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Neuro-scientific basis and effectiveness of music and music therapy in neuromotor rehabilitation

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Abstract

The human brain is exquisitely sensitive to musical stimuli. This review aims to include such concepts and to resume studies regarding the use of music and music therapy in neuromotor rehabilitation. We analysed the main literature about neuroscientific bases of the therapy with music and controlled or randomized trials present in PUBMED, PsychINFO and in the Cochrane Central Register of Controlled Trials using key words like “music”, “music therapy”, “motor rehabilitation”, “neurorehabilitation”, “Parkinson’s disease”, “stroke”, “brain injury”, “multiple sclerosis”, “amyotrophic lateral sclerosis”, “ataxia”. We considered the trials specifically referring to neuromotor rehabilitation treatments. Our analysis indicates significant effects of music and music therapy techniques on neuromotor rehabilitation in particular in the rehabilitation of stroke and Parkinson’s disease. It is emerged a need for a greater definition of the contents of music interventions and for a more scientific and methodological rigor in the conduction of studies.

Introduction

The purpose of this review is to determine the possible effectiveness of the use of music and music therapy (MT) within neuromotor rehabilitation in various pathological contests.

Literature shows few scientifically oriented studies that put the focus on neuromotor outcome. A significant part of these studies refers to the use of music (making or listening) in rehabilitation and not always to any specific music therapeutic techniques. In this regard there is an ongoing debate in the field of MT, in order to define the boundaries of the discipline, distinguishing it from generic intervention with music that, despite their potentials, do not have the characteristics of MT.[1-4] From a scientific point of view it is important to reach a greater definition of the interventions and to the possibility to find adequate resources relative to therapeutic and rehabilitative needs. A “best practice” has to consider addressees, objectives, contents and assessment procedures. As a matter of fact the concept of therapy implies the accomplishment of a praxis supported by applicative evidence and results. In this regard, it is possible to identify specific characteristics attributable to a MT intervention such as: a) the presence of a skilled therapist with a musical, relational and clinical training, b) the presence of a therapeutic setting, c) aims which induce changes that tend to become stable or permanent in time (in relation to the pathology taken in consideration), d) the use of specific techniques (active and receptive) which relate to psychological or neuroscientific models and to practices which focus on the strong link between sound and relationship, released from any esthetic or performable logic.

These elements are not found in generic interventions with music where the worker has a musical education but not necessarily a relational and clinical one or vice versa (especially in clinical settings), where there is no structured therapeutic setting, where the goals are aimed to the development of socialization, to the realization of an esthetic result or to develop learning, rather than creating moments of wellbeing. In rehabilitative interventions with music, making or listening to music often forms the elements on which the recovery of cognitive and motor functions is founded.

Neuroscientific bases of the therapy with music

In recent years, the continuous acquisitions in the neuroscientific field (i.e. in functional and morphological visualization techniques of the brain) have made it possible to detail processing and neuronal coding of various sensorial stimuli. Music in particular (listened to or made) activates, directly or in a distributed way, brain structures involved in cognitive, motor and emotional processing.[5-6] Of great importance for neuromotor rehabilitation are those numerous works demonstrating the presence of an activation of brain structures and regions appointed to movement: sensory motor areas, premotor cortex, basal ganglia and cerebellum. It appears evident that rhythmic musical stimuli are able to induce neurophysiological modifications, both in the short and long-term, which convey the modulation and interference inside neuronal networks and structures.[7] The efficacy of techniques based on the use of music and some neurophysiological trials suggest the presence of something peculiar in the very structure of “music” (in terms of temporal composition and frequency), apparently directly related to the dynamics of synchronization and functioning of neural decoding.[8] In fact, several studies analyzed cortical and subcortical psychophysical and electrophysiological consequences, successive and concomitant to a rhythmic musical experience, both at a cortical and basal ganglia level.[9-10] This effect can be used to modulate the initiative and the timing of compromised automatic motor activities in pathologies concerning the basal ganglia. There are also other specific factors which contribute and justify the effectiveness of therapies based on music in neurocognitive and neuromotor rehabilitation. Among the many demonstrated factors and effects, it is also important to mention the modulation and stimulation of the attentive function which, during rehabilitation sessions, removes possible distracting elements (pain, anxiety, worry, self perceiving fatigue, sadness, etc.).[11-13] Furthermore, some music determines a modulation and activation of the most antique areas of the brain (limbic and paralimbic structures) predisposed to the processing and the creation of emotions.[14] These effects can be used in therapy in order to obtain alternative ways of stimulation for structures deputed to motor control as the basal ganglia and the frontal structures[15] in patients with hypokinetic motor disorders. The emotional content of music can also be used to modulate, by stimulation, the tone of mood that is often a co-morbidity in neurological neurodegenerative disorders. There are also evidence that link music to a predetermined motor behavior and a possibility of the existence of a common and supramodal sensory-motor code which organizes the syntactic processing of actions, speech and music.[16] The almost instantaneous coupling existing between musical perception and movement,[17] both while listening to music and producing it, is the proof of a preordained sensory motor control system of coding and control. These hypotheses arose after the discovery and deepening of the study of a system of neurons with a prevalently frontal-temporal-parietal distribution, which results active both during perception and during action (Mirror Neuron System).[18] This apparent coupling, or mediation, enclosed in a neuronal system with the same function, gives account of some instantaneous motor and behavioral neurophysiological modifications induced by music. Neurophysiological bases for the use of music in motor rehabilitation seem to rest on solid and well proven neurophysiological evidence by now. Studies of the effects of music in populations with neurological pathologies have, in our opinion, a double impact and value. The first is relative to a deeper and more focused and extensive use of the instrument “music” intended as neuro-modulation-rehabilitation, the second is the need of deeper studies from a cognitive and neurophysiological point of view.

Materials and Methods

Our analysis of literature (until 2012) was performed by selecting controlled or randomized trials (in English) present in PUBMED, in PsychINFO, and in the Cochrane Central Register of Controlled Trials, using key words like “music”, “music therapy”, “motor rehabilitation”, “neurorehabilitation”, “Parkinson’s disease”, “stroke”, “brain injury”, “multiple sclerosis”, “amyotrophic lateral sclerosis”, “ataxia”. Major neurological pathologies, degenerative and not, which may imply damage to motor functioning were also considered.

We included the trials specifically referring to a possible effect of music and MT on the outcome in neuromotor rehabilitation treatments, and we excluded other different outcome measures (psychological, behavioral, cognitive, etc.).

Results

A significant part of literature concerns the application of music and MT in stroke.

Hayden et al.[19] reported some interesting results using rhythmic stimulation (Rhythmic Auditory Stimulation, RAS) during conventional physical activities aimed to regain gait in 15 patients with stroke. RAS was introduced into 3 distinct groups of patients at different times in the 30 sessions scheduled for physical therapy (in all the sessions, in the last 20 and in the last 10). Statistically relevant results over time were found in all the conditions relating to stationing on one limb, cadency, speed, step length and inclination of the head. Improvements regarding cadency and stationing on one limb coincided with the introduction of RAS.

Even Jeong and Kim[20] reported important results in a group of 16 patients treated with RAS for 8 weeks: these patients, compared to controls, after treatment showed a wider range of motion and an increased flexibility. Altenmuller et al.[8] involved 32 stroke patients with a partial motor impairment. They were offered 15 sessions of music supported training (MST). Their fine and global motor skills were performed by using a MIDI keyboard or electronic drum pads emitting piano sound. Different aspects such as event-related synchronization/desynchronization (ERD/ERS) and coherence were also studied with EEG. The control group involved 30 patients subjected to 15 sessions of standard rehabilitation. Significant changes could be noticed after the session in the music supported therapy group in global motor skills regarding speed, precision and fluency of movements. Moreover a greater EEG coherence was found after music supported training in MST group. The authors conclude that MST is able to induce relevant changes in motor functions both at clinical and neurophysiological level with an increased cortical connectivity and a greater activation of the motor cortex. Similar clinical results had already been evidenced by Schneider and collaborators[21] using the same approach on a group of 20 patients.

Schauer and Mauritz[22] showed how the musical motor feedback (MMF) that produce a beat adaptation driven by patient's specific gait, could determine an improvement of walking. This was detected on 23 stroke patients randomized in an experimental group attending 15 sessions of MMF and in a control group attending 15 sessions of traditional therapy. The group receiving MMF improved more than the control group as regards stride length, speed of walking, length of the way covered and the symmetry deviation.

Cochrane's review of literature on MT in acquired brain injury[23] mentions other studies[24-25] in which the use of RAS produces a significantly positive effect on speed and cadency of walking and on length and symmetry of stride, compared to the results in control groups undergoing physical therapy according to the Bobath Concept. In this review two studies report some interesting data relative to the rehabilitation of upper limbs.[26-27] One[27] involved 21 patients and shows, as outcome measures, excellent results concerning the extension of the elbow angle, the variability of synchronization and the achievement of trajectory in the compromised limb. The other study[26] involved 20 patients undergoing MT (using electronic devices able to vary/regulate musical parameters, especially the rhythmic pattern) or physiotherapy carried out by a therapist. This study did not show any significant changes between the 2 groups as far as elbow angle extension and elasticity of the shoulder are concerned.

Other studies regarding the use of music and MT in Parkinson's disease are listed below.

De Bruin et al.[28] let 22 patients (mild and moderate stages) undergo a trial in which each patient in the test group listened to his/her favorite music adapted to the cadency of his/her steps during walking exercises (half an hour a week for 13 weeks). The control group continued standard motor activity. In the experimental group, at the follow up, important effects on the severity of motor symptoms, gait speed, time and pace were noticed.

Ma et al.[29] involved 20 patients with PD in their study and randomized them in two different conditions: listening to a music track (rhythm of march) or listening to the weather forecast. In both conditions they underwent 3 different experiments: 1) in the absence of sound; 2) in the presence of sound; 3) in the presence of sound but without paying attention to it. The aim of the study was to verify the influence of the different conditions of auditory stimulation on a task which involved functional movements of an upper limb. The authors evaluated the characteristics of movements performed in various conditions, and they found that auditory stimuli requiring a computing component (e.g. listening to the weather forecast) distract the patient from the primary task assigned, determining a decline in performance. Listening to music in march tempo, however, did not affect the quality of the execution of the motor task, while the results were better in the absence of auditory stimuli or when patients were asked not to pay attention to the musical stimuli during the performance of the task. Craig et al.[30] compared neuromuscular therapy (NMT) to music relaxation (MR). Their study involved 36 subjects with PD who were randomly divided into two groups (an experimental and a control one). Patients were treated twice a week for 4 weeks. The NMT group showed significant improvements in their motor functions, (tremor reduction and "tapping" speed). The other group that was invited to listen to relaxing music did not have any significant tremor reduction and did not amend in other motor functions. MR showed a greater efficacy on non-motor aspects, such as mood and anxiety. From a general point of view, NMT improved the score in the Clinical Global Impression, a feat maintained up to one week after treatment. Initially anxiety was reduced. Bernatzky et al.[31] conducted a controlled study in which 21 subjects were involved (11 with PD and 10 healthy ones). The authors pointed out that listening to music tracks with percussion instruments, chosen by the patients, increased the fine motor coordination in patients with PD (targeting and drawing a line). In particular it improved the precision of arm and finger movements rather than their speed. In both groups there were no statistically significant results relative to finger tapping and firmness. These evaluations were carried out using the "Vienna Test System".

Pacchetti et al.[15], in a randomized control group that involved 32 patients with PD, compared the use of music and MT with physiotherapy (PT), considering its possible efficacy on motor and emotional aspects. Treatments lasted for 3 months with weekly sessions. Music activities and MT included the use of choir singing, vocal and rhythmic exercises and moments of improvisation due to specific music therapeutic techniques. Physical activity was based on passive stretching and other exercises for a better gait and balance. Observing the results, MT produced significant changes in motor activities, particularly regarding bradykinesia while PT reduced rigidity. The members of the MT group also improved their emotional functions, everyday life activities and quality of life.

McIntosh et al.[32], using RAS, measured changes in gait in 4 different conditions: a) individual maximum speed without external stimuli; b) rhythmic stimulation obtained from pace frequency at baseline; c) rhythmic stimulation increased by 10% compared to pace frequency at baseline; d) absence of rhythmic stimulation, verifying the effect immediately after the tests. The sequence was proposed by applying rhythmic stimulation with instrumental Renaissance music with the possibility to modify its progression. 31 patients and 10 healthy subjects were involved in the study. The acceleration of RAS produces a significant increase of the mean speed and stride length in all groups. The close relationship between rhythm frequency and step frequency in the two groups suggests the idea of a possible rhythmic training even in the presence of a dysfunction of the basal ganglia.

Thaut et al.[33] in a previous study also reported important results using RAS (a three-week home training program). The test group of the study, consisting of 15 patients with PD, significantly improved their gait speed, stride length and cadency of steps compared to the 11 patients in the control group without RAS. This approach had positive effects even in other conditions such as cerebral palsy and multiple sclerosis.

Kim et al.[34] compared a group of 14 adult patients with cerebral palsy to a group of 30 healthy subjects. The authors showed in what way RAS was effective in some movement parameters correlated to gait in the group of patients, i.e. in the anterior inclination of the pelvis and in the flexion of the hip. Significant improvements were also seen in the reduction of the deviation index of gait. On the other hand, there were no significant differences in the parameters concerning knees, ankles and feet.

Conklyn et al.[35] reported significant results concerning the application of RAS in multiple sclerosis. (Patients listening to songs from an MP3 player while walking reduced their walking time by 10% compared to their basal time. The study lasted 2 weeks, 20 minutes a day). In patients subjected to RAS, bearing time of the two feet was significantly diminished. The study also reported an important “effect size” as regards gait speed. After a week of RAS treatment, significant improvements were found even in cadency, stride length, pace length, speed and normalized speed. The above mentioned papers are summarized in the Table I.

Discussion and conclusion

In literature, works are mainly related to two pathologies with neuromotor damage: stroke and Parkinson’s disease; moreover structured studies according to scientific criteria are needed. A first gap is given by the poor definition of interventions with a prevailing use of music, not always adequately supported by theoretical-methodological references. The approach based on rhythmic stimulation, considered as rhythmic-musical support to motor activity, prevails.

Neuromotor rehabilitation is essentially based on aspects closely related to physical therapy but we believe that the relational and psychological aspects characterizing MT approaches constitute an essential therapeutic value, facilitating even the rehabilitation process. In the MT setting sound-musical elements can in fact bring into play an important esthetic, psychological and motivational dimension, from which significant changes in the approach with the patient and the rehabilitative action can derive. We also believe that the intersubjective component, which originates from some specific music therapeutic techniques mainly based on musical improvisation, can activate brain areas involved not only in motor activation and regulation, but also in the emotional and behavioural one.[5-6] This is emphasized just in some active music therapeutic approaches based on sound-musical interaction, where music therapist and patient seek a syntonic relation by modulating, regulating and calibrating their respective music productions, in order to share the sonorous contents and the emotions deriving from them.[4] Music therapeutic techniques move the attention from performance, although exerting a significant potential action on motion, providing an adequate relational support in psychic problems that are often associated to neurological damage. In addition to reported studies the existing literature, referred to clinical experience, and the neuroscientific and psychological prerequisites of MT are undoubtedly an excellent base for the necessary studies focusing on the concept of "Evidence Based Music Therapy"[36] in order to demonstrate the effectiveness of interventions of MT in neuromotor rehabilitation. That is why there is a need to individuate targeted musical and music therapeutic interventions according to specific areas and aims, adequately checking the potential therapeutic outcomes. This requires a greater formalization of practice and a more vigorous verification of the results obtained through appropriate research methodologies and an auspicial interdisciplinary dialogue in which MT, music, psychology, neuroscience and clinical practice interact and integrate theoretical knowledge therapeutic-rehabilitative practice.

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Table I. Music therapeutic and musical contents and main characteristics of studies described in this Review.

Studies	Research designs*	N. of patients	Diagnosis	Duration of intevention	Activity	Assessment	Results
Altenmuller et al., 2009 [8]	RCT	62	Stroke	3 weeks (15 sessions)	Music Supported Training (MST)	Fine and global motor skills, event-related synchronization /desynchronization and coherence	Significant changes regarding speed, precision and fluency of movements; reduction of desynchronization and greater coherence in the movements after MST
Bernatzky et al., 2004 [31]	CCT	21	Parkinson's disease	**	Listening to drumming music	Fine motor coordination	Improvement in precision of arm and finger movements (aiming and line tracking); significant improvement on the power-force-working-plate (contact time, variability coefficient for total step and impact maximum)
Conklyn et al., 2010 [35]	RCT	10	Multiple Sclerosis	2 weeks (daily sessions)	RAS	Gait performance	Significant improvements in cadency, stride length, pace length, speed and normalized speed.
Craig et al., 2006 [30]	RCT	36	Parkinson's disease	4 weeks (twice weekly sessions)	Music relaxation (MR)	Motor functions, quality of life and psychological symptoms	Improvement in the MR group of tremor, quality of life, and significant improvement in mood and anxiety.
De Bruin et al., 2010 [28]	RCT	22	Parkinson's disease	13 weeks (half an hour a week)	Listening to favourite music during walking exercises	Motor functions	Improvement of gait velocity, stride time, cadence, and motor symptom severity
Hayden et al., 2009 [19]	CCT	15	Stroke	30 sessions	Rhythmic Auditory Stimulation (RAS)	Gait cadence and balance	Statistically significant improvement in the one-limb stance and cadence with

							RAS
Jeong & Kim, 2007 [20]	RCT	33	Stroke	8 week (2 hours a week)	RAS	Motion and psychological/ relational aspects	Wider range of motion and increase of flexibility; more positive moods, increase of frequency and quality of interpersonal relationships.
Kim et al., 2011 [34]	CCT	44	Cerebral Palsy	**	RAS	Gait patterns	Significant effects in the anterior inclination of the pelvis and in the flexion of the hip; significant improvements in the reduction of the deviation index of gait
Ma et al., 2009 [29]	RCT	20	Parkinson's disease	**	Listening to a music track (rhythm of march)	Kinematic variables of arm movement	No effects of the listening to music
McIntosh GC et al., 1997 [32]	CCT	41	Parkinson's disease	**	RAS	Gait velocity, cadence, stride length and simmetry	Significant improvement in gait velocity, cadence and stride lenght
Pacchetti et al., 2000 [15]	RCT	32	Parkinson's disease	3 months (weekly sessions)	Music and MT activities (choral singing, vocal and rhythmic exercises, free use of body movements, and moments of improvisation)	Motor and emotional aspects	Significant changes in motor activities, particularly as regards to bradykinesia; improvement of emotional functions, everyday life activities and quality of life.
Paul & Ramsey, 1998 [26]	RCT	20	Stroke	10 weeks (twice weekly sessions)	Improvisation sessions	Upper extremity functions	No significant results between groups in the shoulder flexion and elbow extension
Schauer & Mauritz, 2003 [22]	RCT	23	Stroke	3 weeks (15 sessions)	Musical Motor Feedback (MMF)	Motor functions	Improvement of the length and speed of walking, length of the way, decrease of the symmetry deviation
Schneider et al., 2007 [21]	RCT	40	Stroke	3 weeks (15 sessions)	MST	Motor functions	Improvement in speed, precision

							and smoothness of movements; improvement in motor control in every- day activities
Thaut et al., 1996 [33]	CCT	26	Parkinson’s disease	3 weeks (15 sessions)	RAS	Gait velocity, cadence, stride length and simmetry	Significant improvement of gait speed, stride length and cadency of steps
Thaut et al., 1997 [24]	RCT	20	Stroke	6 weeks (twice daily sessions)	RAS	Gait parameters	Significant improvement in the RAS-trained group of velocity, stride length, reduction in EMG amplitude variability of the gastrocnemius muscle; improvement in stride simmetry
Thaut et al., 2002 [27]	RCT	21	Stroke	**	RAS	Arm movements	Significant improvements of spatiotemporal arm control during rhythmic entrainment; significant reduction of variability of timing and reaching trajectories; significant increases in angle ranges of elbow motion
Thaut et al., 2007 [25]	RCT	78	Stroke	3 weeks (15 sessions)	RAS	Motor functions	Significant improvement in the RAS group for velocity, stride length, cadence and symmetry

* RCT= Randomized Controlled Trial; CCT= Clinical Controlled Trial
** No treatment, experimental condition (different tasks and evaluation)