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Music therapy in neurological rehabilitation settings

Elżbieta Galińska

Neurosis Clinic, Institute of Psychiatry and Neurology in Warsaw

Summary

The neurologic music therapy is a new scope of music therapy. Its techniques deal with dysfunctions resulting from diseases of the human nervous system. Music can be used as an alternative modality to access functions unavailable through non-musical stimulus. Processes in the brain activated by the influence of music can be generalized and transferred to non-musical functions. Therefore, in clinical practice, the translation of non-musical therapeutic exercises into analogous, isomorphic musical exercises is performed. They make use of the executive peculiarity of musical instruments and musical structures to prime, cue and coordinate movements. Among musical components, a repetitive rhythm plays a significant role. It regulates physiologic and behavioural functions through the mechanism of entrainment (synchronization of biological rhythms with musical rhythm based on acoustic resonance). It is especially relevant for patients with a deficient internal timing system in the brain. Additionally, regular rhythmic patterns facilitate memory encoding and decoding of non-musical information hence music is an efficient mnemonic tool. The music as a hierarchical, compound language of time, with its unique ability to access affective/motivational systems in the brain, provides time structures enhancing perception processes, mainly in the range of cognition, language and motor learning. It allows for emotional expression and improvement of the motivation for rehabilitation activities. The new technologies of rhythmic sensory stimulation (i.e. Binaural Beat Stimulation) or rhythmic music in combination with rhythmic light therapy appear. This multimodal forms of stimulation are used in the treatment of stroke, brain injury, dementia and other cognitive deficits. Clinical outcome studies provide evidence of the significant superiority of rehabilitation with music over the one without music.

Key words: neurologic music therapy, neurobiological mechanisms of action of music, neurologic music therapy interventions

Introduction

A number of brain researches, especially on neuroplasticity and cortical reorganization has increased with regard to the development of new neuroscience technologies (PET and fMRI) which allow to observe the brain activity during the performance of different mental tasks. As a result the cognitive neuroscience, also in clinical range, has developed significantly. The fMRI technique allows for a more detailed localization of areas that are implicated in the generation of psychopathological symptoms, e.g. it helps to identify the auditory cortex activity accompanying auditory hallucinations in schizophrenia. On the other hand, it might be used to identify areas that support coping strategies, resilience as well as treatment effects [1].

A possibility of the brain monitoring during the processing of musical information and musical production has contributed to better understanding of how music "works" in therapy and to elaborate more precisely the scientific foundation of music therapy. The previous approach to music therapy from perspective of social sciences does not explain how music functions in therapy as the agent of change. Behavioural, psychoanalytic and humanistic approaches have been valued music for its ability to facilitate emotional expression and social integration [2]. While these effects continue to have merit in contemporary practice, the advent of modern research techniques, since 1990s, in cognitive neuroscience, such as brain imaging, brain-wave recordings and kinematic motor analysis, have provided a greater understanding of the neural processes involved in the perception and production of music [3]. Consequently music therapy has evolved from a social science model to a neuroscience model of clinical practice and research [3]. This paradigm shift has resulted in the formation of a new theory known as Neurologic Music Therapy (NMT) [2]. The NMT techniques address cognitive, sensory and motor dysfunction resulting from disease of the human nervous system. They are used in neurological rehabilitation, neuropediatric therapy, neurogeriatric therapy and neurodevelopmental therapy.

The peculiarity of music as a multisensory stimulus in neurological rehabilitation

The music from neurologic perspective is defined as "complex, temporally structured sound language arouses the human brain on a sensory, motor, perceptive-cognitive and emotional level simultaneously and stimulates and integrates neuronal pathways in a music-specific way" [4, p. 526]. Current clinical research indicates that music can stimulate processes in the brain, which can be generalized and transferred to non-musical functions, resulting in measurable therapeutic effects [2, 5–7]. This is possible because music is processed in many areas of the brain. The listening to music activates not only the auditory areas, but large networks throughout the brain. The whole brain reacts to music, although in very different ways. A prominent component of this brain network responsible for multimodal reception and sensimotor integration is the posterior inferior frontal gyrus (IFG), commonly referred to as Broca's area. It has been shown that the IFG is activated when one hears, sees or performs specific actions, especially during the musical activities. This is commonly described as putative human mirror neuron system which is considered as a hypothetical supramodal and hierarchical processor [7]. The morphometric studies [8] found more grey matter volume in the inferior frontal gyrus in musicians compared with non-musicians. This result is convergent with the fact, that learning to associate actions with particular sounds and musical training of non-musicians leads to functional, but also structural changes in frontal cortices [5, 7–10]. Musical training is simultaneously the training of the inferior frontal gyrus and results in a cross-model transfer of acquired skills which results in improvement of behavioural and cognitive functioning. This phenomenon is defined as cross-modal plasticity of the brain [7].

The whole brain reacts to music, but its different areas react to different components of music, e.g. the pitch is processed in the right temporal lobes – the same area that governs speech prosody [11, 12]. The processing of rhythmic cues involves the prefrontal motor cortex, the cerebellum, and other areas resulting in the stimulation of various neural networks [13]. The limbic areas of the brain, known to be associated with emotions, are involved in the rhythm and tonality processing. The brain areas related to emotion and reward have been found to be activated during intensely pleasurable moments of music listening. Memory systems can be stimulated by the associative memories connected to a particular piece of music or the harmonic structures that induce emotional responses [6].

Some areas of neural processing of musical and non-musical functions' elements are common (i.e. the same systems process both musical and non-musical stimuli), and others are distinctive. For example, speech and singing are mediated by different neural networks [12, 13]. Music regulates attention and arousal in the brain in a complex, bilaterally distributed fashion. Learning verbal material through song accesses different neural network configurations than learning through verbal presentation. The result of the complex interaction of music with areas distributed throughout the brain is that it has the ability to engage additional areas and connections in patients with neurological disabilities. Music can be used as an alternative modality to access functions unavailable trough non-musical stimulus, or provide alternative transmission routes for information processing in the brain [2, 5–8].

Mechanisms of music in neurologic music therapy

Michael Thaut [2], in the USA presumed as the creator of neurological music therapy, identifies four mechanisms of music in neurological rehabilitation:

1. Rhythmic stimulation and entrainment – the tuning to "musical pulsation", the synchronization of biological rhythms with musical rhythms (from neuronal activity, through breathe, heart, brain and other rhythms and to complex physiological systems) is based on the phenomenon of acoustic resonance [9]. "Entrainment describes a process whereby two rhythmic processes interact with each other in such a way that they adjust towards and eventually 'lock in' to a common phase and/or periodicity" [14, p 11]. Through the mechanism of entrainment the musical rhythm regulates physiological and behavioural functions. Rhythmic stimulation has an influence on the process of temporal coordination and organization of sensory material, especially in motor control and speech. Rhythmic entrainment provides immediate time regulation as well as templates for spatial orientation and shapes dynamics. Auditory entrainment concerns also the listener's mood, which adjusts immediately according to music emotionality;
2. Patterned information processing. Music is a very complex temporal stimulus structured in various types of patterns – from the spectral patterns of its psychoa-

coustical foundations to the hierarchical rhythmic structure of the layer of musical pattern. Timing is a key component of neural information processing [15]. Musical rhythm patterns and synchronization help in creating temporal structure in neural network activation. Researches suggest that music can uniquely engage the brain as a language of time. Physical exercise accompanied by music can enhance strength and endurance, muscle tone, flexibility, agility, body control, vital capacity, and cardiovascular efficiency. Music becomes not only a motivator for movement, but also provides a rhythmic structure to pace and cue movement patterns for instance in Parkinson's disease. This technique is defined as patterned sensory enhancement. It uses the musical patterns to create functional movement patterns and sequences and to enhance direction and accuracy of single movements of arms and hands e.g. during reaching and grasping;

3. Differential neurological processing of musical components by means of different, not only auditory (described above), brain structures. This property allows for an access to deficient regions and for compensatory takeover of their functions through alternative transmission routes and connections. It is possible because neural processing systems for some musical and non-musical functions are common, and in the case of others are distinctive [2]. The switching, and thus restoration, of functions occur due to plasticity of the brain, i.e. an ability of neural cells to create new connections, especially as a result of musical training [5, 7, 8, 10, 16]. (compare the neurological priming through musical stimulus);
4. Affective-aesthetic response: arousal, motivation, emotions. Music is a powerful stimulus that induces [17] and communicates emotions and meaning through the perception of its intrinsic symbolic structure of musical elements, as well as through emotional responses that have become connected to it through an associative learning process [18]. The music is characterized by an unique ability to access affective-motivational systems in the brain, which have an important regulatory functions in organization of behaviour, change of behaviour and in learning. Attention, perception, memory, learning, executive functions and physical responses can be effectively influenced by appropriate affective states. It is considered a major mechanism of therapeutic effectiveness of music therapy.

Results of clinical studies

Among music elements, metrorhythmic factor, i.e. meter and rhythm as well as all sorts of patterns of temporal organization of music, plays an important role in neurological rehabilitation, especially sensorimotor rehabilitation. The rhythm provides a temporal structure for movement exercises through metrical organization, predictability and patterning. Auditory rhythm is a powerful sensory cue that can regulate motor timing and coordination in the presence of a deficient internal timing system in the brain [4]. In neurological music therapy, rhythm has stimulating, cueing and coordinative function, through the mechanism of entertainment.

Clinical research (for review see [4]) has shown a statically significant superiority of the rehabilitation with music with regard to the kinematic parameters, compared to the rehabilitation without music. For instance, in hemiparetic motor rehabilitation rhythm enhanced stride symmetry and stride length symmetry, and introduced more differentiated patterns of muscle activity in EMG between paretic and non-paretic leg. In Parkinson's disease (PD) rhythmic stimuli helped to initiate movement and regulated a tread. The patients with PD received 3–4 weeks exercise programme which consisted of 30 minutes of walking with music each day. A superiority of metronome stimulation as compared to music stimulation was observed; that was different compared to healthy subjects [19]. Rhythmic metronome stimulation turned out to be useful in improvement of the quality of spatio-temporal mobility in patients after a stroke [5]. However, there are some PD patients for whom the accent has to be on the upbeat (falls between their steps). The upbeat pulse gives them a lift to free their movement [13]. Similarly, the patients examined 20 months after a stroke onset who had been playing with paretic hand on a "delayed" keyboard (which produces a tone randomly delayed by the time interval between 100 and 600ms, which gives delayed auditory feedback) improved strikingly in fine motor skills (nine-hole-pegboard test, after 15 sessions (three weeks) of playing with paretic hand on the "delayed" keyboard) compared to the group playing on the normal keyboard [5]. These results question the role of anticipation and efficiency of precise or mechanical rhythmic regularity of signalling, especially with metronome. It is hypothesised that the patients playing on the modified musical instrument implicitly learn to be independent of the auditory feedback [5].

Music can facilitate awaking from coma. For example, in Poland at the University Hospital in Bydgoszcz for children after CNS hypoxic ischemic injury, as well as in the "alarm clock" Clinic in Miedzylesie Hospital in Warsaw, about 2 hours a day of relaxation music with a frequency of 5–8 Hz are applied [20]. Active music therapy in the form of playing improvisations on instruments, singing and vocals in the dialogue with a therapist according to Nordoff-Robbins has been applied to patients during recovery from prolonged coma (mean duration: 52 days), and a mean interval from coma onset to the beginning of rehabilitation was 154 days on average [21]. It consisted of musical improvisation between patient and therapist by singing or by playing different musical instruments, according to the vital functions, the neurological conditions and the motor abilities of the patients. Music therapy started 15 days after the starting of the routine rehabilitation programme. The inclusion criterion for the study was the lack of verbal initiative and the minimal state of consciousness (GCS < 8). Music therapy was applied 3 times a week for 20–40 minutes depending on the patient's level of attention. It played the role of nonverbal communication. The results showed a significant improvement in the communication and interactive skills as well as a reduction of undesired behaviours such as inertia or psychomotor agitation, but only after a month of music therapy (multiple measurements) [21].

Music has gained a special importance in the treatment of children with epilepsy, especially since 1993, when Frances Rausher et al. discovered the so-called Mozart Effect. They noted that cognitive functions are positively influenced by Sonata for Two Pianos in D Major, K.448. This term soon embraced all the positive effects of music [22]. Although the Mozart Effect is equivocal when it comes to improve patients' IQ (see meta-analysis of 40 studies; effect size 0.37 [23]), but there is no dispute with regard to the treatment of epilepsy. Multiple replication studies have confirmed the anti-epileptic effect of Mozart' music (K. 448) also in patients in a coma [24], as well as in the animal study [25]. This is extremely important because the relaxation without music does not reduce the number of epileptic seizures [26] as well as sometimes (30%) medication is ineffective [26]. Usually the patients listen to Mozart K.448 (Allegro con spirito) for 8 minutes (8.22) once a day before bedtime for 6 months. The epileptiform discharges in children with epilepsy decrease during listening to music and persists after listening [27]. It was shown that piano Sonata in C major K. 545 reduces the number of discharges in the same way [28] (loudness levels of both sonatas was between 60 and 70 dB). The characteristics of the acoustic spectrum (harmonics) of K. 545 were similar to those of K. 448. It is worth noting that the two sonatas are in the same major key, which may have a positive effect on mood. Piano plays a key role here because the string version of K. 448 did not reduce the epileptiform discharges [29]. Positive influence of Mozart's music was observed in the patients with generalized epilepsy, centrencephalic epilepsy and treatment-resistant epilepsy [26]. This is confirmed by a meta-analysis of 12 studies indicating that in 84% of patients there was a statistically significant decrease in interictal epileptic discharges during (by 31.24 %) and after (23.74 %), listening to Mozart's music, especially in those with a higher IQ and generalized and central discharges as well as in those with idiopathic epilepsy [24]. An increase in discharges during listening to k.448 was observed in case of occipital seizures, especially when accompanied by mental retardation [27]. The authors speculate that perhaps the occipital cortex is not involved in the processing of music information. Mukherjee et al. [30] report that lower parasympathetic reactivity, and more severe dysautonomia are found in patients with intractable epilepsy. It is possible that musical enhancing parasympathetic tone may account for the beneficial effects on epilepsy. On the other hand, it is possible that listening to music modifies the dopaminergic pathways contributing to beneficial effects in the treatment of epilepsy [28, 31] (Mozart, Divertimento in D major K.205 was studied).

Clinical techniques of music therapy in neurological rehabilitation

In regard to the empirically verified transfer of the brain processes induced by music on non-musical functions, in the clinical practice the therapeutic exercises and stimuli are translated into analogous musical exercises. Thaut [2] defines them as isomorphic in relation to non-musical ones, because they share the same functional structure[1]. Music should provide aesthetic motivation and have artistic value, i.e. should characterise with adequate level of formal complexity and include optimal musical patterns for rehabilitation exercises (e.g. the upward interval in melodic line can pave upward movement of the hand).

There are dozens of neurological music therapy which focus on three areas of action: sensorimotor (see above), speech and language (melodic intonation therapy e.g. for patients with Broca's aphasia, speech stimulation, rhythmic speech cuing to

[1] In Poland the notion of isomorphism was introduced into music therapy by Galińska already in the 1980s

control the initiation and rate of speech e.g. for patients with Parkinson's disease, dysarthria [13, 32], vocal intonation therapy, therapeutic singing, oral motor and respiratory exercises e.g. in the treatment of dysphagia patients after stroke, developmental speech and language training trough music [33], symbolic communication training through music), and cognitive (musical sensory orientation training, musical neglect training, auditory perception training, musical attention control training, musical mnemonics training, associative mood and memory training, musical executive function training) [4, 34]. Acupuncture, which is introduced in the treatment of cerebral palsy in children, is significantly more effective regarding gross motor skills (crawling, kneeling, standing and walking) and anxiety reduction, when combined with one hour of music therapy (84 days therapy of 30 min. of listening to preferred music during acupuncture and 30 min. of playing on musical instruments, singing or dancing following acupuncture) [35]. Vibro-acoustic techniques reinforcing low frequency sounds 40, 60 and 80 Hz are also used [9]. Introducing background music during physical therapy intervention for little children e.g. with Erb's palsy, reduced the amount of crying and increased satisfaction of parents who had been incorporated into treatment [36]. Uncoordinated patterns of the relationship between mother and child were also tested and modified [37].

It is worth noting that in addition to musical elements such as meter and rhythm, tempo, melody, harmony, timbre, dynamics, etc. the musical instrument plays an important role in neurological rehabilitation. Various groups of instruments can be useful in certain disorders. For example, to play the ganzá, the strong right arm wrist spin is necessary, for the djembe drum reverberated while playing, it is necessary to stick it firmly between the knees. In order to increase lung capacity, deepen the breath and oxygenate the patient, you can offer him playing the flute. The number of appropriate instruments useful for the purposes of rehabilitation is practically endless here, furthermore, the instruments can be used in an unconventional way and placed in various locations to facilitate practice of the desired functional movements (also they can be modified like a "delayed" keyboard; see above). Similarly, there are endless opportunities to work with music and singing in the rehabilitation of speech and language, especially in the case of aphasia or dysarthria, and in training of cognitive functions such as attention, perception, memory [13, 38]. For example, in patients with multiple sclerosis the superior learning and memory increased when patients had been learning verbal material in the form of a song. The EEG showed a significant increase in the coherence in low-alpha band in bilateral frontal networks, which is not present without music [38]. Music (favourite songs) evoked autobiographical memories in patients after a stroke, and the evoked memories were positive [39]. The use of NMT in patients with middle cerebral artery stroke in the early recovery phase (measured 1 week, 3 months, and 6 months after the stroke) indicated that: 1) listening to pleasant music can have a short-term facilitating effect on visual awareness in patients with visual neglect, which is associated with functional coupling between emotional and attentional brain regions; 2) daily, long-term music listening can improve auditory and verbal memory, focus of attention, and mood, as well as induce structural gray matter changes in the early poststroke stage [40].

Music is an extremely effective mnemonic tool, both in the treatment of neuro-degenerative diseases (e.g. Parkinson's disease) and in the treatment of children with attention deficits, memory and learning difficulties (e.g. ADHD). In 65% of children and adolescents diagnosed with ADHD, the prefrontal cortical deactivation was found (4–8Hz, theta). It began when the individual had been asked to perform mental tasks (in contrast to those without ADHD). Researchers have hypothesized that this is one of the causes of hyperactivity in children, which should be understood as the need of external stimulation. Music can easily regulate the levels of sensory stimulation and affect brain wave patterns [41]. New techniques of music relaxation are created for this purpose, such as recorded soundtrack (20 minutes) which begins with the fast music, adjusted to the patient's state of arousal and anxiety (iso principle)[2] and gradually slows the pace, for example, to reduce excessive involuntary movements or dyskinesia, overactive respiration and heart rate, and consequent to facilitate falling sleep in patients with PD and Huntington's disease [13].

Recent neurological rehabilitation techniques are based on new technologies such as stimulation via the so-called Binaural Beat Stimulation [42]. It is a special type of rhythmic auditory stimulation that requires two sine tones, one presented to each ear, differing in frequency by 1 to 30 Hz, creating an auditory beating effect for the listener. This technique appears to be capable of systematically modifying ongoing brain activity and results in states of increased vigilance and altered mood. Another multi-modal technique effective in the treatment of stroke, brain injury, dementia and other conditions of cognitive deficits is an audio-visual stimulation, i.e. the use of rhythmic music in conjunction with rhythmic light therapy. Therapeutic effects of these new techniques of brain stimulation can be controlled by fMRI, in particular through neurofeedback combined with fMRI (and not only the EEG). It allows us to observe not only the altered activity in individual brain regions, but also targeting patterns of interactions or functional connectivity between brain areas [1].

Concluding Remarks

Neurologic Music Therapy (NMT) has dominated other ranges of music therapy in the United States, because it provides evidence that long-term music training and the associated sensimotor skill learning can be a strong stimulant for neuroplastic changes in the developing as well as in the adult brain. It integrates processes of perception and action which results in linking brain regions that might otherwise not be linked together [2, 5–8, 12, 16, 38]. It also increases a motivation for treatment through the activation of reward system in the patient. However, the music as a complex acoustic,

[2] The iso principle prevalent in music therapy means the adjustment of the pace and music character of expression to the patient's mental pace and mood, as a starting point for further therapeutic interventions. It derives from the so-called isopathic music therapy of Aristotle, as opposed to allopathic Pythagorean therapy, operating according to the principle of contraria contrariis curantur (which can be derived from the Pythagorean principles of harmony as compliance opposites) see. E. Galińska (1987) Dzieje poglądów na lecznicze działanie muzyki. Archives of the History and Philosophy of Polish Academy of Sciences, No. 50, 2, p. 235–256 and No. 50, 3, p. 405–426.

emotogenic stimulus could be a double-edged instrument. It may lower the mood, induce anxiety and self-destructive behaviour, as well as become an “autistic object” and deepen the isolation from the environment. It could cause epileptic seizures (see musicogenic epilepsy described for the first time in Poland by Mierzejewski in 1884, followed by A. Piotrowski in 1959 [9], or produce “musical obsessions” when the music is too simple and catchy, may also “overstimulate”, specialists in neonatal care units warn of this; it can also reveal deficits in patient, which cannot be compensated, what exposes him to frustration and lowering of self-esteem [9]. Therefore, the highest professional competences are required from music therapists. The time when music therapy was treated as a “sweet”, luxury supplement is already gone [2]. This statement is not in contradiction with the fact that the NMT can meet the emotional needs of patients, enhance mood, reduce anxiety and pain, provide energy and satisfaction in the arduous rehabilitation training, as well as sometimes be the only means of contact, at least non-verbal contact.

Neurologic Music Therapy is a range of music therapy mostly based on empirical evidence. All research results presented in this paper were controlled, randomized and validated through the multiple measurements at different stages of music rehabilitation. However, it is rather experimental method than discipline with specific treatment guidelines, although attempts are being made to standardize and computerize some techniques [43, 44], what is the precursor to the development of standards for this field of medicine. Therefore, reporting results of the research the information on the onset of music therapy application, the duration of the intervention, as well as the location of brain damage to the possible extend for which the intervention is applied, was provided. In all the reports in the literature including the Polish reports [20], the importance of early and daily music rehabilitation is emphasized. The edition of the Oxford Handbook of Neurologic Music Therapy, announced in the near future, may bring expected medical guidance[3].

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Address: Elżbieta Galińska
Klinika Nerwic
Instytut Psychiatrii i Neurologii
02-957 Warszawa, Sobieskiego Street 9