be largely descriptive or philosophical in nature (Gilbert, 1979; Jellison, 1973). While efforts in experimental research began to increase in the 1980s (Codding, 1987), data collection consisted mainly of behavioral observation, thereby limiting a true understanding of underlying therapeutic mechanisms. Thus, the music therapy profession grew from magical beliefs into a social/emotional framework in which music was valued for its ability to promote a general sense of well-being (de l'Etoile, 2009; Thaut, 2005a).

Paradigm Shift

In the early 1990s, the music therapy profession began a significant transformation with the advent of modern research techniques, such as brain imaging, brain wave analysis, and kinematic motion analysis (de l'Etoile, 2009; Thaut, 2005a). These sophisticated data collection methods began to reveal a much-needed understanding of specific brain processes in relation to music that clarified the underlying neurologic mechanisms for music therapy practice. In essence, technology helped to answer the question, how does music therapy work? This evidence generated a scientific approach for the practice of music therapy based on a perceptual neuroscience model of musical behavior. With this evidence, music therapists can now access the central nervous system in a systematic way to reliably produce functional outcomes for their patients.

Neurologic Music Therapy: An Evidence-Based Approach

This paradigm shift led to the development of a new approach to clinical practice and research, known as Neurologic Music Therapy (NMT; Clair, Pasiali, & LaGasse, 2008; Thaut, 2005a). NMT provides an evidence-based approach to music therapy practice, that is, therapeutic techniques are built from both basic and applied science concerning music and brain function (Thaut, 2000). The findings of such research

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demonstrate how the central nervous system is involved in perceiving and understanding music, creating or producing music, as well as responding to music stimuli.

With an ever-expanding research base, NMT is now recognized as a state-of-the-art neurorehabilitation modality. In fact, the World Federation for NeuroRehabilitation has established a special interest group for NMT to acknowledge the significant contributions of this therapeutic discipline (World Federation for NeuroRehabilitation, n.d.). The extensive research that supports NMT has also contributed to the identification of Current Procedural Terminology (CPT®) Codes for NMT techniques, thus allowing for improved patient access to services (Oliver, Thaut, & Sena, 2005).

NMT techniques are standardized in both application and terminology to enhance communication and clinical efficacy among music therapists and with other health care professionals (de l'Etoile, 2009). Techniques have been designed to improve patient functioning in three areas:

1. Sensorimotor functioning; in regard to mobility as well as strength, endurance, timing, and coordination of gross and fine motor movements in the lower and upper extremities
2. Speech and language functioning; such as vocal control, fluent and intelligible speech production, and meaningful use of both verbal and nonverbal symbols within a communication context
3. Cognitive functioning; including attention, memory, executive function, and psychosocial skills (Thaut, 2005e)

The purpose of this article is to describe one NMT technique in each domain, along with brief explanations of underlying neurologic mechanisms and functional outcomes.

NMT for Sensorimotor Functioning: Rhythmic Auditory Stimulation (RAS)

This NMT technique involves the application of an auditory rhythmic cue to facilitate training of movements that are intrinsically and biologically rhythmical, such as gait (Thaut, 2005c). Using rhythmic cues in either 2/4 or 4/4 meter, the therapist initially matches the rhythm tempo to the patient's current cadence, or limit cycle. The therapist then makes gradual and systematic increases in the rhythm tempo to help the patient obtain a more functional gait pattern. RAS is designed to improve both temporal and spatial parameters of gait, such as step cadence, stride length, velocity, symmetry of stride length and duration, as well as double and single support time of leg stance (Thaut, 2005c).

Scientific foundations for RAS. The basic science supporting RAS stems from three principles: rhythmic entrainment, priming of the auditory-motor pathway, and cueing of the movement period. Research findings have shown that auditory rhythm has a strong, physiological attractor function to entrain movement, such that the timing of the movement will occur at the same frequency or tempo as the rhythm (Thaut, 2005c). As an example, if the therapist has determined that a rhythmic cue set at 90 beats per minute is appropriate for a given patient, the rhythm can help the patient to consistently walk at a cadence of 90 steps per minute. Rhythmic entrainment results from the auditory system's ability to quickly and accurately detect temporal patterns, as well as the rich connections between the auditory and motor systems (Tecchio, Salustri, Thaut, Pasqualetti, & Rossini, 2000). Consequently, rhythmic entrainment does not require training or conscious effort to occur.

Movement is further enhanced during RAS when sound stimuli activate motor neurons via reticulospinal pathways, a process known as priming of the auditory-motor pathway (Thaut, 2005c). Early research demonstrated that rhythm could change muscle activation patterns through supraspinal influences, thus altering various components of locomotor behavior (Pal'tsev & El'ner, 1967; Rossignol & Melvill Jones, 1976). Subsequent research using electromyography has revealed specific changes in lower extremity muscle activation in response to rhythm. These changes occur as a result of more efficient motor unit recruitment patterns that produce consistent and controlled movement, while at the same time allowing for flexible adaptation of gait movements (Miller, Thaut, McIntosh, & Rice, 1996).

Finally, RAS improves gait by effectively cueing the movement period. A simple rhythm offers two critical cues for movement (Thaut, 2005c). First, the audible beat itself cues each heelstrike, which indicates the endpoint of the gait movement. More important, the duration of time between the beats, known as period information, cues all aspects of the gait pattern between heelstrikes, including weight shifting, acceleration, swing phase, and so on (Thaut & Kenyon, 2003). Thus, a rhythmic cue provides a continuous time reference for the execution of the entire movement pattern, resulting in enhanced kinematic stability and smoother movement trajectories (Thaut, 2005c).

An important practical aspect of RAS implementation pertains to a concept known as stepwise limit cycle entrainment. When clinicians implement RAS, they first determine the tempo of the patient's starting gait cadence. This tempo is known as the patient's limit cycle or resonant frequency, which represents the frequency at which any moving system can perform optimally (Thaut, 2005c). When the auditory rhythm matches this tempo, the patient's gait kinematics become more stable. Subsequently, the therapist can establish new limit cycles at faster tempos through a stepwise entrainment process. For example, the therapist may gradually increase the RAS tempo by 5% at each therapy session. As the patient entrains to each new limit cycle, he or she will make progress toward attaining his or her premorbid gait pattern, as indicated.

RAS applications. This technique is most appropriate for individuals with neurologically based gait deficits and can be used in two ways: as an immediate entrainment stimulus, or as part of a long-term gait training program (Thaut, 2005c). Immediate entrainment effects may include changes in both spatial and temporal gait parameters that occur while walking to rhythm, such as improvements in stride rhythmicity and weight bearing, as well as enhanced activation of lower extremity muscles, including reduced variability. These effects have been noted in typical adult populations as well as in clinical samples, such as patients who have experienced strokes (Thaut, McIntosh, Prassas, & Rice, 1992, 1993).

Immediate RAS effects for patients with strokes have also been explored in combination with treadmill walking (Roerdink, Lamoth, Kwakkel, van Wieringen, & Beek, 2007; Roerdink et al., 2009). The authors explain that the use of a treadmill provides control of walking speed, so that any other observed effects on gait can be directly attributed to the addition of auditory pacing. Results indicated that patients with strokes were able to entrain with rhythm while walking on a treadmill and made significant increases in stride frequency, as needed to enhance velocity. Additionally, both spatial and temporal aspects of gait symmetry improved, most likely due to decreased step lengths and step times on the paretic side. Patients also demonstrated the ability to adjust gait according to tempo changes in the rhythm. This improved gait organization may have resulted from patients' tendency to synchronize movement of the nonparetic limb with the auditory cue, thus demonstrating an anchoring effect. Ultimately, RAS combined with treadmill walking may provide an effective method for helping patients adjust their gait according to environmental demands (i.e., gait adaptability).

Long-term gait training programs involve the daily use of RAS over time to achieve gait improvements. Following repetitive practice, positive outcomes then transfer to walking without rhythm (Thaut, 2005c). Patients with strokes who participated in 30-min RAS sessions twice daily for 6 weeks in combination with physical therapy showed increases in velocity, cadence, stride length, and stride symmetry at a much greater rate than a control group that received physical therapy alone (Thaut, McIntosh, & Rice, 1997). Similarly, the patients with strokes who received RAS demonstrated significant reductions in muscle activation variability in comparison with the conventional physical therapy group. A separate study showed that just 3 weeks of gait training with RAS for patients who have experienced strokes produced a multitude of positive effects and that results were superior to those achieved with neurodevelopmental therapy (NDT)/Bobath-based training (Thaut et al., 2007). While patients in both groups demonstrated gait improvements over time, participants who trained daily with RAS showed significantly greater increases in velocity, cadence, stride length, and symmetry than patients who received NDT.

In another clinical trial, patients with Parkinson's disease who walked with RAS for 30 min per day for 3 weeks showed improvements in velocity, cadence, and stride length, as well as reduced variability in lower extremity muscle activation (Miller et al., 1996; Thaut et al., 1996). Additionally, positive changes in muscle activity onset, termination, and duration reflected a more focused muscle activation period. Follow-up testing revealed that participants were able to maintain improvements in stride length, cadence, and velocity as well as changes in muscle activation for 3 to 4 weeks after the training (McIntosh, Rice, Hurt, & Thaut, 1998). By the 5th week posttraining, most gains had returned to pretest values; however, the enduring effects of long-term gait training with RAS are encouraging, considering the degenerative nature of Parkinson's disease. Further research may explore the use of interval training schedules for these patients to maximize potential benefits.

Certain other clinical populations may not show consistent evidence of immediate entrainment effects of RAS; however, research findings indicate that they may still benefit from long-term gait training with RAS. For example, research involving patients with traumatic brain injury showed that gait parameters did not improve significantly during a rhythmic entrainment exercise (Hurt, Rice, McIntosh, & Thaut, 1998). The authors attribute the results to high performance variability across participants, possibly due to diffuse axonal damage that is typical of traumatic injuries and that may interfere with auditory-motor capability. However, after the same participants completed daily sessions of RAS for 5 weeks, significant improvements were noted in velocity, cadence, and stride length. Evidently, repeated exposure to RAS over time was effective in promoting more functional gait patterns.

Similarly, patients with incomplete spinal cord injury (SCI) showed inconsistent responses to RAS during an immediate entrainment study (de l'Etoile, 2008). While high participant variability also influenced these results, a majority of participants showed evidence of entrainment by either maintaining or increasing values for velocity, cadence, and stride length in response to rhythm. Additional findings revealed that younger participants (< 35) were better able to increase stride length than older participants. Furthermore, although the small sample size limits broad generalizations, the data suggested that participants with cervical injuries tended to increase cadence while patients with thoracic injuries were more likely to increase both velocity and stride length. Lengthening stride represents a more efficient approach to increasing velocity and enhancing overall gait kinematics. Thus, the results help to identify patients who may be good candidates for long-term gait training for RAS, such as younger participants with SCI at the thoracic level.

NMT for Communication: Vocal Intonation Therapy (VIT)

This technique consists of structured singing and vocal exercises designed to train all aspects of vocal production, including pitch, timbre, breath control, volume, phonation, resonance, and intonation (Clair et al., 2008; Hurt, 2009; Thaut, 2005d). Exercises may focus on relaxing the head, neck, and upper trunk, as well as warming up the vocal mechanism through diaphragmatic breathing and scale singing. Phonation activities may involve starting and stopping sound production according to musical cues, while intonation exercises may use melodic and rhythmic patterns as well as accenting to enhance prosody (Thaut, 2005d). For a patient who speaks within a limited pitch range, an example might include singing a five-note ascending scale and gradually shifting the starting pitch up or down by half steps, as needed (Hurt, 2009). The exercise could then be extended by adding a functional sentence to the scale, such as, "May I have a cookie?" Incorporation of physical gestures or visual stimuli (i.e., pictures, props) can further promote awareness of pitch level or movement between levels. When implementing VIT, the therapist functions like a well-trained vocal coach or choir director, such that therapy sessions may resemble voice lessons (Thaut, 2005d). Most important, a music therapist will understand the patient's unique deficits and can tailor interventions to produce functional communication outcomes, as opposed to musical gains.

Scientific foundations for VIT. The scientific foundation for VIT stems from shared and parallel processes between music and speech in three domains: perception, physiology, and neuroanatomy. Perceptually, both music and speech are aural forms of communication with common acoustic and auditory parameters, such as frequency, intensity, timbre, duration, rate and cadence, contour, and rhythm (Thaut, 2005e). In one study, participants received auditory feedback during both singing and speaking (Natke, Donath, & Kalveram, 2003). Results indicated that control of fundamental voice frequency was more precise and tightly regulated during singing than in speaking. The authors explain that singing provides an external reference that can be used to alter vocal pitch. With repetitive practice, the ability to modify vocal pitch can then transfer to the speaking voice. Additionally, both singing and speaking use the physiological processes of respiration, phonation, and articulation (Tatham & Morton, 2006; Turner, 2004). Thus, singing essentially "exercises" the perceptual and physiological mechanisms needed for effective voice control during the production of speech and language. This overlap allows for effective transfer of therapeutic effects from singing to functional use of the voice.

From a neurologic perspective, research findings have revealed a number of shared neural correlates or hemispheric homologues in regard to singing and speaking. The left hemisphere of the brain appears dominant for rhythmic and temporal aspects of both processes, while the right hemisphere processes pitch, melody, and holistic contours (Brown, Martinez, Hodges, Fox, & Parsons, 2004; Brown, Martinez, & Parsons, 2006; O'Boyle & Sanford, 1988; Özdemir, Norton, & Schlaug, 2006; Perry et al., 1999). By contrast, other studies have identified distinct differences in brain regions needed for singing versus speaking (Jeffries, Fritz, & Braun, 2003; Peretz, Gagnon, Hebert, & Macoir, 2004). Collectively, these findings suggest that when engaged in a musical experience, the two hemispheres appear to function as a processing team with each half making important contributions (O'Boyle & Sanford, 1988). These shared, segregated, and parallel pathways for music and speech production provide the flexibility needed for neuroanatomical reorganization as well as access to alternate pathways for vocal function in cases of brain damage (Thaut, 2005e).

VIT applications. Vocal intonation therapy is most appropriate for individuals with voice disorders that involve disturbances in phonation or resonance, such as abnormal pitch level or pitch range, deficits in intensity or respiratory control, as well as problems with timbre including excessive breathiness or hoarseness (Clair et al., 2008; Thaut, 2005e). Voice disorders can result from various causes in the sensorimotor, anatomical/physiological, behavioral, or psychogenic domains and thus may be applied and adapted for a number of clinical populations.

Older adults with emphysema benefited from a 12-session group singing instruction program to address chronic breathing problems that interfered with their functional communication (Engen, 2005). Techniques included posture and breathing exercises, vocal warm-ups and exercises, echo singing, and singing of songs with specific attention to the mechanics of breathing and phrasing. Results showed that participants made significant improvements in breath control and support, in addition to shifting from clavicular to diaphragmatic breathing, a benefit that was maintained 2 weeks after the intervention.

VIT can also enhance vocal skills in individuals with dysarthria, a neurogenic communication disorder (Murdoch, Ward, & Theodoros, 2000). In one study, patients with acquired dysarthria due to traumatic brain injury or stroke participated in a 24-session program of singing and vocal exercises (Tamplin, 2008). Techniques were designed to enhance control and strength of the speech musculature, to model appropriate articulation, and to cue the rate of vocal production. Findings revealed that participants made significant improvements in speech intelligibility as well as speech naturalness, which was supported by reductions in the number and length of pauses while speaking.

Many patients with Parkinson's disease are also diagnosed with dysarthria. Haneishi (2001) developed a 12-session voice protocol for patients with Parkinson's disease that included exercises in facial relaxation, breathing, vocalizing, singing, phonation, and speech. The protocol's emphasis on phonatory and respiratory efforts promoted stronger vocal projection, which led to significant gains in vocal intensity and, subsequently, speech intelligibility. These studies demonstrate that VIT can play an important role in helping patients improve fundamental aspects of voice control, such as breath management, speech naturalness, vocal intensity, and speech intelligibility. Additionally, the positive effects of VIT are most likely to be achieved through an intensive vocal training program that involves two to three sessions per week over a period of several weeks. Such efforts will contribute to improvement and maintenance of functional communication.

NMT for Cognitive Rehabilitation: Musical Neglect Training (MNT)

In musical neglect training, patients engage in rhythmically structured playing of musical instruments that are arranged in specific spatial configurations (Clair et al., 2008; Hurt, 2009; Thaut, 2005e). The goal of MNT is for patients to focus attention either repeatedly or continuously on an unattended visual field to remediate the neglect. The most appropriate candidates for this technique include individuals with visual neglect as a result of right hemispheric lesions following stroke or traumatic brain injury (Thaut, 2005e). As an example of an MNT technique, the patient may play a series of resonator bells arranged on a table-top in a straight line from right to left. The therapist provides musical accompaniment (i.e., on piano or guitar) to harmonically and rhythmically cue the bell-playing sequence. As the patient becomes proficient at the task, the therapist can increase task complexity by altering the spatial arrangement of the bells or instructing the patient to play the bells from left to right. In an alternate approach, the therapist may provide receptive music listening to stimulate hemispheric arousal while the patient engages in exercises designed to address visual neglect or inattention.

Scientific foundation for MNT. Music's capacity for neural activation appears to provide the strongest basic evidence for musical neglect training. In one study, Hommel et al. (1990) explored the effect of music as sensory stimuli on visual neglect resulting from right hemispheric lesions in patients who have experienced strokes. Participants completed a visuomotor task (i.e., copying drawings on paper) while being exposed to various passive stimulus conditions. Results indicated significantly better task performance while passively listening to nonverbal auditory stimuli through headphones, such as classical instrumental music or white noise. Patient response during these conditions exceeded performance during the conditions of no stimuli, tactile stimuli, or verbal stimuli. The authors explain that neglect may result from a hypoactive right hemisphere, which carries greater responsibility for attention, as well as an arousal imbalance between the right and left hemispheres. Consequently, white noise and music may have had an activating arousal effect on the right hemisphere that could help to correct the hemispheric imbalance, thus improving patient neglect.

In another study, researchers asked patients with right hemisphere lesions and left visual neglect to identify visual stimuli in various locations, some of which were paired simultaneously with auditory stimuli (i.e., pure tones; Frassinetti, Pavani, & Làdavas, 2002). Results demonstrated that detection of visual targets improved substantially when they were paired with auditory stimuli, especially when the two stimuli originated from the same spatial location. The effect was even larger when the visual target was most difficult to detect (i.e., located in the most peripheral portion of the left visual field). Thus, an auditory cue substantially modified detection of a visual target. Additionally, the sound helped patients with neglect to detect a previously ignored visual target. Frassinetti et al. (2002) explain that these findings are not due to an arousal effect alone, since the improved detection rates were only evident when the two stimuli were in close spatial proximity. Rather, the results may reflect activation of multisensory neurons that lie within designated sensory receptive fields. Auditory receptive fields are known to be larger than visual ones, thus auditory stimuli can activate neurons over a larger region, even extending into visual receptive fields.

Researchers again explored the effect of audiovisual stimuli on the perception of visual events in patients with either hemianopia (i.e., a visual deficit) or neglect (i.e., a visuospatial attentional deficit) and patients with both conditions (Frassinetti, Bolognini, Bottari, Bonora, & Làdavas, 2005). Participants were asked to detect visual stimuli presented alone or in combination with auditory stimuli that were either spatially aligned or spatially disparate. Results indicated that when visual targets were presented simultaneously with spatially aligned auditory stimuli, patients with either neglect or hemianopia showed enhanced visual performance. Patients diagnosed with both conditions did not demonstrate the same effect. The authors explain that sound can improve visual detection when the deficit is due to either a sensory or attentional impairment. This multisensory integration approach appears to access the superior colliculus (SC), a subcortical structure that is responsible for multisensory processing and that is typically spared following lesions that cause either neglect or hemianopia. These basic research findings provide the evidence needed to support clinical applications of musical neglect training.

MNT applications. In an effort to produce long-lasting improvements of visual field deficits, researchers developed a rehabilitation program using audio-visual stimulation of the visual field (Bolognini, Rasi, Coccia, & Làdavas, 2005). This multisensory training program involved detection of visual targets when presented alone or in combination with an acoustic stimulus. In the combined stimulus condition, the spatial disparity between the visual and acoustic stimuli was systematically varied. Training program participants included patients with hemianopia who received 4-hr daily training sessions over nearly a 2-week period.

Results demonstrated a progressive improvement across the training period in patients' ability to accurately detect visual targets in the impaired visual field, as well as the ability to engage more efficiently in visual scanning and exploration. Additional benefits included improved single word reading and self-reported enhancements in activities of daily living. Thus, patients were able to take skills acquired in the training sessions and gradually transfer them to daily life. Follow-up measures also indicated that the positive effects were maintained for at least 1 month posttreatment.

The authors explain that the patients' improved visual performance may have resulted from activation of multisensory neurons in the superior colliculus. As discussed previously, this structure is known to remain intact following lesions that cause either hemianopia or neglect. While the patients in this particular study did not have neglect, they did have visual deficits resulting from a lesion that also spared SC functioning. Thus, patients with neglect may also experience improved visual performance due to SC activation. Indeed, patients with either neglect or hemianopia have responded positively to the combination of auditory and visual stimuli (Frassinetti et al., 2005).

Consequently, this multisensory rehabilitation approach designed for patients with hemianopia would also logically benefit patients with neglect.

Conclusion

The advent of Neurologic Music Therapy represents a significant milestone in the evolution of music therapy practice and research. With scientific evidence at both the basic and applied levels, music therapists now understand how their techniques work and can produce specific and reliable outcomes for their patients. As discussed here, the NMT approach promotes rehabilitation of functional behaviors in the sensorimotor, speech/language, and cognitive domains. Future research concerning the workings of the central nervous system and its interactions with music will only serve to further expand these rehabilitative efforts.

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Bio

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