



Exploring the role of music therapy in multiple sclerosis: brief updates from research to clinical practice

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Abstract

Background Physical, cognitive and mood-behavioral disturbances are very common in people with multiple sclerosis (MS) representing a relevant disease burden. Recently, in this field, several studies investigated the role of music therapy (MT) as a complementary therapeutic approach especially in terms of rehabilitation strategy.

Objectives The aim of this review is to report and discuss the effectiveness of various music-based interventions (MBIs) for clinical outcomes in MS patients.

Data sources All English medical papers registered in the Web of Knowledge, PubMed, Google Scholar, and ScienceDirect from March 1999 to March 2019.

Inclusion and exclusion criteria We selected all the articles concerning MBIs in MS including papers that dealt with human samples and excluding non-human samples, reviews and case reports.

Results Out of 46 articles, we selected 24 papers of which 13 completely following the inclusion criteria were evaluated for the present analysis.

Discussion We explored the efficacy of several MT programs, taking into account the different aspects of application feasibility in the clinical management of MS patients and the future challenges.

Keywords Multiple sclerosis (MS) · Music-based interventions (MBIs) · Music therapy (MT)

Introduction

Multiple sclerosis (MS) is not only a chronic inflammatory-demyelinating but also a neurodegenerative disease of the central nervous system (CNS), representing one of the most common non-traumatic cause of disability in young adults.

Since the disease can affect any area of the CNS, the clinical manifestations are very variable (e.g., visual, motor and sensory deficits, gait and speech disturbances, sphincter disorders, cognitive impairment, sexual problems, fatigue).

To date, pharmacological treatments available in MS, in particular the disease-modifying treatments, aim at achieving the reduction of the clinical relapse severity and frequency, slowing down the disease progression [1].

Nevertheless, many of these symptoms can deleteriously impact the occupational profile, social participation, self-esteem, and quality of life of these patients. During the past 10 years, an increasing number of controlled studies conducted in several neurological disorders have assessed the potential rehabilitative effects of new drug-free treatments, complementary to the standard care, including music therapy (MT) [2–5]. A wide spectrum of music-based interventions (MBIs) are known: writing music, singing songs of light, classic and popular repertoire, rhythm-movement association (from physical relaxation to free gestures or structured in rhythmic or dancing sequences), instrumental improvisation, and listening music tracks [6]. Being non-invasive, it can be easily applied in clinical practice but it also requires a multidisciplinary involvement of skilful professional figures. In stroke patients, functional magnetic resonance imaging (fMRI) studies conducted during music interventions (e.g., music listening) have shown connectivity changes in different brain networks, enhancing motor recovery (gait, balance, rehabilitating arm paresis), cognitive-mood functions (memory, attention, executive functions, depression), and speech gain in chronic aphasia

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[7]. In dementia, music listening coupled with cognitive elements (reminiscence and attention training) or physical exercises improved overall cognitive performances and neuropsychiatric symptoms versus the standard care [8, 9].

Conversely, MT has been poorly explored in MS, often providing conflicting results.

In the present work, we discuss the current state of literature concerning the MBI efficacy for the treatment and clinical management of MS patients, also seeking to shed light on new future perspectives.

Methods

The systematic review was conducted by searching all English medical papers registered in Web of Knowledge, PubMed, Google Scholar, and Science Direct between March 1999 and March 2019.

Specified in PubMed, the search strategy was “music therapy and neurological diseases” or “music therapy” or “music therapy AND multiple sclerosis”, or “music based interventions AND multiple sclerosis.”

We also considered the references of other reviews, as well as the references of the selected articles.

The evidence level of each selected article was evaluated with the PICO format (patient/problem, intervention, comparison, outcome), illustrated in Table 1.

Moreover, in order to compare the effectiveness of methods applied in each study, we also reported, whenever possible, the effect size (improvement effect in specific outcomes before and after treatment), such as small (Choen’s $d \geq 0.2$), medium (Choen’s $d \geq 0.5$), and high (Choen’s $d \geq 0.8$) [2].

Inclusion and exclusion criteria

We collected all the articles concerning MT in multiple sclerosis, including papers that dealt with human samples. Papers dealing with non-human samples, as well as reviews and case reports, were excluded (Table 2, Figs. 1 and 2).

The database was individually evaluated, and a total of 13 articles were included in the present review. We excluded 10 articles with the application of exclusion criteria, and we finally used evidence-based medicine resources (EBMRs) to assess the scientific level of the evidences.

Results

All the selected articles investigated the effect on MT related to the standard medical treatment alone.

Four studies evaluated the effect of rhythm and auditory–motor coupling on gait, walking endurance, and fatigue; 2 respectively reported the improvement in respiratory muscle strength and hand motility recovery through singing/vocal and piano playing exercises; 3 dealt with the effects on balance, gait, and mood disturbances and the remaining 4 mattered with cognitive and mood improvements after different MBI (listening or instrumental) approaches.

MBI in motor-gait disturbances and fatigue: auditory–motor coupling approach

In one study, Baram and Miller [19] measured the effects on walking speed and gait parameters in comparison to 11 healthy controls (HCs), by employing a metronome-based auditory feedback device in 14 MS patients with a moderate MS (EDSS range 3.5–6). Results showed a 12.84% improvement in walking speed and an 8.30% improvement in stride length, but the effect sizes were not reported. In another pilot study, Conklyn et al. [14] tested a 4-week home-based walking program using rhythmic auditory stimulation in a group of 10 MS patients (EDSS range 2–5). Authors found a significant improvement in gait parameters (double support time and walking speed) after 2 weeks of treatments. In a home-based pilot study, Seebacher et al. investigated the feasibility of the rhythmic-cued motor imagery method (mental execution of movements) in 30 adult people with MS (EDSS range 1.5–4.5), compared to healthy subjects. Participants were divided in three groups, randomly received 17 min of motor imagery, six times per week, for 4 weeks, with music (group 1), metronome cues (group 2), or controls (group 3). The primary outcomes were recruitment rates, retention, compliance, adverse effects, and fatigue, while the secondary ones were walking speed (time 25 ft walk) and distance (6-min walk) improvements [12].

Authors did not report adverse effects or compliance issues and found a mild improvement in fatigue in all groups at follow-up compared to baseline. Moreover, motor imagery with instrumental music as well as motor imagery with

Table 1 PICO format for the systematic review

Definition	Description
Patients	MS patients with wide spectrum of clinical disability
Interventions	Different type of music based interventions (active, passive) applied as a non-pharmacological treatment
Comparison	Role of different music-based approaches in clinical outcomes before, during, and after MBI
Outcome	Improvement in physical, cognitive, and behavioral symptoms induced by music therapy

Table 2 Summary of the descriptions of the reviewed papers dealing with music therapy in multiple sclerosis

Author	Study type	Description
Lousin Moumdjian et al. (2019) [10]	Observational case-control study	<i>MBI</i> : auditory-motor coupling. <i>Frequency and duration</i> : two sessions: (I) 15 s of walking in silence, 3 min of the auditory stimuli, and 3 min of rest; (II) synchronize by stepping to the beat with same duration of the first session. <i>N</i> = 30 MS patients and 30 normal controls. <i>Outcomes</i> : walking synchronization and cognitive control.
Young HJ et al. (2019) [23]	Three-arm randomized controlled proof of concept trial	<i>MBI</i> : movement to music (multiple movement routines accompanied with music). <i>Frequency and duration</i> : three 60-min per week for 12 weeks. <i>N</i> = 60 MS patients. <i>Primary outcomes</i> : mobility and balance, walking endurance, Lower extremity functional strength. <i>Secondary outcomes</i> : fatigue and pain.
Seebacher B et al. (2017) [11]	Randomized controlled trial	<i>MBI</i> : rhythmic cued motor imagery. <i>Frequency and duration</i> : 17 min of motor imagery, six times per week, for 4 weeks, with music or metronome cues for 4 weeks <i>N</i> = 112 MS patients. <i>Primary outcomes</i> : walking speed (timed 25-foot walk) and distance (6-min walk test). <i>Secondary outcomes</i> : walking perception (Multiple Sclerosis Walking Scale-12), fatigue (Modified Fatigue Impact Scale), and QoL (Short Form-36 Health Survey, Multiple Sclerosis Impact Scale-29, Euroqol-5D-3L Questionnaire).
Gilberston R and Maryanna KD (2017) [29]	Observational study	<i>MBI</i> : Mindfulness-based intervention using yoga movement, mindfulness meditation and relaxing music (piano music trough CD or MP3). <i>N</i> = 22 MS <i>Frequency and duration</i> : 8 weeks, once per week for 1 h. Patients without control groups. Pre-post comparison 1 week before and after the intervention using four self reported questionnaires (Mental Health Inventory, 36-item Short Form Health Status Survey, Modified Fatigue Impact Scale, Five Facet Mindfulness. <i>Outcomes</i> : motion, stress, anxiety, depression, fatigue, and quality of life.
Seebacher B et al. (2015) [12]	Randomized control feasibility study	<i>MBI</i> : rhythmic cued motor imagery. <i>Frequency and duration</i> : 17 min of motor imagery, six times per week, for 4 weeks, with music or metronome cues for 4 weeks. <i>N</i> = 30 MS patients. <i>Primary outcomes</i> : recruitment rates, retention, compliance, adverse events and fatigue (Modified Fatigue Impact Scale). <i>Secondary outcomes</i> : walking speed (Timed 25-Foot Walk) and walking distance (6-min walk test).
Mandelbaum R et al. (2015) [24]	Pilot observational study	<i>MBI</i> : salsa dance. <i>Frequency and duration</i> : 4 weeks, two 60-min classes per week. <i>N</i> = 10 MS patients (8 included in the study). <i>Outcomes</i> : effects on gait, balance, self efficacy, motivation, evaluated with TUG, dynamic gait index (DGI), activities specific balance confidence scale and Godin leisure time questionnaire, administered at baseline and after 3 months.
Gatti R et al. (2015) [21]	Randomized controlled trial	<i>MBI</i> : playing musical keyboard. <i>Frequency and duration</i> : half an hour per day for 2 weeks. <i>N</i> = 19 MS patients. <i>Primary outcome</i> : perceived hand functional use measured by ABILHAND Questionnaire. <i>Secondary outcomes</i> : hand dexterity, measured by Nine-Hole Peg Test, and hand strength, measured by Jamar and Pinch dynamometers.
Thaut MH et al. (2014) [13]	Randomized controlled trial	<i>MBI</i> : music-assisted learning: single list of 15 words associated to melody of an originally composed song. <i>Frequency and duration</i> : single session of 10 trials. <i>N</i> = 54 MS patients. <i>Outcomes</i> : verbal learning, short term memory improvements (Rey's auditory verbal learning test). Oscillatory network synchronization in prefrontal area (measured with electroencephalogram)
Conklyn D et al. (2010) [14]	Randomized Pilot Study	<i>MBI</i> : rhythmic auditory stimulation (mp3 playing). <i>Frequency and duration</i> : walk to the music 20 min per day every day for 4 weeks

Table 2 (continued)

Author	Study type	Description
Charlton ME et al. (2010) [15]	Observational study	<i>N</i> = 10 MS patients. <i>Outcomes</i> : gait performance and walking speed improving. <i>MBI</i> : Jazzercise approach (structured group exercise program in the context of jazz dancing to the beat of popular music) patient. <i>Frequency and duration</i> : 16 weeks, twice per week for 45 min per session.
Moore KS et al. (2008) [16]	Randomized controlled trial	<i>N</i> = 11 MS <i>Outcomes</i> : balance, coordination, and mood (including satisfaction and motivation to continue the course) improvements, evaluated through a questionnaire. <i>MBI</i> : Music as mnemonic device using an adapted version of Rey's Auditory-Verbal Learning Test (AVLT). <i>Frequency and duration</i> : 15 word list learning and memory through a series of ten learning trials with immediate recall. Follows an interference trial where participants heard and recalled a distracter list, recalling only the first original learned list (immediate and after 20 min). Finally, patients listened to a 50-word list including those of original and interference lists and had 4 s to associate the word to the learned list in spoken or sing format.
Aldridge D et al. (2005) [17]	Randomized controlled trial	<i>N</i> = 54 MS patients divided in a spoken and music group. <i>Outcomes</i> : gain in learning and short memory. <i>MBI</i> : Nordoff Robbins approach: music-making on instruments or singing. <i>Frequency and duration</i> : three blocks of music therapy in single sessions (8–10 per block) over the course of 1 year.
Wiens MS et al. (1999) [18]	Randomized pilot study	<i>N</i> = 20 MS. <i>Outcomes</i> : depression, anxiety and quality of life evaluations (BDI, HADS, SESA, HAQUAMS, MSFC). <i>MBI</i> : relaxation and diaphragmatic breathing, intonation of syllables, and reading or singing phrases, paragraphs and simple songs. <i>Frequency and duration</i> : three individualized 30-min music therapy sessions per week for 12 weeks. <i>N</i> = 20 MS patients. <i>Outcomes</i> : improvement in respiratory muscle strength, speech, and quality of life in advanced MS.

metronome cues improved walking speed and walking distance in the intervention groups ($\geq 20\%$ from baseline to follow-up) compared to controls. Later, the same authors applied rhythmic-cued motor imagery techniques in a randomized controlled trial (RCT) extended to a larger sample of MS patients (EDSS range 1.5–4.5), confirming the improvement in walking, fatigue perception, and quality of life (Cohen's $d = 0.6$) after a treatment of six times per week, for 4 weeks [11].

Walking to rhythm represents a very complex auditory–motor system, involving the interaction between beat perception (a repetitive cycle of auditory stimulus) and the steps of the walker (a repetitive cycle of a walking pattern).

Auditory–motor interactions, otherwise called “entrainment” can be performed in two ways: spontaneous (the person is not instructed to synchronize the steps to a beat) and intended (the person is instructed to synchronize the steps to a beat) were also explored in the contest of lower limb rehabilitation in MS [20]

In a recent study [10], the authors investigated the differences of spontaneous and intended auditory–motor synchronization (at different tempo) in the contest of lower limb rehabilitation in MS patients with and without cognitive impairment and healthy controls (HCs).

In the first session (walking for 15 s in silence, 3 min of the auditory stimuli, and 3 min of rest), no instruction was given regarding synchronization with the music. Conversely, in the second session, the participants were instructed to synchronize by stepping to the beat. Results showed that MS patients, compared to HC, need instructions to better synchronize walking with music, especially those with cognitive impairment, suggesting an active cognitive control component. As further evidence, MS patients provided with instructions proved to be more motivated in performing the auditory–motor task rather than without instructions, compared with HC.

MBI in upper limb mobility

Gatti et al. [21] evaluated the efficacy of musical keyboard playing on hand function improvement in a group of 19 MS patients with a training of half an hour per day for 2 weeks. One half of patients played a turned-on musical keyboard using finger movements (audio on); the remaining one used a turned-off keyboard (audio off). The whole program was divided in a total of 46 exercises of growing difficulty,

Fig. 1 Summary of the study selection criteria

Inclusion/exclusion criteria

Full articles in English with scientific relevance

Participants: ≥ 10 MS patients with motor and/or clinical disturbances.

Music-based interventions: wide spectrum (active and/or passive).

Outcomes: physical, cognitive measures (gait, motor performance in upper and lower limbs, cognitive performance and mood improvement), fatigue and quality of life.

Excluded: case reports and review articles.

previously showed by a music therapist for three times. Results were valuable for improvement in hand dexterity (assessed by the nine-hole peg test) and perceived hand functional use (measured by Abilhand questionnaire) [22] with a difference between the two groups (Cohen's $d = 1.66$).

MBI in respiratory muscle deficits for advanced stage of MS

A randomized pilot study described the effect of a 12-week individual MT setting (singing and reading, intonation of syllables, relaxation, and diaphragmatic breathing) in a group of MS patients with high disability (EDSS range from 7 to 9) and respiratory muscle weakness. The program was divided in three individualized sessions of 30 min per week with the outcome of strengthening respiratory muscles through the coordination of breath and speech.

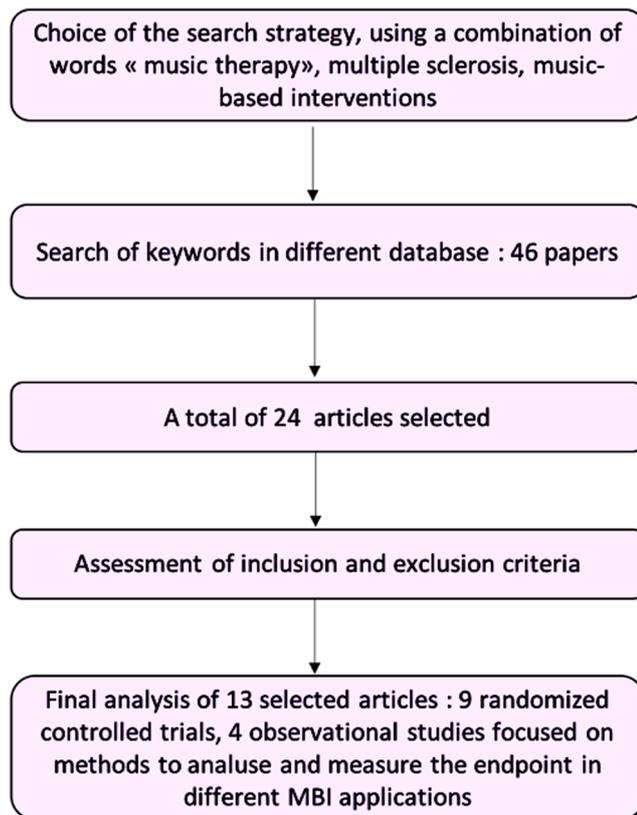


Fig. 2 Flowchart of the systematic review analysis

Despite some clinical improvements observed in comparison with healthy subjects, the statistical significance of these results was not confirmed [18].

MBI in mobility and walk endurance improvement: a dance-based model

To date, only 3 articles report the effect of dance on gait, balance, mobility, and mood in MS [15, 23, 24].

In a recent three-arm randomized controlled proof-of-concept trial, Young et al. [23] evaluated the effects of movement-to-music (M2M) in comparison with adapted yoga (AY) in a sample of 81 MS patients (EDSS range 0–6) performed in a period of 12 weeks.

Patients were randomized in three groups (M2M, AY, and waitlist control). Primary outcomes were improvement in (1) mobility and balance, measured with timed Up and GO test-TUG (time required to rise from a chair, walk to a 3 m mark, turn around, walk back to the chair and sit down); (2) walking endurance, evaluated through the 6-min walk test (6MWT); and (3) lower extremity functional strength measured with the 5 times sit-to-stand test (FTSST) (time required to stand up and sit down as quickly as possible 5 times without assistance). Secondary outcomes were fatigue (using the fatigue-short form 8°) and pain (assessed with Pain Interference–short form 8a) occurrence after 7 days of training. Results showed a significant improvement with moderate effect size in TUG (Cohen's $d = 0.7$) and 6MWT (Cohen's $d = 0.6$) time with a trend in fatigue reduction in M2M group and not in AY, compared to controls.

In another study, authors tested the effect of 16-week jazz dancing program (twice per week for 45 min per session) on mobility, balance, and mood of 14 MS patients. A high percentage of patients showed improvements in confidence (77.8%), flexibility/muscle strength (66.7%), and balance and coordination (55.6%), evaluated with a questionnaire [15].

Salsa dance also showed improvement in gait, balance, and mood as reported in a work performed in 10 MS patients after a 4-week program (two 60-min classes per week) at baseline, immediately postintervention and at 3- and 6-month follow-ups [24].

MBI in cognition, mood, behavioral and verbal communication

Some lines of evidences showed that music mnemonics can facilitate verbal learning and short-term memory in patients with MS. Moore et al. [16] used music as mnemonic device to test learning and memory ability in 38 MS patients (EDSS range 3.5–7) divided in two groups: patients who learn words through music versus patients who learn words through speech. Final results did not show significant differences on the recognition memory test between the two groups. In spite of these results, the authors found a significant correlation between AVLT and clinical measures in the group music compared to the spoken one. Thaut [13] investigated the neural correlates of brain plasticity during verbal memory training with the use of music mnemonics, taking into account that temporal structure of music influences the brain oscillations related to short-term memory for the auditory patterns [25, 26]. In this study, the authors measured oscillatory synchronization (using electroencephalography) in 54 MS patients during the Rey's auditory verbal learning test (RAVLT), randomly administered as spoken or musical (singing) modalities. Results showed a better speech and order memory in musical conditions rather than in spoken ones, with a stronger bilateral frontal alpha learning-related synchronization in the first group [13].

Applying the Nordoff-Robbins approach (active role of both patients and music therapist on vocal improvisation or playing an instruments, without any expectations of previous musical education), Aldridge et al. [17, 27] performed three blocks of MT in a single session over the course of 1 year, in a group of 20 MS patients (EDSS range 0–5.5). Despite no significant differences before and after music treatment were observed in comparison with the healthy subjects, the authors found an improvement with medium effect size on the scales measuring self-esteem (Cohen's $d = 0.5$), depression ($d = 0.63$), and anxiety ($d = 0.63$), explaining that MT can influence the behavior and mood components in MS patients.

O'Callaghan [28] found a song writing and singing effectiveness in 39 advanced MS patients (EDSS > 7, cognitively impaired). The therapeutic approach, performed in single or group sessions, in palliative care was mediated by a music therapist that supported patients in creative production, according to individual clinical impairment and needs. It was a qualitative research study, and the main results were found in an enrichment in psycho-social and spiritual needs.

Gilberston et al. [29], after 8-week program of mindfulness-based intervention (including relaxing piano music listening during gentle stretching, meditation, and yoga relaxation) performed in 22 MS people, found a significant improvement in physical performances, vitality, and mental health, evaluated with Mental Health Inventory questionnaire, 36-item Short Form Health Status, Modified Fatigue Impact

Scale, and Five Facet Mindfulness. In particular, strong improvements were observed in anxiety, depression, positive affect, and fatigue.

Discussion

Our analysis reveals that MBI can offer promising expectancies as complementary therapeutic alternative in MS clinical management.

These studies evaluated the MT as a tool for relational and rehabilitative purposes, through active (musical improvisation, playing an instrument to sing, writing songs) and passive (music imagery, listening to music) techniques, both aimed at building up a musical relationship between patient and therapist and promoting the motor and cognitive recovery.

The rehabilitative effect of music in neurological disorders appears linked to a brain neuroplasticity and neural activation changes [2, 7, 30], but the specific mechanism still remains unknown.

Impaired walking speed due to gait limitations or fatigue plays a crucial role in reducing activities of daily living in MS people. Rhythmic auditory stimulation is a novel MBI developed to improve the intrinsic rhythmic movements of gait and the coordination processes. This may be related to different motor brain area involvement, such as cortex, cerebellum, and spinal tract [14, 31].

Music also exploits the relationship between body language and sound, such as interaction between perception and action. In this context, rhythmic auditory stimulation, more than simple metronome cues, has been developed to promote walking speed and distance in people with motor limitations. Moreover, playing an instrument represents an active music experience that, including repetitive movements (e.g., fingers movements on a keyboard), involves different cerebral regions across a multisensory stimulation effect (visual, vestibular, tactile, and proprioceptive), thus promoting the hand functional recovery [21, 32–34].

The positive effects of MT on motoricity and cognitive dysfunctions are well known and in the last few years many evidences confirmed the power of music and rhythm in rehabilitation of patients with Parkinson disease [35–38], stroke [30, 32, 38–40], and Alzheimer disease [2, 41], supporting the role of temporal structures of music in motor and memory gain [2, 38–41].

Unfortunately, studies on cognition improvement of MS people are still few and sometimes they show conflicting results.

Cognitive impairment affects 40–70% of MS people [42], and some deficits, especially in memory, attention, and information processing speed, are present since the early stage of disease. To date, there is a lack of effective drugs or other

treatments that may help to cope with these cognitive dysfunctions.

In one study, rhythmic and melodic phrases within music does not seem to directly support music as a mnemonic device in facilitating learning process and the information retrieval, may be because the recognition tasks are not the most appropriate method of measuring the effectiveness of temporal structure in retrieving the learned information [16]. Authors explained these results assuming that the participants do not have enough time to memorize the information and that the music can represent also a distractor element. But, it is also true that in the same work, the analysis of correlations in the music group showed that less cognitively impaired MS patients gain more benefits from music mnemonic in learning and memory processes [16].

Conversely, other researchers promoted the music as a mnemonic tool to improve the neuronal plasticity of the temporal regions and the oscillatory network synchronization in prefrontal area, resulting in better learning and memory performance [13]. Ultimately, these data require further investigations.

As instead better documented, MT seems to bring improvements also in mood dysfunction such as depression, fatigue, self-acceptance, and in quality of life in MS people, and this can be explained by the effect on neurohormonal circuits such as activation of the mesolimbic dopaminergic system (nucleus accumbens, hippocampus, amygdala) [43, 44]. In detail, music is able to activate the parasympathetic nervous system in contrast to the sympathetic one, promoting cytokine secretion and changes in catecholamine levels [45].

Mindfulness meditation accompanied to relaxing piano music listening [29] and varied dance styles (classic, jazz, Latin, etc.) requiring attention to movement coordination over space and time, could be a valid tool to improve the psychophysical well-being and emotional integration in MS patients.

Music represents a part of our genetic heritage, a kind of universal language focused on the relationship between the language of the body and that of sound [6, 46], which is able to reduce stress and preserve the mental health conditions. These data are promising and lead to consider the use of MT as a drug-free treatment in supporting the individual coping strategies in MS.

Limitation of this review consists in the lacking of a meta-analysis in favor of MBI compared to other rehabilitation approaches, because of the heterogeneity of samples, follow-up period, modality of music intervention, and the number of participants included in each work.

Indeed, the studies discussed are mostly qualitative and carried out on small groups, with short observational periods and a different MBI performed. MT effect can be underestimated, according to the progressive MS disease course and the role of music therapist still appears unclear.

Being a simple and low-cost intervention, MT deserves to be studied in larger samples of MS patients, with a wide spectrum of clinical disability and the choice of appropriate approaches tailored to the individual clinical outcomes.

Conclusions and future perspectives

MT seems to be safe and effective in clinical rehabilitation of MS patients, but these data should be confirmed.

In light of these premises, it would be essential to define and identify more standardized methods and global strategies to apply in each clinical context. Researchers should better clarify the objectives, data collection, measured variables, and the techniques performed, through a methodological control and scientific validation of the results stratified according to the clinical demand and patients needs.

Furthermore, the role of the music therapist should be better understood and included in a multidisciplinary approach for the different MBI settings.

In the future, it would be very fascinating to investigate the music effect on brain connectivity (anatomical and functional) of MS people with a wide spectrum of clinical disability, through MRI studies.

This can help to further explain the role of music on brain neuroplasticity changes and better address the single intervention strategies within a useful therapeutic window, thus confirming the strong relevance of MT in clinical practice.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflicts of interest.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

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