Neuroscientific basis and effectiveness of music and music therapy in neuromotor rehabilitation

A Raglio1,2*, P Fazio2, C Imbriani1, E Granieri2

Abstract
Introduction
The human brain is exquisitely sensitive to musical stimuli. This critical review aims to include concepts of music therapy and resume studies regarding the use of music and music therapy in neuromotor rehabilitation.

Materials and methods

We considered the trials specifically referring to neuromotor rehabilitation treatments.

Results
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.

Conclusion
The need for a greater definition of the contents of music interventions and for a more scientific and methodological rigor, has emerged in the conduction of studies using music and music therapy in neuromotor rehabilitation.

* Corresponding author
Email: raglio@tin.it

© 2013 Raglio et al.; licensee OA Publishing London. This is an Open Access article distributed under the terms of the Creative Commons Attribution License (CC-BY), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Licensee OA Publishing London 2013. Creative Commons Attribution Licence (CC-BY)

of synchronisation and functioning of neural decoding\(^8\). In fact, several studies analysed 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) pre-disposed 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 the tone of mood that is often, a co-morbidity in neurological neurodegenerative disorders, by stimulation. There are also evidences that link music to a pre-determined motor behaviour and a possibility of the existence of a common and supramodal sensory-motor code, which organises 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 pre-ordained 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 actively, 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 behavioural neurophysiological modifications induced by music. By now, neurophysiological bases for the use of music, in motor rehabilitation, seem to rest on solid and well-proven neurophysiologic evidence. In our opinion, studies of the effects of music in populations with neurological pathologies have a double impact and value. The first requirement is relative to a deeper and more focused and extensive use of the instrument ‘music’ intended as neuro-modulation-rehabilitation, the second is the requirement of deeper studies from a cognitive and neurophysiological point of view. The purpose of this critical review is to determine the possible effectiveness of the use of music and MT, within neuromotor rehabilitation, in various pathological contests.

**Materials and methods**

Our analysis of the published literature (until 2012) was performed by selecting controlled or randomised trials (in English) present in PubMed, PsychINFO and the Cochrane Central Register of Controlled Trials, using key words like ‘music’, ‘music therapy’, ‘motor rehabilitation’, ‘neurorehabilitation’, ‘Parkinson’s disease’ (PD), ‘stroke’, ‘brain injury’, ‘multiple sclerosis’, ‘amyotrophic lateral sclerosis’ and ‘ataxia. Major neurophysiological pathologies, degenerative and non-degenerative, 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 neuro-motor rehabilitation treatments, and we excluded other different outcome measures (psychological, behavioural, cognitive etc.).

**Results**

A significant part of the published 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 three distinct groups of patients at different times in 30 sessions, scheduled for physical therapy (in all the sessions, in the last 20 sessions and in the last 10 sessions). Statistically, relevant results over time were found in all the conditions related 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 eight weeks, i.e., these patients, compared to controls, after treatment showed a wider range of motion and an increased flexibility. Altenmüller et al.\(^9\) involved 32 stroke patients with a partial motor impairment. These patients were offered 15 sessions of music-supported training (MST). Their fine and global motor skills were performed by using a musical instrument digital interface (MIDI) keyboard or electronic drum pads emitting piano sound. Different aspects, such as event-related synchronisation/desynchronisation (ERD/ERS) and coherence were also studied with electroencephalography (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.
Critical review

regarding speed, precision and fluency of movements. Moreover, a greater EEG coherence was found in MST group. The authors concluded that MST is able to induce relevant changes in motor functions, both at clinical and neurophysiological levels, 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 produces a beat adaptation driven by patient’s specific gait could determine an improvement of walking. This was detected on 23 stroke patients randomised in an experimental group attending 15 sessions of MMF and in a control group attending 15 sessions of traditional therapy. The group that received MMF improved more than the control group in terms of stride length, speed of walking, length of the way covered and the symmetry deviation.

Cochrane’s review of the published 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 critical review, two studies reported some interesting data relative to the rehabilitation of upper limbs\(^{26,27}\). One\(^{27}\) involved 21 patients and showed excellent results concerning the extension of the elbow angle, the variability of synchronisation and the achievement of trajectory in the compromised limb, as outcome measures. The other study\(^{26}\) involved 20 patients undergoing MT (using electronic devices able to vary/regulate musical parameters, especially the rhythmic pattern) or physiotherapy (PT) carried out by a therapist. This study did not show any significant changes between the two groups as far as elbow angle extension and elasticity of the shoulder were concerned.

Other studies regarding the use of music and MT in PD are listed below. de Bruin et al.\(^{28}\) allowed 22 patients (with mild and moderate stages) to undergo a trial, in which each patient in the test group listened to his/her favourite 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 observed.

Ma et al.\(^{29}\) involved 20 patients with PD in their study and randomised them in two different conditions, i.e., listening to a music track (rhythm of march) or listening to the weather forecast. In both conditions, the patients underwent three different experiments as follows: in the absence of sound, in the presence of sound, and in the presence of sound, but without paying attention to it. The aim of this 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 group and a control group). The patients were treated twice a week for four 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. The 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 observed to reduce. Bernatzky et al.\(^{31}\) conducted a controlled study, in which 21 patients were involved (11 patients with PD and 10 healthy patients). 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 the 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 randomised control group that involved 32 patients with PD, compared the use of music and MT with PT, considering its possible efficacy on motor and emotional aspects. The treatments lasted for three months with weekly sessions. Music activities and MT included the use of choir singing, vocal and rhythmic exercises and moments of improvisation because of specific music therapeutic techniques. Physical activity was based on passive stretching and other exercises for a better gait and balance. MT produced significant changes in motor activities, particularly regarding bradykinesia, while PT was observed to reduce

Licensee OA Publishing London 2013. Creative Commons Attribution Licence (CC-BY)

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 four different conditions as follows: individual maximum speed without external stimuli, rhythmic stimulation obtained from pace frequency at baseline, rhythmic stimulation increased by 10% compared to pace frequency at baseline and 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. In this study, 31 patients and 10 healthy subjects were involved. The acceleration of RAS produced a significant increase of the mean speed and stride length in all the groups. The close relationship between rhythm frequency and step frequency in the two groups suggested 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 this 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 observed in the reduction of the deviation index of the 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. This study lasted for two weeks, 20 minutes a day. In patients subjected to RAS, bearing time of the two feet was significantly diminished. This study also reported an important 'effect size' in terms of gait speed. After a week of RAS treatment, significant improvements were found even in cadency, stride length, pace length, speed and normalised speed.

The above mentioned papers are summarised in the Table 1.

**Discussion**

In this review, the authors have referred to some of their own studies. These referenced studies have been conducted in accordance with the Declaration of Helsinki (1964) and the protocols of these studies have been approved by the relevant ethics committees associated to the institutions in which they were performed. All human subjects, in these referenced studies, gave informed consent to participate in the studies.

In the published literature, works are mainly related to two pathologies with neuromotor damage, i.e., stroke and PD; moreover, structured studies according to scientific criteria are required. 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. However, the approach based on rhythmic stimulation, considered as rhythmic-musical support to motor activity, prevails.

Neuromotor rehabilitation is essentially based on aspects closely associated to physical therapy, but we believe that the relational and psychological aspects characterising 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 important aesthetic, psychological and motivational dimensions, from which significant changes can be derived, in the approach with the patient and the rehabilitative action. We also believe that the inter-subjective 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 ones36. This is emphasised 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 them4. 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 published literature, referred to clinical experience, and the neuroscientific and psychological pre-requisites 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.

**Conclusion**

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 formalisation of practice and a more vigorous verification of the results obtained through...
Table 1. Music therapeutic and musical contents and main characteristics of studies described in this critical review.

<table>
<thead>
<tr>
<th>Studies</th>
<th>Research designs*</th>
<th>No. of patients</th>
<th>Diagnosis</th>
<th>Duration of intervention</th>
<th>Activity</th>
<th>Assessment</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Altenmüller et al., 2009³⁸</td>
<td>RCT</td>
<td>62</td>
<td>Stroke</td>
<td>3 weeks (15 sessions)</td>
<td>Music-supported training (MST)</td>
<td>Fine and global motor skills, event-related synchronisation/desynchronisation and coherence</td>
<td>Significant changes regarding speed, precision and fluency of movements; reduction of desynchronisation and greater coherence in the movements after MST.</td>
</tr>
<tr>
<td>Bernatzky et al., 2004³¹</td>
<td>CCT</td>
<td>21</td>
<td>Parkinson’s disease</td>
<td>**</td>
<td>Listening to drumming music</td>
<td>Fine motor coordination</td>
<td>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).</td>
</tr>
<tr>
<td>Conklyn et al., 2010³⁵</td>
<td>RCT</td>
<td>10</td>
<td>Multiple sclerosis</td>
<td>2 weeks (daily sessions)</td>
<td>RAS</td>
<td>Gait performance</td>
<td>Significant improvements in cadency, stride length, pace length, speed and normalised speed.</td>
</tr>
<tr>
<td>Craig et al., 2006³⁰</td>
<td>RCT</td>
<td>36</td>
<td>Parkinson’s disease</td>
<td>4 weeks (twice weekly sessions)</td>
<td>Music relaxation (MR)</td>
<td>Motor functions, quality of life and psychological symptoms</td>
<td>Improvement in the MR group of tremor, quality of life, and significant improvement in mood and anxiety.</td>
</tr>
<tr>
<td>De Bruin et al., 2010²⁸</td>
<td>RCT</td>
<td>22</td>
<td>Parkinson’s disease</td>
<td>13 weeks (half-an-hour a week)</td>
<td>Listening to favourite music during walking exercises</td>
<td>Motor functions</td>
<td>Improvement of gait velocity, stride time, cadence, and motor symptom severity.</td>
</tr>
<tr>
<td>Hayden et al., 2009¹⁹</td>
<td>CCT</td>
<td>15</td>
<td>Stroke</td>
<td>30 sessions</td>
<td>Rhythmic auditory stimulation (RAS)</td>
<td>Gait cadence and balance</td>
<td>Statistically significant improvement in the one-limb stance and cadence with RAS.</td>
</tr>
<tr>
<td>Jeong and Kim, 2007²⁰</td>
<td>RCT</td>
<td>33</td>
<td>Stroke</td>
<td>8 week (2 hours a week)</td>
<td>RAS</td>
<td>Motion and psychological/relational aspects</td>
<td>Wider range of motion and increase of flexibility; more positive moods, increase of frequency and quality of interpersonal relationships.</td>
</tr>
</tbody>
</table>
Table 1 Continued

<table>
<thead>
<tr>
<th>Studies</th>
<th>Research designs*</th>
<th>No. of patients</th>
<th>Diagnosis</th>
<th>Duration of intervention</th>
<th>Activity</th>
<th>Assessment</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ma et al., 200929</td>
<td>RCT</td>
<td>20</td>
<td>Parkinson’s disease</td>
<td>**</td>
<td>Listening to a music track (rhythm of march)</td>
<td>Kinematic variables of arm movement</td>
<td>No effects of the listening to music.</td>
</tr>
<tr>
<td>McIntosh et al., 199732</td>
<td>CCT</td>
<td>41</td>
<td>Parkinson’s disease</td>
<td>**</td>
<td>RAS</td>
<td>Gait velocity, cadence, stride length and symmetry</td>
<td>Significant improvement in gait velocity, cadence and stride length.</td>
</tr>
<tr>
<td>Pacchetti et al., 200015</td>
<td>RCT</td>
<td>32</td>
<td>Parkinson’s disease</td>
<td>3 months (weekly sessions)</td>
<td>Music and MT activities (choral singing, vocal and rhythmic exercises, free use of body movements, and moments of improvisation)</td>
<td>Motor and emotional aspects</td>
<td>Significant changes in motor activities, particularly as regards to bradykinesia; improvement of emotional functions, everyday life activities and quality of life.</td>
</tr>
<tr>
<td>Paul and Ramsey, 199826</td>
<td>RCT</td>
<td>20</td>
<td>Stroke</td>
<td>10 weeks (twice weekly sessions)</td>
<td>Improvisation sessions</td>
<td>Upper extremity functions</td>
<td>No significant results between groups in the shoulder flexion and elbow extension.</td>
</tr>
<tr>
<td>Schauer and Mauritz, 200323</td>
<td>RCT</td>
<td>23</td>
<td>Stroke</td>
<td>3 weeks (15 sessions)</td>
<td>Musical motor feedback (MMF)</td>
<td>Motor functions</td>
<td>Improvement of the length and speed of walking, length of the way, decrease of the symmetry deviation.</td>
</tr>
<tr>
<td>Schneider et al., 200721</td>
<td>RCT</td>
<td>40</td>
<td>Stroke</td>
<td>3 weeks (15 sessions)</td>
<td>MST</td>
<td>Motor functions</td>
<td>Improvement in speed, precision and smoothness of movements; improvement in motor control in everyday activities.</td>
</tr>
<tr>
<td>Thaut et al., 199733</td>
<td>CCT</td>
<td>26</td>
<td>Parkinson’s disease</td>
<td>3 weeks (15 sessions)</td>
<td>RAS</td>
<td>Gait velocity, cadence, stride length and symmetry</td>
<td>Significant improvement of gait speed, stride length and cadency of steps</td>
</tr>
<tr>
<td>Thaut et al., 199724</td>
<td>RCT</td>
<td>20</td>
<td>Stroke</td>
<td>6 weeks (twice daily sessions)</td>
<td>RAS</td>
<td>Gait parameters</td>
<td>Significant improvement in the RAS-trained group of velocity, stride length, reduction in EMG amplitude variability of the gastrocnemius muscle; improvement in stride symmetry.</td>
</tr>
</tbody>
</table>
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.

**Abbreviations list**

EEG, electroencephalography; MMF, musical motor feedback; MR, music relaxation; MST, music-supported training; MT, music therapy; NMT, neuromuscular therapy; PD, Parkinson’s disease; PT, physiotherapy; RAS, rhythmic auditory stimulation.

**References**


Licensee OA Publishing London. Creative Commons Attribution Licence (CC-BY)


