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Neurologic Music Therapy to Facilitate Recovery from Complications of Neurologic Diseases

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Abstract

Neurologic music therapy (NMT) has fostered recovery from complications in patients suffering from a wide variety of neurologic diseases. Combining music and virtual reality with standard rehabilitation therapies can improve patient compliance and make therapy more enjoyable. Listening to music can reduce epileptiform discharges and enhances brain plasticity. Music produces variations in brain anatomy between musicians and non-musicians. Music therapy is an inexpensive intervention to help post-stroke patients to recover faster and more efficiently if applied soon after the event. There is evidence that incorporating music into a rehabilitation program fosters recovery of hand function, dexterity, spatial movement, cognitive function, mood, coordination, stride length and memory. Learning words as lyrics, melodic intonation therapy and singing can help the aphasic patient to recover faster. NMT therapists are valuable members of the rehabilitation team. NMT has been approved by the World Rehabilitation Federation as an effective evidence based method of treatment.

Keywords: Neurologic diseases; Music; Rehabilitation; Neurologic music therapy; Stroke

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Introduction

Incorporating music into routine rehabilitation programs not only fosters initial recovery but also contributes to improvement and enduring benefit after stopping the treatment. Disabilities stem from different neurologic disorders, work-related injuries and trauma such as motor vehicle accidents and sport injuries. Disabilities can have devastating physical, emotional and financial effects on the lives of patients and their families. It is important to identify and incorporate strategies that supplement traditional rehabilitation therapy in order to optimize the recovery of function and quality of life. NMT, by facilitating the patients' recovery, contributes to positive patient outcomes. The following reviews the evidence base highlighting the importance of adding music to more standard forms of rehabilitation therapy. It references the neurobiological foundation of NMT, its history and applications. Evidence in support of its use to facilitate recovery from a wide range of complications related to specific neurological diagnoses will be discussed.

Literature Review

Time is a central coordinative unit of motor control and the related concept of entrainment is important to consider in any discussion about motor function. Entrainment is the synchronization or frequency locking, of two oscillating objects. The stronger "oscillator" locks the weaker into its frequency. When both oscillating bodies have equivalent energy, the systems approach each other. The more rapid system slows and the slower system accelerates until they lock into a common movement period. The function of rhythmic entrainment in rehabilitative training and learning was established by Thaut and colleagues in the early 1990s [1]. The firing rates of auditory neurons, triggered by auditory rhythm and music, entrain the firing patterns of motor neurons, thus driving the motor system into different frequency levels [1]. There are two additional mechanisms in regard to entrainment that are clinically significant. The first is that auditory stimulation primes the motor system to a state of readiness to move which facilitates the motor response quality [1].

Secondly, entrainment impacts changes in motor planning and execution. Rhythmic stimuli create a stable anticipatory time scale or motor template and anticipation is a critical element in improving movement quality [1].

Rhythm provides precise anticipatory time cues for the brain to plan and prepare for motor tasks. Rhythmic cues can provide comprehensive information to the brain for optimizing and re-programming movement [1].

The auditory system has a wide distribution of neural connections to motor centers in the spinal cord, brainstem, subcortical, and cortical levels [2-4].

In auditory entrainment (the basis of NMT), the motor period entrains to the period of the auditory rhythm. This not only influences movement timing but also modulates patterns of muscle activation and control of movement in space [5]. Rhythmic cuing for upper extremity movement or for full body coordination in hemiparetic stroke patients [6-11] and children with cerebral palsy [12,13] is an effective rehabilitation strategy. Emerging research shows that speech rate control benefits from rhythmic entrainment using rhythm and music [14-18]. This improves rate dependent aspects of speech such as intelligibility, oral motor control, articulation, voice quality, and respiratory strength. The brain's ability to use entrainment to re-program the execution of a motor pattern also makes rhythmic entrainment an important potential tool for motor rehabilitation [19,20].

Music is defined as a complex, temporally structured sound language which stimulates and integrates brain neuronal pathways in a music-specific way [21]. It affects sensory, motor, perceptive-cognitive and emotional circuits simultaneously [21]. An improved understanding of the scientific foundation of music and its application in rehabilitation is emerging along with new technologies that monitor brain function during musical exposure and production [22].

NMT to address sensory, motor and cognitive dysfunction has been employed in a wide variety of neurologic diseases and cases of developmental delay [22]. Watching, hearing, and performing specific actions during musical activity activates the inferior frontal gyrus, Broca's area. This area integrates sensory-motor information and has multi-modal reception characteristics [22]. Musicians have more gray matter volume in Broca's area than non-musicians [22].

Learning verbal material through song activates different neural networks than learning through verbal presentation does [22]. Music with its metro-rhythmic parameters can play an important role in sensorimotor rehabilitation [22]. Music has also become an important modality in treating epileptic children ever since Frances Rusher et al. discovered the “Mozart effect” which will be discussed later [22]. NMT [23] research has progressed from a social science model to a neuroscience model with applications for clinical practice [21]. Neurological and emotional responses stimulated by music lead to measurable therapeutic effects. This is the basis for music therapy [21,24-26].

Listening to music and playing a musical instrument engage motor and multi-sensory networks, induce changes within those networks and foster linking between distant but functionally related brain regions [27]. Repeated exposure and experience create new and efficient connections between neurons in the brain. This rewiring process is integral to the brain’s plasticity [28]. Music is a potent stimulus for the rewiring process due to its rhythmic patterns which drive priming and timing of the motor system and the rich connections between the auditory and motor systems. NMT offers some advantages over other types of therapy for motor control [28]. Two important findings regarding the application of NMT standout [28].

First, music activates brain networks and areas which are not unique to music processing and second, music based learning increases brain volume and efficiency [28]. Active learning and training optimize rewiring in the injured brain and the recovery of its function [29].

Music can facilitate rehabilitation in congenital or acquired neurological dysfunctions through the induction of emotions and the reward system in the brain [27]. Exposure to music is one of the richest human emotional, sensorimotor and cognitive experiences and is commonly associated with strong emotions such as happiness or sadness (known as Apollo’s gift) [27]. Neurohormonal status modulations induced by music provide a pleasurable experience but also play a role in NMT [27]. Dopamine has a dominant role in the neurobiology of reward based learning and curiosity, and facilitates plastic adaptations in the brain [27]. Dopamine is secreted when a new pleasure is experienced. Serotonin is associated with feelings of Satisfaction [27].

It has also been shown that more aggressive environmental sensory stimuli the more the chance to have Peripheral and central nervous system disorders [30]. Lifestyle factors such as regular good quality of sleep and Physical activities, during the whole life, have tremendous effect On the prevention of neurodegenerative diseases [30]. The frontal lobe is involved in integrating auditory and motor information, imitation and empathy. It has an important role in learning musical skills and emotional expression [27]. The cerebellum is active during a musical experience and involved in timing, rhythm processing, and motor coordination [27].

Finally, the emotive network of the cingulate gyrus, amygdala, hippocampus, and midbrain plays an important role in any musical activity and underlies the motivation to listen to music [27]. Skilled musicians have a larger corpus callosum in response to high demands for bimanual coordination and the rapid exchange of information between hemispheres [31]. Children learning to play a musical instrument [31] show a similar change with greater brain plasticity than adult amateur musicians [32].

Bengtsson et al. [33] and Rueber et al. [34] have found structural differences in the corticospinal tract between musicians and non-musicians. These are most striking in the posterior limb of the internal capsule. They have also identified differences between musician groups, with a difference seen between keyboard players and string instrumentalists [34]. Between-group differences were related to measures of training intensity as well as to the specific demands of the instruments played [34].

Professional musicians tend to have a larger cerebellar gray matter volume than non-musicians. This results from increased and repetitive demands for precise timing, coordination of motor functions, and accuracy when playing a musical instrument [35,36]. Skilled musicians have an enlarged homuncular hand representation in the motor cortex that results from repeated music practice [37]. Music also has a wide variety of other physiological effects on the human body. It can affect the autonomic system. Music can modulate heart rate, respiration, blood pressure, skin conductivity, skin temperature, muscle tension, and multiple biochemical responses [38,39].

Music-supported therapy (MST), in contrast to NMT, is the addition of music to a standard therapy modality in order to reduce the disability burden of coordinative, emotional, or sensory-motor impairment [27]. Music-supported training is more efficient and effective than functional motor training without auditory feedback [27]. Playing music can make rehabilitation therapies more enjoyable and, similar to NMT, help to remediate impaired neural processes or neural connections by engaging and linking brain regions with each other that might otherwise not be linked [27]. Aphasia is the loss of language comprehension (Wernicke aphasia) and/or loss of the ability to produce language (Broca's aphasia) [27].

Aphasia can be classified broadly as fluent (Wernicke's) or non-fluent (Broca's). These types of aphasia result from lesions of the left posterior superior temporal lobe and left posterior inferior frontal lobe respectively [27]. Patients with Wernicke's aphasia have normal articulation with speech comprehension deficits while those with Broca's aphasia have relatively intact comprehension for conversational speech but have marked impairments in articulation and speech production [27].

Singing mainly relies on right hemispheric function and can help people with left hemispheric lesions produce speech by bypassing the injured hemisphere [40]. Learning a list of words in a song activates frontal and temporal brain areas on both sides of the brain while spoken-word learning activates only areas in the left hemisphere [41]. Melodic Intonation Therapy (MIT) engages a sensorimotor network of articulation in the unaffected hemisphere through rhythmic tapping. It was developed [42,43] based upon the clinical observation that patients with severe Broca's aphasia can sing lyrics better than they can speak the identical words [43,44].

MIT increases right-hemisphere network activation [45] and produces volume gains in the right hemisphere arcuate Fasciculus [46,47]. Persistent and continuous use of therapies such as MIT in chronic stroke patients leads to speech output improvements [47]. Stroke ranks fourth among all causes of death in the United States [48]. It is a leading cause of serious physical and cognitive long-term disability in adults [49]. The annual incidence of stroke approaches 800,000 US residents, of which 600, 000 are first events [50]. The USA prevalence (stroke survivors) exceeds 5.7 million but only five percent of these regain full upper extremity function despite intensive rehabilitation [51]. Approximately eighty percent of new stroke survivors each year need hand therapy [52-54].

Few technologies exist to supplement upper extremity exercise and functional retraining-the typical standard rehabilitation program-or the home exercise program for the chronic stroke patient [55].

Rehabilitation can be expensive due to the one by one delivery of care by trained physical or occupational therapists. Access can be limited by service availability, financial problems or other health care issues [55]. Also, home hand therapy devices can be expensive, patients may not be sufficiently motivated and community gyms generally lack suitable equipment to improve hand dexterity [55]. The home program may not be focused on training hand movement for activities of daily living.

The addition of music, along with positive feedback on motor performance, can help to motivate patients [55]. Motivation for training hand motor performance significantly improves by adding music to training session [55]. Adamovich developed a virtual piano trainer to use for regaining finger dexterity. The trainer uses a haptic device (CyberGrasp) worn over a data glove (Cyber Glove) [56]. The system supports the use of a pair of CyberGloves (220 grams) for hand tracking combined with a CyberGrasp (450 grams) to apply variable forces for haptic effects [56]. They designed the game architecture to use various tracking mechanisms to retrieve arm, hand, and finger movement data simultaneously [56]. The system presents the virtual hands in a first person perspective because visual information processing is much easier when one looks at one's own hand rather than someone else's (similar to mirror therapy) [56].

Adamovich et al. trained subjects to move their fingers effectively and to combine hand movements with arm tracking by providing the realistic visual and auditory feedback of a piano keyboard during use of the Virtual Piano Trainer [56]. Subjects ranged from eleven months to seven years post stroke. They were trained ninety minutes per day for eight to nine sessions using the virtual piano trainer. Subjects had mild to moderate impairments and minimal to moderate spasticity and had at least ten degrees of active finger extension. All subjects improved in key press duration, key press time once the note was cued, and accuracy as measured by comparing the number of correctly pressed keys the first time to the total number of keys pressed. In order to manipulate small objects during daily activities, fractionation, or the ability to move each finger independently, is necessary. Use of the virtual piano trainer improved fractionation in all subjects [56].

Rehabilitation progress can be monitored by the objective measurement of hand use during therapy sessions. Motor function can be improved through feedback about movement performance [57]. Nizan and Friedman et al. developed the MusicGlove for such purpose. This is a music based rehabilitation device to help people regain hand function in both clinic and home settings [58].

In a study of 10 chronic stroke patients, the MusicGlove was used with subjects who had severe hand impairment quantified by a

Box and Block score of 7 out of 60 [58]. Most participants in the MusicGlove trial found the device to be a motivating tool and preferred to continue its use for rehabilitation. The MusicGlove based therapy significantly improved hand motor control in post-stroke patients after multiple training sessions compared to a conventional tabletop exercise and isometric movement rehabilitation group [58].

Velocity and walking distance improve in both the laboratory and the community by combining robotic and virtual environment strategies for gait training [59]. Music enhanced this effect in a study focusing on restoration of ability rather than compensatin for a deficit in the acute and sub-acute stages of recovery. Retention of gains was also improved when combining music with multiple tasks in one therapy session [60,61].

Teppo and Sarkamo et al. recruited sixty stroke subjects to test whether coupling VR games, robotic training and music enhances speed, precision, force, attention, and timing during the recovery of arm use [62]. They provided self-selected music CDs and portable CD players to subjects in a music group and portable cassette players with narrated audio books to subjects in a non-music group [63]. Both groups were compared to a control group. Individually, subjects listened to the provided material for a minimum of one hour daily for two months and documented their time in a listening diary [63]. Subjects were assessed at 2 and 6 months. Verbal memory, working and short term memory, visuospatial cognition, language, music cognition, executive functions, sustained attention and focused attention were evaluated by clinical neuropsychological assessment [63].

There were no statistically significant differences between the groups in the baseline demographic, cognitive performance, or Mood. Subjects who listened to their favourite music showed significant improvement in verbal memory and focused attention when compared to those who listened to audio books or received no listening material at 2-months. Subjects who listened to music tended to be less confused and less depressed [63].

A music enriched environment, electrical cortical and peripheral stimulation, and virtual environments will improve post-stroke motor recovery [63]. Music increases not only well-being, attention span and neuropsychological performance but also promotes plastic changes in the motor cortex [64-68]. Mozart's music (K.448) has an anti-epileptic effect in comatose patients [69]. A meta-analysis of 12 studies showed that idiopathic epileptic subjects and those with generalized central discharges associated with a high IQ had significantly decreased epileptic activity, 31.24% during, and 23.74% after exposure to Mozart's music [69].

Interestingly, relaxation without music does not reduce the number of epileptic discharges [70]. Mozart's music has anti-epileptic effects in children as well [71]. Intriguingly, in contrast to the classic piano piece the string version of K. 448 has no effect on epileptiform discharges [72]. The anti-epileptogenic effect of music may result from modulation of dopaminergic pathways or enhancement of parasympathetic tone, both of which can be involved in intractable epilepsy and its treatment [73,74].

Combining acupuncture with an of hour music therapy might be more effective than acupuncture alone in helping children with cerebral palsy acquire gross motor skills (kneeling, walking, standing and crawling) and can reduce anxiety during therapy [75]. Using background music during pediatric physical therapy sessions reduces the amount of crying and increases parent's satisfaction [76].

Several virtual reality models have been developed for the assessment and training of neglect, which occurs in 50% of right hemispheric stroke patients [77]. These include the virtual supermarket [78-80], virtual wheelchair navigation [81] and a three-dimensional virtual street [82]. Listening to preferred music while engaged in a virtual reality task increases visual awareness versus adding non-preferred music or omitting music altogether [83].

Combining rhythmic music listening with a specialized rehabilitation program improves gait velocity, stride length, symmetry, interpersonal relationships and mood in post stroke patients in comparison to the rehabilitation program alone [84]. Environmental stimulation enhances the plastic changes happening in the brain during the first months of recovery after stroke [85,86]. Adding auditory, visual and olfactory stimuli to an enriched motor environment enhances motor and cognitive recovery more than an enriched motor environment alone [87].

Discussion and Conclusion

Music is a universal language with useful applications as therapy for patients with a neurological based disability. Its effects are mediated through neuromodulation and impact mood, body function, inter-personal communication, learning, and memory. Music can facilitate recovery from hereditary and acquired neurologic conditions. Listening to and producing music are useful methods to help address disabilities related to motor weakness, language deficits, impaired memory, cognitive dysfunction and epilepsy. NMT, MST and MIT are inexpensive methods to help patients recover during the initial months following stroke. NMT is recognized by the World Federation of Neurorehabilitation and should become a standard tool for rehabilitation care [88].

Neurologic Music Therapy has become a distinct science that is taught worldwide. Music therapists have become members of rehabilitation teams in many hospitals. As this science develops it will become more focused with clearer applications and protocols for effecting neurological repair and recovery of function through the use of specific types of music and musical Instruments.

References

1 Thaut MH, McIntosh GC, Hoemberg V (2015) Neurobiological foundations of neurologic music therapy: Rhythmic entrainment and the motor system. Front Psychol 5: 1185.

2 Koziol LF, Budding DE (2009) Subcortical structures and cognition: Implications for neuropsychological assessment. Springer Science & Business Media, Germany.

3 Schmahmann JD, Pandya DN (2009) Fiber pathways of the brain. New York, NY: Oxford: Oxford University Press, USA.

4 Felix RA, Fridberger A, Leijon S, Berrebi AS, Magnusson AK (2011) Sound rhythms are encoded by post inhibitory rebound spiking in the superior paraolivary nucleus. J Neurosc 31: 12566-12578.

5 Thaut MH, Kenyon GP, Schauer ML, McIntosh GC (1999) The connection between rhythmicity and brain function. IEEE Eng Med Biol Mag 18: 101-108.

6 Luft AR, McCombe WS, Whitall J (2004) Repetitive bilateral arm training and motor cortex activation in chronic stroke: A randomized controlled trial JAMA 292: 1853-1861.

7 McCombe-Waller S, Harris LM, Liu W, Whitall J (2006) Temporal coordination of the arms during bilateral simultaneous and sequential movements in patients with chronic hemiparesis. Exp Brain Res 168: 450-454.

8 Schneider S, Schoenle PW, Altenmueller E, Muente T (2007) Using musical instruments to improve motor skill recovery following stroke. J Neurol 254: 1339-1346.

9 Altenmueller E, Marco PJ, Muente TF, Schneider S (2009) Neural reorganization underlies improvement in stroke-induced motor dysfunction by music supported therapy. Ann NY Acad Sci 1169: 395-405.

10 Malcolm MP, Massie C, Thaut MH (2009) Rhythmic auditory-motor entrainment improves hemiparetic arm kinematics during reaching movements. Topics in Stroke Rehabil 16: 69-79.

11 Grau SJ, Armengual JL, Rojo N, Rubio F, Altenmueller E, et al. (2013) Plasticity in the sensorimotor cortex induced by music-supported therapy in stroke patients: A TMS-study. Front Hum Neurosci 7: 494.

12 Peng Y, Lu T, Wang T, Chen Y, Liao H, et al. (2010) Immediate effects of therapeutic music on loaded sit-to-stand movement in children with spastic diplegia. Gait Posture 33: 274-278.

13 Wang TH, Peng YC, Chen YL, Lu TW, Liao HF, et al. (2013) A home-based program using patterned sensory enhancement improves resistance exercise effects for children with cerebral palsy: A randomized controlled trial. Neurorehabil Neural Repair 27: 684-694.

14 Pilon MA, McIntosh KW, Thaut MH (1998) Auditory versus visual timing cues as external rate control to enhance verbal intelligibility in mixed spastic-ataxic dysarthric speakers: A pilot study. Brain Inj 12: 793-803.

15 Wambaugh JL, Martinez AL (2000) Effects of rate and rhythm control treatment on consonant production accuracy in apraxia of speech. Aphasiology 14: 851-871.

16 Thaut MH, McIntosh GC, McIntosh KW, Hoemberg V (2001) Auditory rhythmicity enhances movement and speech motor control in patients with Parkinson's disease. Funct Neurol 16: 163-172.

17 Natke U, Donath TM, Kalveram KT (2003) Control of voice fundamental frequency in speaking versus singing. J Acoust Soc Am 113: 1587-1593.

18 Lim K, Kim Y, Lee H, Yoo J, Hwang J, et al. (2013) The therapeutic effect of neurologic music therapy and speech language therapy in post-stroke aphasic patients. Ann Rehabil Med 37: 556-562.

19 Thaut MH, Abiru M (2010) Rhythmic auditory stimulation in rehabilitation of movement disorders: A review of current research. Music Perception 27: 263-269.

20 Thaut MH, McIntosh GC (2014) Neurologic music therapy in stroke rehabilitation. Curr Phys Med Rehabil Rep 2: 106-113.

21 De l'Etoile S (2011) Processes of music therapy: Clinical and scientific rationales and models. The `Oxford Handbook of Music Psychology. New York, NY: Oxford University Press, USA. pp. 493-502.

22 Galińska E (2015) Music therapy in neurological rehabilitation settings. Psychiatr Pol 49: 835-846.

23 Thaut MH (2005) Rhythm, music and the brain: Scientific foundations and clinical applications. Routledge, UK.

24 Altenmüller E, Schlaug G (2013) Neurologic music therapy: The beneficial effects of music making on neurorehabilitation. Acoust Sci Technol 34: 5-12.

25 Tomaino CM (1993) Music and limbic system: Current research in arts and medicine. Music, science, and the rhythmic brain: Cultural and implications. A Capella Books. Chicago, USA. 393-398.

26 Schlaug G (2011) Music, musicians, and brain plasticity. The Oxford Handbook of Music Psychology. Oxford University Press, UK. pp. 197-207.

27 Eckart A, Gottfried S (2015) Apollo's gift: New aspect of neurologic music therapy. In: Eckert A, Stanley F, Francois B, (eds). Music, neurology, and neuroscience: Evolution, the musical brain, medical conditions, and therapies. Elsevier, Netherlands. 217: 237-252.

28 Thaut MH, McIntosh GC (2010) How music helps to heal the injured brain: Therapeutic use crescendos thanks to advances in brain science, Cerebrum.

29 Hummelsheim H (1999) Rationales for improving motor function. Curr Opi Neurol 12: 697-701.

30 Sosso FAE (2017) Negative involvement of the working environment in the occurrence of cognitive disorders. Trans Biomed 18: 2.

31 Hyde KL, Lerch J, Norton A, Forgeard M, Winner E, et al. (2009) Musical training shapes structural brain development. J Neurosci 29: 3019-3025.

32 Bangert M, Altenmüller E (2003) Mapping perception to action in piano practice: A longitudinal DC-EEG-study. BMC Neurosci 4: 26-36.

33 Bengtsson SL, Nagy Z, Skare S, Forsman L, Forssberg H, et al. (2005) Extensive piano practicing has regionally specific effects on white matter development. Nat Neurosci 8: 1148-1150.

34 Rueber T, Lindenberg R, Schlaug G (2015) Differential adaptation of descending motor pathways in musicians. Cereb Cortex 25: 1490-1498.

35 Gaser C, Schlaug G (2003) Brain structures differ between musicians and non-musicians. J Neurosci 23: 9240-9245.

36 Hutchinson S, Lee LHL, Gaab N, Schlaug G (2003) Cerebellar volume: Gender and musicianship effects. Cereb Cortex 13: 943-949.

37 Amunts K, Schlaug G, Jäncke L, Steinmetz H, Schleicher A, et al. (1997) Motor cortex and hand motor skills: Structural compliance in the human brain. Hum Brain Mapp 5: 206-215.

38 Hodges DA (2010) Psychophysiological measures. Handbook of music and emotion. Oxford University Press, UK. pp. 279-311.

39 Kreutz G, Quiroga M C, Bongard S (2012) Psychoneuroendocrine research on music and health. In: Raymond M, Gunter K, Laura M (eds). Music, health, and wellbeing. Oxford University Press, UK. pp. 457-476.

40 Belin P, Van Eeckhout P, Zilbovicius M (1996) Recovery from non-fluent aphasia after melodic intonation therapy. Neurology 47: 1504-1511.

41 Thaut MH, Peterson DA, McIntosh GC (2005) Temporal entrainment of cognitive functions: Musical mnemonics induce brain plasticity and oscillatory synchrony in neural networks underlying memory. Annals of the New York Academy of Sciences 1060: 243-254.

42 Albert ML, Sparks RW, Helm NA (1973) Melodic intonation therapy for aphasia. Arch Neurol 29: 130-131.

43 Schlaug G, Norton A, Marchina S, Zipse L, Wan CY (2010) From singing to speaking: Facilitating recovery from nonfluent aphasia. Future Neurol 5: 657-665.

44 Sparks RW, Holland AL (1976) Melodic intonation therapy for aphasia. J Speech Hear Disord 41: 287-297.

45 Schlaug G, Marchina S, Norton A (2008) From singing to speaking: Why patients with Broca's aphasia can sing and how that may lead to recovery of expressive language functions. Music Percep 25: 315-323.

46 Schlaug G, Marchina S, Norton A (2009) Evidence for plasticity in white-matter tracts of patients with chronic Broca's aphasia undergoing intense intonation-based speech therapy. Ann NY Acad Sci 1169: 385-394.

47 Wan C, Zheng X, Marchina S, Norton A, Schlaug G (2014) Intensive therapy induces contralateral white matter changes in chronic stroke patients with Broca's aphasia. Brain Lang 136: 1-7.

48 www.cdc.gov/nchs/data/mortab/1999-2009CMFDocumentationR.pdf

49 Bault MW, Hootman J, Helmick CG, Theis KA, Armour BS (2009) Prevalence and most common causes of disability among adults-USA. Centers for Disease Control and Prevention CDC 58: 421-426.

50 Go AS, Mozaffarian D, Roger VL (2014) American heart association statistics, committee, and stroke statistics subcommittee. Heart disease and stroke statistics update: A report from the American heart association circulation 129: 282-292.

51 Gowland C, DeBruin H, Basmajian JV, Plews N, Burcea I (1992) Agonist and antagonist activity during voluntary upper-limb movement in patients with stroke. Phys Ther 72: 624-633.

52 Parker VM, Wade DT, Langton HR (1986) Loss of arm function after stroke: Measurement, frequency, and recovery. Int Rehabil Med 8: 69-73.

53 Heller A, Wade DT, Wood VA, Sunderland A, Hewer RL, et al. (1987) Arm function after stroke: Measurement and recovery over the first three months. J Neurol Neurosurg Psychiatry 50: 714-719.

54 Bard G, Hirschberg GG (1965) Recovery of voluntary motion in upper extremity following hemiplegia. Arch Phys Med Rehabil 46: 567-572.

55 Friedman N, Chan V, Bachman M, Reinkensmeyer DJ, Reinkensmeyer AN, et al. (2014) Retraining and assessing hand movement after stroke using the MusicGlove: Comparison with conventional hand therapy and isometric grip training. J Neuroeng Rehabil 11: 76.

56 Adamovich SV, Fluet GG, Mathai A, Qiu Q, Lewis J (2009) Design of a complex virtual reality simulation to train finger motion for persons with hemiparesis: A proof of concept study. J Neuroeng Rehabil 6: 28.

57 Dobkin BH, Plummer DP, Elashoff R, Lee J (2010) International randomized clinical trial, stroke inpatient rehabilitation with reinforcement of walking speed (SIRROWS), improves outcomes. Neurorehabil Neural Repair 24: 235-242.

58 Friedman N, Chan V, Zondervan D, Bachman M, Reinkensmeyer DJ (2011) MusicGlove: Motivating and quantifying hand movement rehabilitation by using functional grips to play music. Annu Int Conf IEEE, Eng Med Biol Soc 1: 2359-2363.

59 Mirelman A, Bonato P, Deutsch JE (2008) Effects of training with a robot-virtual reality system compared with a robot alone on the gait of individuals after stroke. Stroke 40: 169-174.

60 Huang VS, Krakauer JW (2009) Robotic neurorehabilitation: A computational motor learning perspective. J Neuroeng Rehabil 6: 5.

61 Da Silva C M, Bermúdez I, Badia S, Duarte E, Verschure PF (2011) Virtual reality based rehabilitation speeds up functional recovery of the upper extremities after stroke: A randomized controlled pilot study in the acute phase of stroke using the rehabilitation gaming system. Restor Neurol Neurosci 29: 287-298.

62 Takahashi CD, Der YL, Le V, Motiwala RR, Cramer S C (2008) Robot-based therapy after stroke. Brain 131: 425-437.

63 Särkämö T, Tervaniemi M, Laitinen S, Forsblom A, Soinila S, et al. (2008) Music listening enhances cognitive recovery and mood after middle cerebral artery stroke. Brain A J Neurol 131: 866-876.

64 Altenmüller E, Marco PJ, Münte TF, Schneider S (2009) Neural reorganization underlies improvement in stroke-induced motor dysfunction by music-supported therapy: The Neurosciences and Music III, Disorders and Plasticity. Ann NY Acad Sci 1169: 395-405.

65 Russo NM, Nicol TG, Zecker SG, Hayes EA, Kraus N (2005) Auditory training improves neural timing in the human brainstem. Behav Brain Res 156: 95-103.

66 Meyer M, Elmer S, Baumann S, Jancke L (2007) Short-term plasticity in the auditory system: Differential neural responses to perception and imagery of speech and music. Restor Neurol Neurosci 25: 411-431.

67 Baumann S, Koeneke S, Schmidt CF, Meyer M, Lutz K, et al. (2007) A network for audio-motor coordination in skilled pianists and non-musicians. Brain Res 1161: 65-78.

68 Koelsch S (2009) A neuroscientific perspective on music therapy: The neurosciences and music III, disorders and plasticity. Ann NY Acad Sci 1169: 374-384.

69 Dastgheib SS, Layegh P, Sadghi R, Fovoughipur M, Shoeibi A, et al. (2014) The effects of Mozart's music on interictal activity in epileptic patients: Systematic review and meta-analysis of the literature. Curr Neurol Neurosci Rep 14: 420.

70 Lin LC, Lee WT, Wang CH, Chen HL, Wu HC, et al. (2011) Mozart K.448 acts as a potential add-on therapy in children with refractory epilepsy. Epilepsy and Behav 20: 490-493.

71 Lin LC, Lee WT, Wu HC, Tsai CL, Wei RC, et al. (2011) The long-term effect of listening to Mozart K.448 decreases epileptiform discharges in children with epilepsy. Epilepsy Behav 21: 420-424.

72 Lin LC, Lee WT, Wu HC, Tsai CL, Wei RC, et al. (2010) Mozart K. 448 and epileptiform discharges: Effect of ratio of lower to higher harmonics. Epilepsy Res 89: 238-245.

73 Lin LC, Lee MW, Wei RC, Mok HK, Wu HC, et al (2010) Mozart K. 545 mimics Mozart K.448 in reducing epileptiform discharges in epileptic child. Epilepsy Res 89: 238-245.

74 Sutoo D, Akiyama K (2004) Music improves dopaminergic neurotransmission: Demonstration based on the effect of music on blood pressure regulation. Brain Res 1016: 255-262.

75 You Hb, Liu Yf, Wu Lx (2009) Acupuncture combined with music therapy for treatment of 30 cases of cerebral palsy. J Tradit Chin Med 29: 243-248.

76 Rahlin M, Cech D, Rheault W, Stoecker J (2007) Use of music during physical therapy intervention for an infant with Erb's palsy: A single-subject design. Physiother Theory Pract 23: 105-117.

77 Johansson BB (2012) Multi-sensory stimulation in stroke rehabilitation. Front Hum Neorosci 6: 60

78 Ansuini C, Pierno AC, Lusher D, Castiello U (2006) Virtual reality applications for the remapping of space in neglect patients. Restor Neurol Neurosci 24: 431-441.

79 Broeren J, Samuelsson H, Blomstrand C, Stibrant S KS, Rydmark M (2007) Neglect assessment as an application of virtual reality. Acta Neurol Scand 116: 157-163.

80 Rand D, Katz N, Weiss PL (2009) Intervention using the V-Mall for improving motor and functional activity of the upper extremity in post stroke participants. Eur J Phys Rehabil Med 45: 113-121.

81 Buxbaum LJ, Palermo MA, Mastrogiovanni D, Read MS, Rosenberg-Pitonyak E, et al. (2008) Assessment of spatial attention and neglect with a virtual wheelchair navigation task. J Clin Exp 30: 650-660.

82 Kim DY, Ku J, Chang WH, Park TH, Lim JY, Han K, et al. (2010) Assessment of post-stroke extrapersonal neglect using a three-dimensional immersive program. Acta Neurol Scandinavica 121: 171-177.

83 Soto D, Funes MJ, Guzmán G A, Warbrick T, Rotshtein P, et al. (2009) Pleasant music overcomes the loss of awareness in patients with visual neglect. Proceedings Natl Acad Sci USA 106: 6011-6016.

84 Jeong S, Kim MT (2007) Effects of a theory-driven music and movement program for stroke survivors in a community setting. Appl Nurs Res 20: 125-131.

85 Witte OW (1998) Lesion-induced plasticity as a potential mechanism for recovery and rehabilitative training. Curr Opin Neurol 11: 655-662.

86 Kreisel SH, Bazner H, Hennerici MG (2006) Pathophysiology of stroke rehabilitation: Temporal aspects of neuro-functional recovery. Cerebrovasc Dis 21: 6-17.

87 Maegele M, Lippert-Gruener M, Ester-Bode T, Sauerland S, Scha Fer U, et al. (2005) Reversal of neuromotor and cognitive dysfunction in an enriched environment combined with multimodal early onset stimulation after traumatic brain injury in rats. J Neurotrauma 22: 772-782.

88 Hoemberg V (2015) Evidence-based medicine in neurologic rehabilitation: A critical Review. Acta Neurochirurgica 93: 3-14.