Current Neurology and Neuroscience Reports (2019) 19: 83
https://doi.org/10.1007/s11910-019-1005-0

NEUROREHABILITATION AND RECOVERY (J KRAKAUER AND T KITAGO, SECTION EDITORS)

Music Therapy and Music-Based Interventions for Movement Disorders

Kerry Devlin[1] · Jumana T. Alshaikh[2] · Alexander Pantelyat[2]

Published online: 13 November 2019

Abstract

Purpose of Review There is emerging evidence that music therapy and other methods using music and rhythm may meaningfully improve a broad range of symptoms in neurological and non-neurological disorders. This review highlights the findings of recent studies utilizing music and rhythm-based interventions for gait impairment, other motor symptoms, and non-motor symptoms in Parkinson disease (PD) and other movement disorders. Limitations of current studies as well as future research directions are discussed.

Recent Findings Multiple studies have demonstrated short-term benefits of rhythmic auditory stimulation on gait parameters including gait freezing in PD, with recent studies indicating that it may reduce falls. Demonstration of benefits for gait in both dopaminergic "on" and "off" states suggests that this intervention can be a valuable addition to the current armamentarium of PD therapies. There is also emerging evidence of motor and non-motor benefits from group dancing, singing, and instrumental music performance in PD. Preliminary evidence for music therapy and music-based interventions in movement disorders other than PD (such as Huntington disease, Tourette syndrome, and progressive supranuclear palsy) is limited but promising.

Summary Music therapy and other music and rhythm-based interventions may offer a range of symptomatic benefits to patients with PD and other movement disorders. Studies investigating the potential mechanisms of music's effects and well-controlled multicenter trials of these interventions are urgently needed.

Keywords Music therapy · Movement disorders · Parkinson disease · Huntington disease · Rhythmic cueing · Rhythmic auditory stimulation

Introduction

Music therapy and other music- and rhythm-based interventions have been used in an effort to improve symptoms of a number of diseases in different disciplines, including oncology, palliative care, neurology, psychiatry, physical medicine and rehabilitation, and pediatrics. Within neurology, music therapy and related interventions have been applied to movement disorders such as Parkinson disease (PD) with increasing frequency. Recently, there has been a growing effort to study the effects of these interventions systematically and quantitatively in order to begin clarifying their mechanism of action and to develop best evidence-based practices for their applications. While much work remains to be done, the evidence available to date necessitated a critical appraisal of published work in movement disorders in order to distill salient findings and identify key knowledge gaps. The timely nature of this review is underscored by the fact that the National Institutes of Health (NIH) and the Kennedy Center for the Performing Arts (Washington, DC) formed a partnership ("Sound Health") in 2017, which has led to a recent multi-institute request for grant applications related to mechanisms and applications of Music in Health and funded by the NIH and the National Endowment for the Arts [1•].

This article is part of the Topical Collection on *Neurorehabilitation and Recovery*

✉ Alexander Pantelyat
apantel1@jhmi.edu

[1] Peabody Institute, Johns Hopkins University, Baltimore, MD, USA

[2] Department of Neurology, Johns Hopkins University School of Medicine, Baltimore, MD, USA

Defining Music Therapy and Music-Based Interventions

For context, it is important to define the three core types of interventions covered in this review. When the terms "music therapy" or "music therapist" are used, this means that the intervention described has been implemented by a therapist who holds a credential such as board-certified music therapist (MT-BC in USA), registered music therapist (RMT in Australia and UK), music therapist accredited (MTA in Canada), or a similar credential indicating that they have completed a standardized certification process and academic degree in their country of residence. Music therapists in the USA hold a bachelor's degree or higher from an accredited music therapy program, complete 1200 hours of clinical training, and must pass a national board certification exam administered by the Certification Board for Music Therapists.

"Neurologic Music Therapy" references a research-based system of standardized clinical techniques for sensorimotor, speech/language, and cognitive training (see Table 1). A neurologic music therapist typically holds a music therapy credential and has completed additional Neurologic Music Therapy training within the last 3–5 years, though other professionals with related experience can practice neurologic music therapy provided they fulfill the credentialing requirements set by the Academy of Neurologic Music Therapy (based in Toronto, Ontario, Canada).

"Music-based interventions" are implemented by a provider who is not a music therapist, but is rather a member of another profession, such as a dance/movement therapist, physical therapist, occupational therapist, speech therapist, nurse, or physician. Music-based interventions may use music to achieve therapeutic goals but cannot be labeled "music therapy" per se because they are not being delivered by a credentialed music therapist. They are frequently referred to as "music medicine" in other contexts.

Proposed Mechanisms for Music and Rhythm-Based Interventions

Various mechanisms have been proposed to explain the therapeutic effects of music and rhythm on motor symptoms in patients with PD. One potential mechanism involves recruitment of alternative neural pathways that are relatively spared in PD. Impairments in basal ganglia function in PD patients interfere with their perception of internal timing since the basal ganglia are directly involved in internal timing and rhythm perception. The loss of rhythmicity for timed movements impairs alternating timed movements such as walking, leading to freezing of gait, reduced velocity and stride length, and other gait abnormalities seen in PD [2]. This may be compensated for by the recruitment of cerebellar networks, which rely on external (such as auditory or visual) cues, and are typically spared in PD [3]. The effect of music on network connections has been demonstrated in several functional MRI (fMRI) studies of healthy individuals, as well as those with PD. Use of music, dance, and rhythmic auditory cues led to an observed increase in functional neural connectivity between (1) the auditory cortex and executive control network and between the executive control network and the cerebellum that occurred during finger tapping with and without the use of rhythmic auditory stimulation (RAS) during fMRI acquisition; (2) the primary motor cortex and the cerebellum during fMRI with finger tapping without auditory stimulation; and (3) the basal ganglia and premotor cortex at rest [4–6]. Several of these networks—particularly the frontal lobe-basal ganglia networks—are disrupted in PD [7]. Additionally, the provision of rhythmic timed cues allows the brain to anticipate movement, which in turn leads to improvement in movement synchronization (e.g., a normal gait pattern) and precision [8–10].

Another potential mechanism involves the concept of *rhythmic entrainment*, which is internal body patterning to external rhythms whereby the auditory system synchronizes with the motor system to facilitate movement [8, 11]. Electroencephalographic (EEG) analysis in normal individuals and in PD patients shows synergistic activation of auditory and motor cortices with music therapy [12, 13•]. Rhythmic entrainment may also occur by the utilization of central pattern generators in the spinal cord, which leads to direct auditory-motor coupling without cognitive involvement [8, 11].

Other suggested mechanisms for the therapeutic effects of music in PD include priming, stimulated neural coherence, increased cortical activity, accelerated learning, and cellular responses [8, 14–17]. In priming, music readies the motor system to be prepared for movement [8]. Stimulated neural coherence is the mechanism by which external rhythmic auditory stimulation (RAS, see next section below) may enhance the synchronization of neurons in the primary motor cortex [14]. Increased motor cortical activity with rhythmically cued walking was observed in healthy adults by using functional near-infrared spectroscopy, which may be applicable to the PD population as well [15]. Furthermore, the auditory context and motivational effects of music may lead to the acceleration of motor learning. This is likely to be an important mechanism, particularly for diseases like PD (with dopaminergic deficits) that affect motivation [16]. The impact of music at the cellular and genetic level is poorly studied, but it may modulate the activity of specific brain regions by promoting the production of brain-derived neurotrophic factor as seen in mice [14, 17]. Lastly, learned cognitive responses might explain the benefit of music on non-motor symptoms of PD such as cognitive and mood disturbances, in which music can trigger specific emotions and memories, thereby producing a therapeutic effect [14].

Impact of Rhythmic Cueing (RAS) on Gait in Parkinson Disease

Many patients with PD present with a range of gait abnormalities, which may include stooped posture, decreased range of motion, decreased step length and arm swing, a shuffling

Table 1 Neurologic music therapy interventions

Sensorimotor training	
Rhythmic auditory stimulation (RAS)	Application of auditory entrainment stimulus to intrinsically rhythmic movements, such as gait, to achieve more functional movement patterns
Patterned sensory enhancement (PSE)	Application of rhythmic, melodic, harmonic, and dynamic-acoustical elements of music to provide temporal, spatial, and force cues for non-rhythmic movements (e.g., functional exercises, activities of daily living)
Therapeutic instrumental music performance (TIMP)	Playing of musical instruments to exercise and stimulate functional movement patterns
Speech and language training	
Melodic intonation therapy (MIT)	Technique for expressive aphasia utilizing a patient's unimpaired ability to sing to facilitate speech through sung and chanted melodies resembling natural speech intonation patterns
Musical speech stimulation (MUSTIM)	Use of familiar music materials (songs, phrases, chants) to stimulate non-propositional speech
Rhythmic speech cueing (RSC)	Application of rhythmic cueing via metronome, drum, or moving the client's hand to prime and control initiation and rate of speech
Vocal intonation therapy (VIT)	Application of vocal exercises simulating normal speech patterns to train all aspects of voice control (i.e., inflection, pitch, breath control, timbre, dynamics)
Therapeutic singing (TS)	Use of singing activities to facilitate speech initiation, development, articulation, and respiration
Oral motor and respiratory exercises (OMREX)	Use of music materials, such as vocalization and wind instrument play, to support articulation and respiration as related to speech
Developmental speech and language training through music (DSLM)	Application of developmental appropriate music experiences (i.e., singing, instrument play, movement) targeting speech and language development
Symbolic communication training through music (SYCOM)	Use of vocal or instrumental improvisation to simulate social interaction and train elements of communication including behavior, language pragmatics, speech gestures, and nonverbal emotional communication
Cognitive training	
Musical sensory orientation training (MSOT)	Application of live or recorded music to stimulate arousal and emphasize orientation to time, place, and person
Musical neglect training (MNT)	Active structured performance of exercises on musical instruments with appropriate spatial instrument placement to focus attention to a neglected visual field.
Auditory perception training (APT)	Use of tactile, visual, and kinesthetic musical exercises to emphasize sound discrimination, including time, tempo, duration, pitch, timbre, rhythmic patterns, and speech sounds.
Musical attention control training (MACT)	Application of active or receptive musical experiences involving pre-composed songs or improvisation during which musical elements cue specific attentional responses (e.g., sustained, selective, divided, alternating attention functions)
Musical mnemonics training (MMT)	Facilitation of memory encoding and recall functions through the use of musical stimuli and exercises, often involving the organization of non-musical information into musical contexts (i.e., songs, rhymes, chants)
Associative mood and memory training (AMMT)	Use of musical mood induction techniques to facilitate memory recall or to access associative mood and memory functions through the induction of positive emotional states during the learning and recall process
Musical executive function training (MEFT)	Use of improvisation and music composition exercises to practice executive function skills within a social context

Adapted from [18]

Interventions used most frequently for movement disorders are in italic

gait pattern that may be excessively slow or fast to prevent falling forward, and difficulties with freezing of gait, turning, and balance [18]. RAS is a neurologic music therapy technique in which an auditory rhythmic cue is given to facilitate the training of movements that are "intrinsically and biologically rhythmical," such as gait [18]. During RAS, the therapist assesses the patient's current gait parameters, introduces a rhythmic cue in either 2/4 (duple) or 4/4 time signature matched to the patient's baseline cadence, and then gradually modulates the tempo frequency in increments of 5–10% to optimize patient gait parameters, which most commonly include cadence, stride length, and velocity [18, 19]. Rhythmic auditory cues may include a simple metronome pulse, a complex music structure such as live or recorded music, or modified music with the rhythmic pulse highlighted [20]. The ultimate goal of RAS is to fade and eventually remove the rhythmic stimulus over time and re-assess the patient's gait parameters without applied rhythmic cues.

RAS is commonly implemented in 30-min training sessions for a range of 3 to 7 days per week over a dosing period of three to 6 weeks [21–23].

Thaut, Rice, Janzen, Hurt-Thaut, and McIntosh found that in a 24-week study, the strongest gains in gait were made during the first 8 weeks of a RAS protocol [24]. This study utilized a randomized withdrawal design during which an experimental group completed 24 weeks of RAS for 30 min daily while a control group discontinued RAS between weeks 8 and 16. At week 8, there were no significant differences between the groups, indicating similar improvement after completion of the same RAS protocol, while at the 16-week mark (8 weeks after the control group had discontinued RAS training), there were significant between-group differences, including deterioration of gait parameter gains (velocity, stride length, left and right foot dorsiflexion metrics, and fall index) within the control group and continued improvement in the experimental group. This suggests an 8-week duration of daily RAS with a need for continued maintenance to prolong improvements, but the question of dosing still merits further investigation. A recent meta-analysis of 50 studies measuring the impact of rhythmic cueing on Parkinsonian gait builds on these findings, indicating that RAS training should occur for a minimal period of 20–45 min per day for a minimum of 3–5 days per week [25].

In idiopathic PD, RAS has been shown to improve gait parameters such as normalizing gait velocity and cadence, increasing stride length and swing time (the time a leg is in the air during gait), and importantly, to contribute to a reduction in falls [21, 22, 24, 26–29]. RAS may also significantly reduce freezing of gait (FOG) and turn time during both ON and OFF dopaminergic medication periods. RAS has effectively been applied to PD patients in the medication ON phase, successfully decreasing the number and duration of FOG episodes during walking with and without turns [30, 31]. When individualized RAS frequencies at + 10% of baseline cadence during the ON phase were implemented during the end of dose phase, patients experienced reduced FOG episodes and demonstrated improved gait parameters [23]. Additionally, when RAS was implemented with patients in both ON and OFF medication phases, most patients with PD demonstrated improved gait patterns, though the OFF patient group experienced larger and more variable synchronization errors than ON patients [26]. More research is needed to determine the benefits of RAS during the end of dose and OFF phases (including optimal dosing), but it appears that RAS has important therapeutic potential for symptoms such as FOG, which for many patients are not adequately addressed by any other interventions.

Immediate effects have been observed during the implementation of rhythmic auditory cues, resulting in gait change during an intervention, short-term effects 15 minutes after [32], and longer-term improvements in gait that have been maintained for up to 4 weeks post-intervention [33]. Changes in gait patterns during RAS also suggest that this intervention may influence positional and muscular control, expanding potential gains to include improvements in perceptual and motor timing abilities for non-gait tasks in patients with PD [22, 34, 35].

Effectiveness of RAS may vary depending on stimulation frequency and the individualization of this frequency to each patient's baseline gait parameters. Notably, RAS may be most effective when implemented on an individualized basis, rather than with a fixed tempo for all study participants [3, 23]. Even when individualized, RAS stimulation frequency as compared to each patient's preferred walking cadence may impact overall cue effectiveness. RAS applied at 5–10% above baseline speed has been shown to result in increased cadence, stride length, and swing time for patients on and off dopaminergic medications [22, 26, 29, 32, 36].

However, for patients with freezing of gait, stride length only increased when the stimulus frequency was set to 10% *below* baseline cadence, indicating that cueing frequency should be adjusted to individualized gait deviations [30]. A rhythmic metronome stimulus applied at the patient's baseline cadence did not positively impact freezing variables, resulting in slower patient ambulation and increased walking time [37]. When RAS was applied at speeds 10% slower than preferred walking cadence and combined with attentional cues for patients without freezing of gait, it was shown to be equally effective, but not more effective, than simple attentional cues [38].

Individual responses to RAS may vary significantly and may also be impacted by patients' baseline musical and sensorimotor abilities and by the severity of patient gait disturbance [21, 39, 40]. When patient performance pre-RAS was tested via finger tapping and sensorimotor gait tasks, then applied to a logistic regression model aimed at predicting the probability of positive RAS response, patients who had the slowest gait speed and who showed the poorest synchronization accuracy were shown to be most likely to benefit from RAS [21]. However, strong music ability demonstrated pre-RAS, such as beat perception given tempo changes, natural ability to synchronize footsteps to a pulse without explicit instructions, and history of musical training may also significantly affect patient response to rhythmic cueing [39, 40]. Additionally, "groove," or "how much music makes a person want to move," in combination with clear instructions to synchronize with the beat while walking may impact RAS effectiveness [41]. Results indicate that low groove stimuli and instructing poor beat perceivers to synchronize may interfere with gait performance, while high groove stimuli overall led to more stable gait parameters.

Benefits of exposure to RAS may exist even for patients who lack positive responses to rhythmic stimuli while walking. Walking with music, which contains complex textures and an ability to evoke emotions, may still "increase a patient's mobility and motivation to walk," even if their responses to RAS are below the level of clinical significance [39]. Additionally, RAS may be used in combination with other neurologic music therapy techniques to further support gait and promote gains in other areas. An experimental group of PD patients who attended music therapy sessions utilizing RAS in addition to two other neurologic music therapy sensorimotor techniques (Therapeutic Instrumental Music Performance and Patterned Sensory Enhancement) experienced improvements in gait parameters in addition to improvement of proprioception when compared with the control group [42]. Overall, it is clear that while RAS holds significant potential benefits for gait in PD, an individualized therapeutic approach is required to optimize the effectiveness of this intervention. Findings from key studies described in this and other sections are summarized in Table 2.

Impact of Rhythmic Cueing (RAS) on Gait in Non-PD Patients

There is mixed, limited evidence supporting the use of RAS to improve gait parameters in patients with non-Parkinsonian disorders. In a recent feasibility study, a home-based program incorporated rhythmic cues set at individualized tempos in relation to preferred walking cadences for five patients with progressive supranuclear palsy (PSP), an atypical parkinsonian disorder that currently lacks effective symptomatic therapy [43]. After 8 sessions delivered over 4 weeks, all 5 patients reported satisfaction with the program, with some patients demonstrating improvements in gait stability, such as increased step cadence and stride length as well as reduced timing variability. The duration of benefit from RAS in PSP, patient characteristics that determine likelihood of RAS benefit, and the potential of RAS to reduce falls in this population deserve further investigation.

There is some evidence indicating that while gait velocity can be adapted to RAS for patients with Huntington's disease (HD), locomotor timing skills and other factors may impact the success of rhythmic cues [44•]. In a review of 14 studies exploring the impact of rhythmic cueing on patients with non-PD neurological diagnoses, two studies focused on patients with HD [45]. While one study showed a significant increase in gait velocity with RAS, both were uncontrolled, resulting in insufficient evidence to date on the impact of this technique in HD. Another study found that 27 patients with HD were able to successfully modulate their gait speed given rhythmic cues presented at 10% slower and 10–20% faster than patient baseline cadence, but only with a metronome, and not with musical cues [46].

Interventions Delivered Using Wearable Devices

In recent years, wearable devices and smartphone-based applications incorporating rhythmic cueing have been assessed and developed, particularly for use in patients with PD with the goal of utilizing rhythmic entrainment. Wearable technology, such as the interactive Walk Mate® system, utilizes data sent from pressure sensors worn in a patient's shoes to adjust rhythmic auditory cues in relation to the patient's footsteps [47]. In 20 patients who participated in experimental conditions including Walk Mate, fixed-tempo RAS individualized to patient baseline cadence, and unassisted walking without rhythmic cues, the Walk Mate intervention led to improved stride time variability, as well as subjective reports that patients' gait felt most stable when using the Walk Mate system.

Smartphone, tablet, and internet-based applications that can be implemented on patients' personal devices have been developed for use at home during gait training practice and activities of daily living, as well as to assess beat perception and create platforms for patient-therapist communication and supervision [48–50]. Most of these studies have involved small sample sizes and primarily focus on device/platform accuracy, rather than the specific impact on gait parameters or rhythmic ability. Overall, the evidence suggests that internet-based applications may be feasible for home use due to portability, flexibility, and ability to track patient performance over time and send data to the patient's medical team as permitted.

Other studies with small sample sizes and limited treatment time ranging from 1 to 3 sessions have combined wearable devices and customizable smartphone applications to gauge short-term impact on gait parameters and freezing of gait in PD. The use of Listenmee®, a system with wearable glasses, a portable auditory device, and corresponding smartphone application with individualized auditory cues, led to improvements in walking speed, cadence, and stride length [51]. Additionally, a system called GaitAssist®, comprised of ankle sensors that send data to the user's smartphone, cues a simple metronome stimulus when freezing of gait or gait patterns leading to freezing of gait were detected at home during natural walking and gait training exercises [52]. Results related to impact on freezing of gait were equivocal, but participants had a generally positive attitude toward wearability, system operation, and exercise content.

Dance in Parkinson Disease

There are a number of studies to date suggesting that various dance-based interventions can improve motor and non-motor symptoms and quality of life in PD. For example, the dance for PD® program integrates multiple dance styles, originated in Brooklyn, NY, in 2001 and has spread to over 300 communities and 25 countries since that time. In terms of evidence for specific dance types, Argentine Tango ballroom dance has been studied most extensively, with findings summarized below.

Table 2 Selected studies utilizing music therapy or music-based interventions in movement disorders

Type of study	Citation	Population	Study design	Number of participants	Intervention type	Intervention duration	Outcome measures	Results
Rhythmic cueing								
	[21]	PD	Controlled intervention trial	14	RAS via metronome-click embedded music	4 weeks	Auditory-paced hand tapping and spatiotemporal gait parameters	Increased gait speed and stride length; positive response to RAS predicted by synchronization performance on hand tapping and gait tasks
	[23]	PD	Controlled intervention trial	19 (10 PD+FOG; 9 PD−FOG)	Auditory rhythmic stimulation via headphones at 10% above baseline cadence	Immediate effect at end of dose period	Number and duration of freezing episodes and spatiotemporal gait parameters	Reduced FOG and turn time, and increased velocity and cadence
	[24]	PD	Randomized withdrawal	60	RAS via metronome-click embedded music	24 weeks (control discontinued RAS between weeks 8–16)	Velocity, stride length, cadence, ankle dorsiflexion, Berg Balance Scale, Timed Up and Go, Falls Efficacy Scale, and the Fall Index	Reduction in falls and improved gait parameters (velocity, stride length)
	[26]	PD	Controlled intervention trial	31	RAS via metronome-click embedded music at baseline cadence and 10% faster	Immediate effect	Spatiotemporal gait parameters	Faster RAS produced significant improvements in gait velocity, cadence, and stride length in all groups (ON and OFF dosing periods; OFF group experienced greater synchronization errors
	[30]	PD	Controlled intervention trial	20 (10 PD+FOG, 10 PD−FOG)	Rhythmic cueing via metronome at various tempi (at baseline cadence, 10–20% faster, 10–20% slower)	Immediate effect	Gait analysis with motion capture	Cueing frequency impacted freezers and non-freezers differently. Stride length decreased at + 10% tempo for freezers, while it increased for non-freezers.
	[31]	PD	Uncontrolled intervention trial	15 (+FOG)	RAS via metronome and headphones at predefined points on training path (e.g., turns)	6 weeks	Freezing of gait questionnaire, video analysis, gait speed	Number and duration of FOG episodes decreased; responsiveness varied on questionnaire and gait speed
	[32]	PD	Controlled intervention trial	29	RAS via metronome (at baseline and 10% faster)	Immediate and carryover effect (2 and 15 min)	Spatiotemporal gait parameters	RAS matched to baseline cadence improved gait speed, stride length, and swing time, but did not impact variability. With RAS at + 10%, reductions in gait variability were observed and persisted at 2 and 15 min later.
	[43]	PSP	Feasibility trial	5	Rhythmic cues at individualized tempos	4 weeks	Spatiotemporal gait measures	Improvements in gait stability, such as increased step cadence and stride length as well as reduced timing variability.
	[46]	HD	Uncontrolled intervention trial	27	Rhythmic cueing	Immediate effect	Stride parameters, gait velocity	With metronome able to successfully modulate their gait speed. This was not achieved with musical cues.
	[47]	PD	Uncontrolled intervention trial	20	Wearable (interactive Walk Mate system)	Immediate effect	Detrended fluctuation analysis fractal-scaling exponent as a measure of healthy gait	Improved stride time variability. Subjective improvement in gait stability.
	[48]	PD		16		6 weeks		

Table 2 (continued)

Type of study	Citation	Population	Study design	Number of participants	Intervention type	Intervention duration	Outcome measures	Results
			Uncontrolled intervention trial		Wearable (music-based game on a tablet device)		Beat perception as a measure of rhythmic skills	Improved beat perception in majority of patients.
Dance								
	[53••]	PD	Randomized controlled trial (RCT)	62	Argentine Tango (AT) 2×/week	12 months	MDS-UPDRS Part III (Motor) scores; Mini-BESTest of balance; Freezing of Gait questionnaire; 6-Minute Walk Test, forward and dual-task walking velocities; 9-hole PEG test of upper extremity function	Significant motor benefits in Tango group at 12 months for gait (including freezing), balance, forward and dual-task walking velocities, and 9-hole PEG test. Assessments were performed in the off state and suggest that sustained twice-weekly AT may modify PD progression.
	[54•]	PD	RCT	10	AT 2×/week	24 months	MDS-UPDRS; Mini-BESTest; gait velocity (forward and backward); Timed Up and Go and dual-task Timed Up and Go; Six-Minute Walk Test; Freezing of Gait Questionnaire	At both 12 and 24 months, AT participants had better MDS-UPDRS Part I (non-motor ADLs), II (motor ADLs), and III (motor examination) scores, as well as better scores on the 6MWT and the MiniBESTest.
	[57•]	PD	Nonrandomized controlled intervention trial	16 (8 per group)	1-h twice-weekly dance for PD classes vs. twice-weekly partnered Argentine Tango classes	12 weeks	Gait velocity; mini-balance evaluation systems test; four square step test; five times sit to stand; 6-min walk time; MDS-UPDRS Motor scores; functional mobility (Timed Up and Go test)	Measures of balance, repeated sit-to-stand performance and endurance improved from pre- to post-intervention similarly in both groups. MDS-UPDRS motor ratings and functional mobility improved in the Tango group and worsened in the Dance for PD group, while gait velocity was not affected by either intervention.
Singing								
	[59]	PD	Uncontrolled 2-dose trial	27	Once-weekly vs. twice-weekly group (choir) singing	8 weeks	Inspiratory/expiratory pressure; phonation time; voice-related quality of life; overall quality of life	Increased inspiratory/expiratory pressure, phonation time, voice-related quality of life and overall quality of life
	[62•]	PD	Controlled intervention trial	90 (30 PD/30 older controls/30 younger controls; 1:1 M:F)	External rhythmic auditory cueing set at participants' preferred cadence (listening and walking to the beat of "Row, row, row your boat") vs. internal cueing (singing "Row, row, row your boat" aloud)	Single 1-day visit	Gait parameters (velocity, cadence, stride length, variability) assessed for forward and backward gait	Internal cueing was associated with greater improvements in gait velocity, cadence, and stride length in the backward direction, and reduced variability in both forward and backward walking, with greater improvements observed among older controls and PD participants.
Instrumental performance								
	[76•]	Tourette's syndrome		29		Immediate and short-term	Tic severity	Significant tic reduction with all interventions, most notably with

Table 2 (continued)

Type of study	Citation	Population	Study design	Number of participants	Intervention type	Intervention duration	Outcome measures	Results
			Uncontrolled intervention trial		Musical performance, listening to music, and mental imagery of music	effects 15 min post-intervention		musical performance in which the effect was sustained for 15 min after the performance ended.
Other studies								
	[44•]	HD	RCT	63	Group music therapy, mostly receptive	16 weeks	Social-cognitive functioning subscale of the Behavior Observation Scale Huntington	No additional benefit on communication or behavior compared with group recreational therapy.
	[66]	PD	RCT	25	Combination of methods including production of music, singing, and dancing	24 weeks	QoL; motor function; cognition	Short-term improvement in QoL and cognition not sustained at 24 weeks. No significant improvement in motor function.
	[67]	PD	RCT	18	Ronnie Gardiner Rhythm and Music Method	6 weeks	Mobility, cognition, QoL	No significant difference between music group and control group following intervention. Within music group, only there was a significant improvement in mobility, cognition, and QOL post-intervention compared to pre-intervention.

Argentine Tango

Intuitively, the gait-related benefits of Argentine Tango in PD may stem from the large/exaggerated steps required in multiple directions for this dance style, which can counteract the reduced stride length characteristic of PD-related gait impairment. Duncan and Earhart performed a 12-month randomized controlled trial of Argentine Tango (AT) vs. usual care in 62 patients with PD [53••]. In the off dopaminergic medication state, control participants showed little change from baseline while AT participants demonstrated improvements from baseline in Movement Disorder Society-Unified Parkinson Disease Rating Scale (MDS-UPDRS; an ordinal rating scale consisting of a non-motor activities of daily living (ADL) assessment questionnaire, a motor ADL assessment questionnaire, and a motor examination) Part III (Motor examination) scores, the MiniBESTest of balance, the Freezing of Gait questionnaire, 6-Minute Walk Test (6MWT), forward and dual-task walking velocities, and 9-hole PEG test of upper extremity function. The 12.8-point average improvement on MDS-UPDRS Part III has robust clinical significance, and the overall findings of this study suggest that continued participation in AT classes may modify disease progression in PD. The same authors subsequently performed a pilot randomized controlled study of 10 PD patients assigned to twice-weekly AT classes or usual care and assessed by blinded raters at 12 and 24 months; there were no group differences in ADL or motor scores at baseline [54•]. At both 12 and 24 months, AT participants had better MDS-UPDRS Part I (Non-Motor ADLs), II (Motor ADLs), and III scores, as well as better scores on the 6MWT and the MiniBESTest. While very small, this study demonstrates the potential long-term benefits of dance-based interventions in PD. Beevers et al. (2017) sought to assess specific musical features used for Tango dance classes in PD using a mixed-methods approach [55]. Results from both software-based structural analysis of the music and the qualitative questionnaires filled by physical therapists found that the most "successful" music (in terms of motor and quality of life improvement reported by PD patients undergoing Tango lessons) ranged in tempo between 105 and 125 beats per minute, was in simple duple time, had a clear downbeat, moderate pulse clarity, and minimal key modulations. These findings represent an important attempt to determine the characteristics of music used in dance classes that may underlie observed benefits in PD and need to be replicated in larger multicenter studies.

Other Dance-Based Interventions

Bognar et al. used semi-structured interviews from participants in a Dancing with Parkinson's (a community-based dance therapy) program and found that beyond motor improvements, dancing was felt to facilitate redevelopment of the social self, increasing sense of enjoyment in life, fostering positive change in patients' perspective toward their PD diagnosis, and thereby increasing feelings of self-efficacy [56]. By breaking down social isolation, group dance can potentially improve cognitive and emotional challenges in PD—non-motor aspects of the disease that often do not respond to dopaminergic therapy.

McNeely et al. performed a study comparing 1-h twice-weekly dance for PD classes with twice-weekly partnered Argentine Tango classes over 12 weeks [57•]. Participants in each group were matched for age and gender, and comparisons were done on 8 participants per group; evaluations were performed off dopaminergic medication within 1 month of intervention completion. Measures of balance, repeated sit-to-stand performance, and endurance improved from pre- to post-intervention to a similar extent in both groups. MDS-UPDRS motor ratings and functional mobility (Timed Up and Go test time) improved in the Tango group and worsened in the dance for the PD group, while gait velocity was not affected by either intervention [57•]. While these findings are preliminary, they reflect much-needed direct comparisons of interventions already in use among individuals with PD.

Singing in Parkinson Disease

Speech impairment (decreased voice volume and clarity) is a common and often debilitating symptom in PD and can adversely impact communication. A prior (2016) systematic review of therapeutic singing in PD summarized evidence from 7 studies that assessed the impact of singing on speech; 5 studies found partial evidence of benefit, while 2 found no evidence of benefit [58]. No included study evaluated the impact of singing on motor function or cognitive status. Stegemoller et al. performed an open-label 8-week study of group singing (led by music therapists) in 27 patients with PD who were assigned to twice-weekly or once-weekly singing, and found improvements in inspiratory/expiratory pressure, phonation time, voice-related quality of life, and overall quality of life; they found no differences between once-weekly or twice-weekly intervention frequency [59]. Han et al. performed a small open-label study in 9 PD patients that examined the effects of an individual singing program (6 sessions over 2 weeks) administered by a music therapist [60]. Significant improvements in maximum phonation time, Geriatric Depression Scale ratings, voice-related quality of life, and the Voice Handicap Index scores were found 6 months after intervention. Butala et al. performed a blinded cross-over trial of weekly group singing in patients with PD that assessed motor and non-motor outcomes over 30 weeks in participants randomly assigned to group singing or a weekly PD support group discussion for 12 weeks, with subsequent cross-over [61]. Significant objective improvements in conversational voice volume on two independent measures (Rainbow Passage reading and Cookie Theft description, ranging from 2 to 8 dB) were observed at the end of study interventions and 6 weeks later, and improvements on the PDQ-39 quality of life questionnaire (domains of communication and body discomfort) were attributable to the singing intervention. Interestingly, significant motor improvements on the MDS-UPDRS motor rating scale (5.9–8.4 points) were observed at end of interventions and 6 weeks later regardless of intervention order, possibly attributable to physical warm-ups prior to singing rehearsals and movements incorporated into the singing classes [61]. Overall, the studies of singing in PD performed to date have been underpowered, but multicenter randomized controlled trials with active behavioral control interventions (such as speech therapy) are feasible and justified given the evidence to date.

Singing may also be helpful in improving other symptoms in PD, such as gait. Harrison et al. performed a comparative study of external rhythmic auditory cueing set at participants' preferred cadence (listening and walking to the beat of "Row, row, row your boat") vs. internal cueing (singing "Row, row, row your boat" aloud) in 30 patients with PD, 30 younger, and 30 older controls [62•]. Internal cueing was associated with greater improvements in gait velocity, cadence, and stride length in the backward direction, and reduced variability in both forward and backward walking, with greater improvements observed among older controls and PD participants. This study is noteworthy in that it is difficult to motivate PD patients to consistently walk to external cues at home, while singing may be implementable for more patients.

Instrumental Performance in Parkinson Disease

There is limited research exploring the impact of instrumental performance on motor function in PD.

Typically, mention of instrumental performance is included as part of a group music therapy intervention but is not explicitly evaluated as a primary intervention. One review of 68 articles exploring the effectiveness of singing or playing a wind instrument to improve respiratory function in patients with long-term neurologic disorders (PD, multiple sclerosis, spinal cord injury, among others) found that though studies were generally of low quality, most trended toward improved respiratory function [63]. Another study found that PD patients who participated in 13 weekly music therapy sessions consisting of a range of interventions, including both structured and improvisational percussion instrument play, demonstrated improvement in bradykinesia [64]. Rigorously designed research studies are clearly needed in this area.

Music Therapy/Interventions for Non-motor Symptoms in Parkinson Disease

The non-motor manifestations of PD play a great role in disease-related disability and are often difficult to treat [65]. Some studies show that music therapy (MT) or music-based interventions can be beneficial in the management of these symptoms.

Effect on Cognition

A randomized study of 25 patients with PD evaluated the effects of active MT on cognition through detailed neuropsychological examinations [66•]. Results showed significant improvements in frontal lobe function such as cognitive flexibility, processing speed, attention, and working memory at the end of the 6-month music therapy program. However, these beneficial effects disappeared on reassessment 6 months after the end of music therapy sessions, which suggests that music therapy needs to be continued to maintain its beneficial effects on cognitive functioning [66•]. Another study evaluated the effects of the Ronnie Gardiner Rhythm and Music (RGRM) method on cognition in PD patients [67]. It showed significant improvement in verbal memory, language, executive function, and attention vs. usual care controls.

Effect on Mood

The available studies of music therapy and its effects on mood show mixed results. In some studies, there was a significant improvement in depression, emotions, self-esteem, and social isolation with various music-based interventions such as active MT, singing, and RAS [60, 64]. On the other hand, different studies showed no significant improvement in mood-related symptoms such as depression and anxiety with music-based interventions, which included singing, drum circle classes, and exercise facilitated by auditory music cues [68–71]. Notably, in all of these studies, mood was assessed by self-reported questionnaires as opposed to clinician-rated measures.

Effect on Quality of Life

PD-related quality of life (QoL) was assessed in studies that utilized different music-based interventions, with multiple studies showing significant improvement in QoL. The interventions studied include active MT, functional-oriented music therapy (FMT), RGRM method, West African drum circle classes, and dancing [56, 64, 66•, 67, 70]. In one study, this beneficial effect on QoL was not sustained long-term, as QoL deteriorated again when patients were reassessed 6 months after the end of their MT sessions [66•]. Moreover, the use of MT to ameliorate pain in PD has been suggested, as MT has been shown to improve pain in other medical conditions [72, 73]. Currently, no studies using music for pain in PD have been published to the authors' knowledge.

Music Therapy/Interventions for Other Movement Disorders

The effects of music therapy on non-gait-related symptoms in other movement disorders are poorly studied. In one single-center study, patients with HD did not significantly improve their communication skills or behavior with group music therapy when compared with group recreational therapy [44]. There is a need for larger studies to further evaluate this, as most music therapy referrals for HD patients are due to communication, social, and emotional problems [74]. The music therapy assessment tool for advanced HD can potentially be used to study the impact of music therapy on communication, psychological, physical, and social aspects of advanced HD [75]. In regard to Tourette's syndrome, a study in Germany evaluated the effects of music on tic frequency by utilizing the Yale Global Tic Severity Scale and the modified Rush Video-Based Tic Rating Scale [76•]. Results showed that tic reduction occurred with all the musical interventions in the study, which included performance of music, listening to music, and mental imagery of music. The greatest impact on tic reduction was achieved with musical performance, where the effect was sustained for 15 minutes after the performance ended [76•].

Conclusions and Future Directions

Several types of music therapy (particularly RAS, Therapeutic Instrumental Music Performance, and Therapeutic Singing) and music and rhythm-based interventions (particularly AT and group singing) have evidence from multiple studies demonstrating a benefit for various motor and non-motor symptoms in PD. A few studies have assessed long-term outcomes (1–2 years) and suggest that interventions like AT, when continued long-term, may modify disease progression in PD. However, the extent to which this is specifically attributable to exercise-, music-, or rhythm-related aspects of AT (or their combination) is unclear. Methodological limitations of many studies (such as small sample size, short follow-up duration, inadequate description of specific music-related methodologies, and use of passive control groups) notwithstanding, there is clearly an improving evidence base to support certain music and rhythm-based interventions in PD, and studies in other movement disorders are warranted.

It is also clear that an optimized approach to music and rhythm-based treatments involves *individualized* selection of stimuli ("precision music therapy/music medicine") in order to achieve an optimal degree of benefit for specific patients.

This poses an important challenge for the design of randomized controlled trials for music therapy/music-based interventions. Alternative investigational approaches utilizing n-of-1 randomized controlled trials, potentially coupled with smartphone applications to facilitate interventions and assessments at home, need to be explored. The validity of home-based symptom and quantitative assessments remains to be established, and this area of research holds significant promise in making music and rhythm-based interventions widely accessible to patients with movement disorders.

Compliance with Ethical Standards

Conflict of Interest Kerry Devlin, Jumana Alshaikh, and Alexander Pantelyat each declare no potential conflict of interest.

Human and Animal Rights and Informed Consent This article is a review and reports only studies approved by editorial boards based on peer reviews. When we cited our own work, all the procedures performed in the studies involving human materials or animals were conducted in accordance with the ethical standards of our institution, with informed consent obtained from patients and approval from ethics committees.

References

Papers of particular interest, published recently, have been highlighted as:
• Of importance
•• Of major importance

1.• Cheever T, Taylor A, Finkelstein R, et al. NIH/Kennedy center workshop on music and the brain: finding harmony. Neuron. 2018;97(6):1214–8 **This is a white paper broadly outlining the knowledge gaps in the mechanisms of music's effect on the body and the effects of music-based interventions in improving health; findings from the workshop summarized in this paper informed a subsequent request for grant applications related to Music in Health (NIH/NEA).**
2. Jones CR, Jahanshahi M. Motor and perceptual timing in Parkinson's disease. Adv Exp Med Biol. 2014;829:265–90.
3. Ashoori A, Eagleman DM, Jankovic J. Effects of auditory rhythm and music on gait disturbances in Parkinson's disease. Front Neurol. 2015;6:234.
4. Alves-Pinto A, Turova V, Blumenstein T, Thienel A, Wohlschlager A, Lampe R. fMRI assessment of neuroplasticity in youths with neurodevelopmental-associated motor disorders after piano training. Eur J Paediatr Neurol. 2015;19(1):15–28.
5. Batson G, Soriano C, Laurienti P, Burdette J, Migliarese S, Hristov N. Effects of group-delivered improvisational dance on balance in adults with middle stage Parkinson's disease: a two-phase pilot with fMRI case study. J Park Dis. 2013;3:192.
6. Braunlich K, Seger CA, Jentink KG, Buard I, Kluger BM, Thaut MH. Rhythmic auditory cues shape neural network recruitment in Parkinson's disease during repetitive motor behavior. Eur J Neurosci. 2018.
7. Ma LY, Chen XD, He Y, Ma HZ, Feng T. Disrupted brain network hubs in subtype-specific Parkinson's disease. Eur Neurol. 2017;78(3–4):200–9.
8. Thaut MH, McIntosh GC, Hoemberg V. Neurobiological foundations of neurologic music therapy: rhythmic entrainment and the motor system. Front Psychol. 2015;6.
9. Thaut MH, McIntosh KW, McIntosh GC, Hoemberg V. Auditory rhythmicity enhances movement and speech motor control in patients with Parkinson's disease. Funct Neurol. 2001;16(2):163–72.
10. Thaut MH. The discovery of human auditory-motor entrainment and its role in the development of neurologic music therapy. Prog Brain Res. 2015;217:253–66.
11. Thaut MH, Kenyon GP, Schauer ML, McIntosh GC. The connection between rhythmicity and brain function. IEEE. 1999;18(2):101–8.
12. Buard I, Dewispelaere WB, Thaut M, Kluger BM. Preliminary neurophysiological evidence of altered cortical activity and connectivity with neurologic music therapy in Parkinson's disease. Front Neurosci. 2019;13:105.
13.• Nozaradan S, Peretz I, Mouraux A. Selective neuronal entrainment to the beat and meter embedded in a musical rhythm. J Neurosci. 2012;32(49):72–81 **This small study utilizing surface electroencephalography in healthy controls provides indirect evidence of *neuronal rhythmic entrainment*, with emergence of spontaneous internal representation of beat frequencies at multiples of beat frequencies being heard (e.g., hearing 1.25-Hz frequency and averaged EEG frequency spectrum peaks at 1.25 Hz, 2.5 Hz, 5 Hz, and 10 Hz).**
14. Clements-Cortes A, Bartel L. Are we doing more than we know? Possible mechanisms of response to music therapy. Frontiers in medicine. 2018;5:255.
15. Vitorio R, Stuart S, Gobbi LTB, Rochester L, Alcock L, Pantall A. Reduced gait variability and enhanced brain activity in older adults with auditory cues: a functional near-infrared spectroscopy study. Neurorehabil Neural Repair. 2018;32(11):976–87.
16. Schaefer RS. Auditory rhythmic cueing in movement rehabilitation: findings and possible mechanisms. Philosophical transactions of the Royal Society of London Series B, Biological sciences. 2014;369(1658):20130402.
17. Angelucci F, Fiore M, Ricci E, Padua L, Sabino A, Tonali PA. Investigating the neurobiology of music: brain-derived neurotrophic factor modulation in the hippocampus of young adult mice. Behav Pharmacol. 2007;18(5–6):491–6.
18. Thaut CP, Rice RR. Rhythmic auditory stimulation (RAS). In: New York: Oxford University Press. 2014.
19. De l'Etoile SK. Neurologic music therapy: a scientific paradigm for clinical practice. Music and Medicine. 2010;2(2):78–84.
20. Dreu Md, Kwakkel G, Wegen, Erwin E H van. Rhythmic auditory stimulation (RAS) in gait rehabilitation for patients with Parkinson's disease: a research perspective. In: New York: Oxford University Press; 2014.
21. Bella SD, Benoit CE, Farrugia N, Keller PE, Obrig H, Mainka S, et al. Gait improvement via rhythmic stimulation in Parkinson's disease is linked to rhythmic skills. Sci Rep. 2017;7:42005.
22. Benoit CE, Dalla Bella S, Farrugia N, Obrig H, Mainka S, Kotz SA. Musically cued gait-training improves both perceptual and motor timing in Parkinson's disease. Front Hum Neurosci. 2014;8:494.
23. Arias P, Cudeiro J. Effect of rhythmic auditory stimulation on gait in parkinsonian patients with and without freezing of gait. PLoS One. 2010;5(3):e9675.
24. Thaut MH, Rice RR, Braun Janzen T, Hurt-Thaut C, McIntosh GC. Rhythmic auditory stimulation for reduction of falls in Parkinson's disease: a randomized controlled study. Clin Rehabil. 2019;33(1):34–43.
25. Ghai S, Ghai I, Schmitz G, Effenberg AO. Effect of rhythmic auditory cueing on parkinsonian gait: a systematic review and meta-analysis. Sci Rep. 2018;8(1):506.
26. McIntosh GC, Brown SH, Rice RR, Thaut MH. Rhythmic auditory-motor facilitation of gait patterns in patients with

Parkinson's disease. J Neurol Neurosurg Psychiatry. 1997;62(1):22–6.
27. Pau M, Corona F, Pili R, Casula C, Sors F, Agostini T, et al. Effects of physical rehabilitation integrated with rhythmic auditory stimulation on spatio-temporal and kinematic parameters of gait in Parkinson's disease. Front Neurol. 2016;7.
28. Rochester L, Hetherington V, Jones D, Nieuwboer A, Willems AM, Kwakkel G, et al. The effect of external rhythmic cues (auditory and visual) on walking during a functional task in homes of people with Parkinson's disease. Arch Phys Med Rehabil. 2005;86(5):999–1006.
29. Thaut MH, McIntosh GC, Rice RR, Miller RA, Rathbun J, Brault JM. Rhythmic auditory stimulation in gait training for Parkinson's disease patients. Mov Disord. 1996;11(2):193–200.
30. Willems AM, Nieuwboer A, Chavret F, Desloovere K, Dom R, Rochester L, et al. The use of rhythmic auditory cues to influence gait in patients with Parkinson's disease, the differential effect for freezers and non-freezers, an explorative study. Disabil Rehabil. 2006;28(11):721–8.
31. Plotnik M, Shema S, Dorfman M, Gazit E, Brozgol M, Giladi N, et al. A motor learning-based intervention to ameliorate freezing of gait in subjects with Parkinson's disease. J Neurol. 2014;261(7):1329–39.
32. Hausdorff JM, Lowenthal J, Herman T, Gruendlinger L, Peretz C, Giladi N. Rhythmic auditory stimulation modulates gait variability in Parkinson's disease. Eur J Neurosci. 2007;26(8):2369–75.
33. Kadivar Z, Corcos DM, Foto J, Hondzinski JM. Effect of step training and rhythmic auditory stimulation on functional performance in Parkinson patients. Neurorehabil Neural Repair. 2011;25(7):626–35.
34. Benoit CE, Farrugia N, Schwartze M, Dalla Bella S, Kotz S. Non-gait related benefits of auditory cueing in Parkinson's disease. J Park Dis. 2013;3:138.
35. Thaut MH, Abiru M. Rhythmic auditory stimulation in rehabilitation of movement disorders: a review of current research. Music Percept. 2010;27(4):263–9.
36. Matsumoto L, Magalhaes G, Antunes GL, Torriani-Pasin C. Effect of rhythmic auditory cue on gait in patients with Parkinson's disease. Revista Neurociencias. 2014;22(3):404–9.
37. Cubo E, Leurgans S, Goetz CG. Short-term and practice effects of metronome pacing in Parkinson's disease patients with gait freezing while in the 'on' state: randomized single blind evaluation. Parkinsonism Relat Disord. 2004;10(8):507–10.
38. Baker K, Rochester L, Nieuwboer A. The immediate effect of attentional, auditory, and a combined cue strategy on gait during single and dual tasks in Parkinson's disease. Arch Phys Med Rehabil. 2007;88(12):1593–600.
39. Bella SD, Dotov D, Bardy B, de Cock VC. Individualization of music-based rhythmic auditory cueing in Parkinson's disease. Ann N Y Acad Sci. 2018;1423:308–17.
40. Cock CD, Dotov DG, Ihalainen P, et al. Rhythmic abilities and musical training in Parkinson's disease: do they help? NPJ Parkinson's disease. 2018;4:8.
41. Ready EA, McGarry LM, Rinchon C, Holmes JD, Grahn JA. Beat perception ability and instructions to synchronize influence gait when walking to music-based auditory cues. Gait Posture. 2019;68:555–61.
42. Bukowska AA, Krężałek P, Mirek E, Bujas P, Marchewka A. Neurologic music therapy training for mobility and stability rehabilitation with Parkinson's disease - a pilot study. Front Hum Neurosci. 2016;9.
43. Wittwer JE, Winbolt M, Morris ME. A home-based, music-cued movement program is feasible and may improve gait in progressive supranuclear palsy. Front Neurol. 2019;10:116.
44.• van Bruggen-Rufi MC, Vink AC, Wolterbeek R, Achterberg WP, Roos RA. The effect of music therapy in patients with Huntingtons Dis: a randomized controlled trial. J Huntingtons Dis. 2017;6(1):63–72 **This was a randomized controlled trial that evaluated the effect of group music therapy when compared with group recreational therapy of social-cognitive functioning in HD and showed no difference in outcomes between both groups.**
45. Wittwer JE, Webster KE, Hill K. Rhythmic auditory cueing to improve walking in patients with neurological conditions other than Parkinson's disease—what is the evidence? Disabil Rehabil. 2013;35(2):164–76.
46. Thaut MH, Miltner R, Lange HW, Hurt CP, Hoemberg V. Velocity modulation and rhythmic synchronization of gait in Huntington's disease. Mov Disord. 1999;14(5):808–19.
47. Hove MJ, Suzuki K, Uchitomi H, Orimo S, Miyake Y. Interactive rhythmic auditory stimulation reinstates natural 1/f timing in gait of Parkinson's patients. PLoS One. 2012;7(3):e32600.
48. Dauvergne C, Begel V, Geny C, Puyjarinet F, Laffont I, Dalla BS. Home-based training of rhythmic skills with a serious game in Parkinson's disease: usability and acceptability. Ann PM&R. 2018;61(6):380–5.
49. Zhu S, Ellis RJ, Schlaug G, Ng YS, Wang Y. Validating an iOS-based rhythmic auditory cueing evaluation (iRACE) for Parkinson's disease. MM 2014 - Proceedings of the 2014 ACM Conference on Multimedia. 2014:487–496.
50. Cancela J, Moreno EM, Arredondo MT, Bonato P. Designing auditory cues for Parkinson's disease gait rehabilitation. Conference proceedings: Annual International Conference of the IEEE Engineering in Medicine and Biology Society IEEE Engineering in Medicine and Biology Society Annual Conf Proc IEEE Eng Med Biol Soc. 2014;2014:5852–5.
51. Lopez WOC, Higuera CAE, Fonoff ET, de OS, Albicker U, JAE M. Listenmee® and listenmee® smartphone application: synchronizing walking to rhythmic auditory cues to improve gait in parkinson's disease. Hum Mov Sci. 2014;37:147–56.
52. Mazilu S, Blanke U, Dorfman M, et al. A wearable assistant for gait training for Parkinson's disease with freezing of gait in out-of-the-lab environments. ACM Transactions on Interactive Intelligent Systems. 2015;5(1).
53.•• Duncan RP, Earhart GM. Randomized controlled trial of community-based dancing to modify disease progression in Parkinson disease. Neurorehabil Neural Repair. 2012;26(2):132–43 **This is a 12-month study of Argentine Tango (AT) vs. passive control in PD that demonstrated clinically and statistically significant motor benefits from AT at 12 months for gait (including freezing), balance, forward and dual task walking velocities, and 9-hole PEG test of upper extremity function. The assessments were performed in the dopaminergic off state and suggest that sustained twice-weekly AT may modify PD progression.**
54.• Duncan RP, Earhart GM. Are the effects of community-based dance on Parkinson disease severity, balance, and functional mobility reduced with time? A 2-year prospective pilot study. J Altern Complement Med. 2014;20(10):757–63 **This small study represents the longest published follow up of a continued music-based intervention in PD to date and demonstrated both objective and patient-reported motor and non-motor ADL benefits sustained for 2 years since beginning Argentine Tango intervention.**
55. Beevers WA, Morris ME. A structural analysis of music in tango dance classes for Parkinson's disease. Aust J Music Ther. 2017;28:67–85.
56. Bognar S, DeFaria AM, O'Dwyer C, et al. More than just dancing: experiences of people with Parkinson's disease in a therapeutic dance program. Disabil Rehabil. 2017;39(11):1073–8.
57.• McNeely ME, Mai MM, Duncan RP, Earhart GM. Differential effects of tango versus dance for PD in Parkinson disease. Front

Ag Neurosci. 2015;7:239 **This is one of a small number of studies comparing 2 active music-based interventions in PD. MDS-UPDRS motor ratings and functional mobility (Timed Up and Go test time) improved in the Tango group and worsened in the Dance for PD group, while gait velocity was not affected by either intervention.**

58. Barnish J, Atkinson RA, Barran SM, Barnish MS. Potential benefit of singing for people with Parkinson's disease: a systematic review. J Park Dis. 2016;6(3):473–84.
59. Stegemöller EL, Radig H, Hibbing P, Wingate J, Sapienza C. Effects of singing on voice, respiratory control and quality of life in persons with Parkinson's disease. Disabil Rehabil. 2017;39(6):594–600.
60. Han EY, Yun JY, Chong HJ, Choi KG. Individual therapeutic singing program for vocal quality and depression in Parkinson's disease. J Mov Disord. 2018;11(3):121–8.
61. Butala A, Swaminathan A, Dunlop S, et al. Parkinsonics-a prospective, randomized, blinded, cross-over trial of group singing for motor and non-motor symptoms in idiopathic Parkinson's disease (PD). Mov Disord. 2017;32.
62.• Harrison EC, Horin AP, Earhart GM. Internal cueing improves gait more than external cueing in healthy adults and people with Parkinson disease. Sci Rep. 2018;8(1):15525 **This study suggests that internal cueing (singing while walking) may improve gait parameters in PD to a greater extent than external rhythmic cues. Internal cueing was associated with greater improvements in gait velocity, cadence, and stride length in the backward direction, and reduced variability in both forward and backward walking, with greater improvements observed among older controls and PD participants**.
63. Ang K, Maddocks M, Xu H, Higginson IJ. The effectiveness of singing or playing a wind instrument in improving respiratory function in patients with long-term neurological conditions: a systematic review. J Music Ther. 2017;54(1):108–31.
64. Pacchetti C, Mancini F, Aglieri R, Fundaro C, Martignoni E, Nappi G. Active music therapy in Parkinson's disease: an integrative method for motor and emotional rehabilitation. Psychosom Med. 2000;62(3):386–93.
65. Pfeiffer RF. Non-motor symptoms in Parkinson's disease. Parkinsonism Relat Disord. 2016;22 Suppl 1:119.
66.• Spina E, Barone P, Mosca LL, et al. Music therapy for motor and nonmotor symptoms of parkinson's disease: a prospective, randomized, controlled, single-blinded study. J Am Geriatr Soc. 2016;64(9):e39 **This was a randomized controlled trial that evaluated effects of several MT interventions in PD on motor function, quality of life, and cognition. Results showed short-term improvements in quality of life and cognition with MT that disappeared shortly after completion of MT.**
67. Pohl P, Dizdar N, Hallert E. The ronnie Gardiner rhythm and music method - a feasibility study in Parkinson's disease. Disabil Rehabil. 2013;35(26):2197–204.
68. Elefant C, Baker FA, Lotan M, Lagesen SK, Skeie GO. The effect of group music therapy on mood, speech, and singing in individuals with Parkinson's disease–a feasibility study. J Music Ther. 2012;49(3):278–302.
69. Haneishi E. Effects of a music therapy voice protocol on speech intelligibility, vocal acoustic measures, and mood of individuals with Parkinson's disease. J Music Ther. 2001;38(4):273–90.
70. Lyons KE, Hamburg J, Clair AA. A feasibility study of the effects of music and movement on physical function, quality of life, depression, and anxiety in patients with Parkinson disease. Music Med. 2012;4(1):49–55.
71. Pantelyat A, Syres C, Reichwein S, Willis A. DRUM-PD: the use of a drum circle to improve the symptoms and signs of Parkinson's disease (PD). Mov Disord Clin Pract. 2016;3(3):243–9. https://doi.org/10.1002/mdc3.12269.
72. Lee JH. The effects of music on pain: a meta-analysis. J Music Ther. 2016;53(4):430–77.
73. Skogar O, Lokk J. Pain management in patients with Parkinson's disease: challenges and solutions. J Multidiscip Healthc. 2016;9(1):469–79.
74. Daveson B. Findings of an audit of music therapy referrals in a specialist in-patient setting for 16 patients with advancing Huntington's disease. Aust J Music Ther. 2007;18:2–19.
75. O'Kelly J, Bodak R. Development of the music therapy assessment tool for advanced Huntington's disease: a pilot validation study. J Music Ther. 2016;53(3):232–56.
76.• Bodeck S, Lappe C, Evers S. Tic-reducing effects of music in patients with Tourette's syndrome: self-reported and objective analysis. J Neurol Sci. 2015;352(1-2):41-47. **This study evaluated the effects of musical performance, listening to music, and mental imagery of music on tic severity in Tourette's syndrome. There was significant tic reduction with all musical interventions. The most profound effect was with musical performance.**