# The Therapeutic Role of Rhythmic Music in Motor Function Rehabilitation for Parkinson's Disease and Stroke

## Executive Summary

This expert report examines the scientific basis, clinical practices, and documented effectiveness of using music, particularly rhythmic beats, as a therapeutic tool for improving motor function in patients with Parkinson's disease (PD) and stroke. The analysis reveals that the core therapeutic principle lies in a phenomenon known as auditory-motor entrainment. The auditory system, being highly sensitive to temporal patterns, can provide an external, reliable cue that bypasses damaged or dysfunctional neural pathways responsible for internally generated movement. This process activates alternative motor networks in the brain, offering a powerful, non-pharmacological means of mitigating motor deficits.

The evidence for this approach is robust across both conditions. In Parkinson's disease, Rhythmic Auditory Stimulation (RAS) has demonstrated significant improvements in key gait parameters, including velocity, stride length, and cadence, and has been effective in alleviating severe axial symptoms like freezing of gait and poor balance. For stroke patients, music-based therapies, such as Music-Supported Therapy (MST), have proven effective in restoring both gait function and fine motor skills in the affected upper limbs. Beyond specific motor improvements, the report highlights the profound non-motor benefits of music therapy, including enhanced mood, motivation, and quality of life, which are critical for patient adherence and long-term recovery.

While current research, often limited by small sample sizes and a lack of standardized protocols, provides a strong foundation, the future of this field is moving towards personalized, technology-assisted interventions. Emerging technologies like wearable devices and closed-loop systems promise to deliver real-time, adaptive rhythmic cues tailored to individual patient needs, unlocking new levels of therapeutic precision and efficacy. This comprehensive review concludes that music-based interventions represent a safe, cost-effective, and deeply beneficial component of a multidisciplinary neurorehabilitation strategy.

## 1. The Neurobiological Underpinnings of Auditory-Motor Coupling

### 1.1 The Neurological Basis of Rhythmic Perception and Motor Control

The human brain possesses a remarkable, innate ability to perceive and move in time with a musical beat, a process known as entrainment. This seemingly effortless behavior is orchestrated by a complex and highly integrated neural network that links the auditory and motor systems.1 Core structures involved in this process include cortical areas such as the premotor cortex and supplementary motor area (SMA), as well as subcortical structures like the basal ganglia, and the cerebellum.1 The basal ganglia, in particular, play a key role in perceiving the beat and regulating the timing and sequencing of movements.1

A key advantage of the auditory system is its temporal precision. Research indicates that the human auditory system's reaction time to stimuli is 20-50 milliseconds faster than that of the visual and tactile systems.1 This superior temporal processing capacity makes auditory cues exceptionally effective for providing a reliable, external reference point for movement. By leveraging this natural, rapid coupling between the auditory and motor systems, music-based therapies can provide a powerful tool to influence movement patterns. The rich connectivity between these systems at multiple cortical, subcortical, and even spinal levels forms the neuroanatomical basis for the therapeutic efficacy of rhythmic interventions.3

### 1.2 The Impaired Internal Timing System in Parkinson's Disease

Parkinson's disease is a progressive neurodegenerative disorder primarily caused by the loss of dopaminergic neurons in the substantia nigra, a region of the brain that provides crucial input to the basal ganglia.1 The basal ganglia are essential for regulating the brain's internal timing system, which is responsible for the automatic, sequential execution of motor commands.3 The disruption of dopamine projections within these networks directly leads to significant impairments in beat perception and production abilities.1

Patients with Parkinson's disease often exhibit deficits in tapping tasks and rhythm discrimination, which are directly linked to the dysfunction of the basal ganglia.1 These motor timing deficits can be temporarily improved by dopaminergic medication, confirming the crucial role of dopamine in rhythm processing.1 Therefore, the motor symptoms of PD, such as bradykinesia and freezing of gait, can be understood not merely as a loss of motor function but as a fundamental failure of the brain's internal mechanism for generating and maintaining a stable, predictable temporal sequence of movements.3

### 1.3 Auditory-Motor Entrainment: A Compensatory Mechanism

The central therapeutic principle of music-based interventions for Parkinson's disease is auditory-motor entrainment. This process involves the synchronization of motor movements with an external rhythmic cue, such as a musical beat or a metronome.3 The efficacy of this approach is rooted in the brain's ability to engage alternative, intact neural networks to bypass the primary pathology of basal ganglia dysfunction. By providing an external, reliable temporal signal, RAS recruits compensatory motor control pathways that do not rely on the impaired internal timing system.

Neuroimaging studies have shown that rhythmic stimuli can activate brain regions such as the premotor cortex and supplementary motor area (SMA), even in the absence of explicit motor action.6 These cortical structures have rich neural connections to the auditory system and are recruited to drive movement when the basal ganglia are impaired.3 This compensatory mechanism essentially creates a "temporal scaffold" that guides and facilitates movement. The external rhythmic cue acts as a direct, non-dopaminergic input to the SMA, providing a powerful, non-pharmacological way to modulate a core motor-planning network.6 This intervention is not just a temporary fix; by repeatedly engaging these alternative pathways, it can promote neuroplasticity and the long-term establishment of new, functional motor control circuits.8 This ability to "re-wire" the brain offers a compelling rationale for the sustained benefits of rhythmic music therapy.3

## 2. Rhythmic Interventions for Parkinson's Disease: A Clinical Efficacy Review

### 2.1 Addressing Gait Deficits: Velocity, Stride Length, and Cadence

Rhythmic Auditory Stimulation (RAS) has been widely studied and proven effective in addressing the gait disturbances that are hallmark symptoms of Parkinson's disease. Multiple meta-analyses and systematic reviews have concluded that RAS can significantly improve key spatiotemporal gait parameters.4 Studies have consistently shown that rhythmic cues increase gait velocity, stride length, and cadence in patients with PD.1 The improvements in these parameters lead to a more fluid and efficient walking pattern, which is a critical goal of rehabilitation.

The positive effects of RAS are not limited to the duration of the external cue; research indicates that the benefits can persist even after the stimulus is removed, demonstrating a carry-over effect that suggests the induction of lasting motor learning.2 This is supported by the finding that rhythm can produce an internal beat that a patient can retrieve and use even when the music is absent.1 This points to the fact that rhythmic therapy serves as a form of implicit motor learning, teaching the brain to generate a more stable and regular movement pattern independently.13

### 2.2 Alleviating Axial Symptoms: Balance and Freezing of Gait

Beyond improving specific gait parameters, music-based movement therapy has demonstrated significant efficacy in mitigating some of the most debilitating axial symptoms of Parkinson's disease, including poor balance and freezing of gait. A systematic review and meta-analysis of 17 studies involving 598 participants found that music-based movement therapy, which often incorporates rhythmic stimulation, led to significant improvements in balance.11 The positive outcomes were measured using standardized tools such as the Berg Balance Scale and the Mini-Balance Evaluation Systems Test.11

Furthermore, the therapy significantly improved freezing of gait, a severe motor block that can cause a patient to feel "stuck" in place.6 This is a particularly crucial finding as freezing episodes are a major contributor to falls and loss of independence. The rhythmic cueing provides a powerful external signal that helps patients overcome these motor blocks.5 The effectiveness of this approach is evidenced by a study using a wearable device that adapted musical stimulation to a patient's gait cadence, which resulted in a statistically significant reduction in the number of falls per week from

0.26 to 0.14.14

### 2.3 The Impact on Fine Motor Skills and Tremor Management

Music-based interventions are not limited to improving gross motor functions like walking; they also offer documented benefits for fine motor skills and the management of tremors. An intriguing case study in a master's thesis notes that a patient with severe Parkinson's disease experienced a disappearance of his tremor while playing and focusing on music.1 Similar anecdotal and clinical reports suggest that active engagement with musical instruments, such as the piano or drums, can help reduce muscle stiffness and involuntary movements.1

This effect is attributed to the brain's ability to use external rhythms to bypass impaired internal motor loops.17 Since current medications are often less effective in addressing fine motor difficulties, music-based therapy provides a promising and complementary approach for managing these symptoms.17 Additionally, a type of therapy called vibroacoustic therapy, which uses low-frequency sound vibrations, has been shown to decrease body stiffness and reduce tremors, offering a unique mechanism for motor symptom relief.1

### 2.4 Non-Motor Benefits: A Link to Mood, Motivation, and Creativity

The therapeutic benefits of music extend far beyond motor function to encompass significant improvements in the non-motor symptoms of Parkinson's disease. A compelling study found that PD patients with more than three years of music training exhibited beat production abilities comparable to healthy adults, while patients with minimal training performed significantly worse.1 This finding suggests that a history of musical engagement may create a form of cognitive reserve that helps preserve rhythmic motor timing abilities, offering a protective effect against the neurodegenerative process.1

Moreover, music-based interventions have a powerful effect on emotional and psychological well-being. Studies have shown that music therapy can improve mood, reduce anxiety, and enhance overall quality of life.1 This is particularly important for managing the common neuropsychiatric symptoms associated with PD, such as depression and apathy.1 The social aspect of group activities, such as choir or dance classes, can also significantly improve patient well-being by providing a sense of community and combating social isolation.15

A fascinating phenomenon reported by some patients is a "release of creativity" after starting dopaminergic treatment.1 Music-making and listening are known to activate the brain’s limbic system and dopamine reward pathways 1, which are also targeted by these medications. This connection suggests that the emotional benefits of music therapy are not merely psychological but are likely mediated by the same neurochemical systems involved in PD. This makes music a potential component in a "drug-music co-regulation protocol" 18, allowing patients to leverage a pleasurable, non-pharmacological activity to directly influence their brain chemistry and manage non-motor symptoms.

## 3. The Efficacy of Music-Based Therapies in Stroke Rehabilitation

### 3.1 Gait and Balance Recovery in Post-Stroke Patients

Similar to its application in Parkinson's disease, Rhythmic Auditory Stimulation (RAS) has been validated as an effective intervention for gait and balance recovery in stroke patients.7 Stroke, a highly disabling condition, often leaves patients with motor dysfunction and decreased balance.19 RAS addresses these deficits by providing a steady, rhythmic cue to which the patient can synchronize their walking pattern. This technique helps to reorganize gait patterns by promoting neuroplasticity and engaging alternative motor pathways in the brain.7

A meta-analysis of clinical randomized controlled studies provided solid evidence that RAS is effective in improving gait parameters, walking function, and balance in stroke patients.19 The analysis confirmed statistically significant advantages for the intervention group in terms of step length, step cadence, and velocity.19 These improvements are particularly vital for stroke survivors, as they contribute directly to restoring independence and daily living activities.10

### 3.2 Restoring Upper Limb Motor Function through Music-Supported Therapy

While RAS is primarily a tool for gait rehabilitation, other music-based therapies have been specifically developed to address the upper limb motor deficits common in stroke patients. Music-Supported Therapy (MST) is a targeted intervention that uses a standardized program of keyboard and drum exercises to improve fine motor function.20 This therapy is highly effective due to several key mechanisms: audio-motor coupling, motor skill shaping, and emotional-motivational effects.20 The immediate auditory feedback from playing an instrument—whether a correct note on a keyboard or a drum beat—directly reinforces the motor movement, facilitating neural reorganization and motor learning.20

Two meta-analyses on music-based interventions for post-stroke upper extremity rehabilitation found statistically significant improvements in motor function as measured by outcomes such as the Box and Block Test and the Nine-Hole Peg Test.20 Furthermore, for patients with speech impairments (aphasia), a singing-based therapy called Melodic Intonation Therapy (MIT) has shown efficacy.22 MIT engages the right hemisphere's sensorimotor networks and provides continuous rhythmic cueing for syllable production, helping patients regain some of their speech capabilities.22

### 3.3 The Role of Music in Enhancing Motivation and Cognitive Function

A crucial, yet often overlooked, aspect of music-based therapy in stroke rehabilitation is its ability to enhance patient motivation and cognitive function. Stroke rehabilitation is a long and challenging process, and patient adherence is a significant factor in long-term outcomes.24 Music therapy, by its very nature, is engaging and enjoyable, which increases a patient's willingness to participate in a demanding and repetitive training regimen.8 A clinical trial on stroke patients hypothesized that an increase in motivation, which is a known benefit of music therapy, would correlate with functional improvements in both motor and cognitive domains.24

Beyond motivation, music therapy provides multisensory stimulation that can improve a range of cognitive functions.8 Research indicates that music-based interventions can lead to improvements in attention, memory, and executive function.8 For example, one study found that personalized music listening programs improved cognitive assessment scores in post-stroke patients with cognitive impairment.8 These benefits underscore the multidimensional nature of music therapy, positioning it as an intervention that addresses not only physical deficits but also the cognitive and psychological challenges that can impede a patient's recovery.

## 4. The Spectrum of Music-Based Interventions: From Beat to Artistry

### 4.1 Comparative Analysis of Therapeutic Modalities

The field of music-based neurorehabilitation encompasses a range of distinct therapeutic modalities, each with its own mechanisms and target outcomes. A primary distinction is drawn between simple rhythmic cueing and the use of full musical compositions. Rhythmic Auditory Stimulation (RAS), which often employs a metronome or a simple beat, is a rehabilitative technique focused on improving specific motor functions like gait.1 Its primary mechanism is auditory-motor entrainment, and its goal is to provide a precise, external temporal reference.3

In contrast, traditional music therapy, which incorporates the full range of musical elements—melody, harmony, and timbre—is a more holistic and relational approach. This modality aims to address emotional, communicative, and cognitive aspects of a patient's condition, often in addition to motor symptoms.1 The decision of which modality to use depends on the specific therapeutic goals. While a metronome may be sufficient for a targeted gait training exercise, a rich musical piece may be more effective for a patient whose primary needs are emotional expression, social engagement, or cognitive stimulation.

### 4.2 The Clinical Application of Music-Based Movement and Dance Therapy

Dance therapy is a unique and effective form of rhythmic movement intervention that combines auditory cues with whole-body coordination. It is particularly well-suited for patients with Parkinson's disease, as it addresses several key symptoms simultaneously.1 A study on the effects of tango and Irish dancing on PD patients found that these activities improved mobility, balance, and quality of life.11

Although one study on healthy adults found no significant effect of dance training on beat perception, this may be due to the fact that dancers rely heavily on visual-motor entrainment in addition to auditory cues.1 For a clinical population, the social dimension of dance classes, which provides a supportive, community-based environment, is a critical factor in improving mental well-being and combating isolation.1

### 4.3 Active Music Making: Beyond Gait, Towards Fine Motor and Vocal Rehabilitation

Active music-making, which involves playing an instrument or singing, represents a powerful form of music therapy that engages a broader range of motor and cognitive skills than passive listening. In the context of Parkinson's disease, active music therapy through improvisation and instrument playing has been shown to improve both motor and emotional functions.1 A case study demonstrated that a PD patient's tremor disappeared while actively playing a piano.1 This type of therapy provides a unique opportunity for patients to practice fine motor skills in an engaging and self-expressive way.1

Similarly, singing therapy has been found to be a highly effective intervention, particularly for managing vocal symptoms of PD such as hypophonia (soft voice) and reduced vocal projection.15 A clinical trial on group singing for PD patients reported significant improvements in vocal loudness, pitch, and swallow control.15 This approach leverages the fact that singing shares many of the same neural networks and structural mechanisms as speech, making it an ideal therapeutic medium.25

### 4.4 The Potential of Vibroacoustic Therapy

Vibroacoustic therapy (VA) stands out as a distinct modality that uses low-frequency sound waves to produce physical vibrations in the body.1 This technique is based on the principle that the physical resonance of sound can directly influence physiological and motor systems. The application of VA has been anecdotally and clinically linked to a reduction in muscle stiffness, body rigidity, and tremors in patients with Parkinson's disease.1

A study on VA for PD patients found that the treatment led to improvements in language capacity, writing skills, swallowing, and daily living activities.1 The approach is particularly notable for its ability to induce deep relaxation, which can alleviate muscle tension and provide a sense of well-being. This physical, resonance-based mechanism offers a unique complement to the auditory-based cueing of RAS and the motor training of active music-making.

## 5. Research Limitations, Gaps, and the Future of the Field

### 5.1 Methodological Challenges in Current Research

While the evidence for music-based neurorehabilitation is compelling, the field faces significant methodological challenges that limit the generalizability and robustness of its findings. A primary limitation is the small sample sizes of many clinical studies, with numerous trials involving fewer than 50 participants.8 This constrains statistical power and makes it difficult to draw definitive conclusions.

Furthermore, there is a pervasive lack of standardization in treatment protocols. Studies often differ significantly in the type of music used, the duration and frequency of sessions, and the outcome measures employed.8 This heterogeneity makes it challenging to compare results across trials and synthesize a unified body of evidence. A third critical gap is the dominance of short-term follow-up periods, with most studies lasting less than six months. This weakens the evidence for the long-term effects and sustained benefits of the interventions.8

### 5.2 The Need for Standardization and Rigorous Clinical Trials

To address these limitations, a clear consensus exists within the research community regarding the need for more rigorous, standardized, and large-scale clinical trials. The field requires a shift from exploratory studies to methodologically robust trials with larger, more representative patient cohorts.10 The development of international consensus guidelines for therapeutic protocols, including standardized measures for music selection and dosage, is essential for improving the comparability of future research.8

Moreover, there is a call for a standardized musical intervention to help improve specific motor skills, such as fine motor dexterity in Parkinson's disease, which are not adequately addressed by current pharmacological treatments.17 By adopting more rigorous methodologies, researchers can obtain stronger conclusions and facilitate the broader acceptance of music therapy as a mainstream clinical intervention.

### 5.3 Emerging Technologies: Wearable Devices and Closed-Loop Systems

The future of music-based neurorehabilitation is inexorably linked to the integration of intelligent technologies. Traditional interventions are being complemented or replaced by innovative, technology-assisted platforms that can offer unprecedented precision and personalization. Wearable devices, such as the Charco CUE1, are being developed to deliver constant, individualized rhythmic cues through vibrotactile stimulation.26 Another promising example is the BeatPark device, which combines ankle sensors with a smartphone application to modify music tempo in real-time, synchronizing it with the patient's gait cadence and progressively increasing it by 10%.14

A particularly groundbreaking development is the concept of "closed-loop" systems. These systems use real-time physiological data from the patient (e.g., gait kinematics, brain activity via EEG) to dynamically adjust the rhythmic stimulus in real-time.13 This represents a fundamental shift from a one-way, "open-loop" intervention to a responsive, two-way feedback system. This type of personalized, adaptive technology has the potential to optimize therapeutic efficacy and allows for at-home rehabilitation, which can significantly increase accessibility and patient independence.13

### 5.4 Personalization of Interventions: The Future of Precision Neurorehabilitation

A recurring theme in the research is the high degree of inter-individual variability in response to rhythmic cues.13 The effectiveness of a cue can depend on a patient's preserved rhythmic abilities and personal music preferences. This highlights the limitations of a "one-size-fits-all" approach and underscores the need for highly personalized interventions. Studies have shown that self-selected music, rather than pre-determined tracks, yields superior therapeutic benefits by enhancing a patient's motivation and physiological response.13

The future of music-based neurorehabilitation will therefore involve a move towards precision medicine. Interventions will need to be tailored to the individual, leveraging adaptive algorithms and real-time biometric data to optimize the rhythmic cue and therapeutic content for each patient. By customizing the intervention based on a patient's unique neural and behavioral profile, clinicians can maximize the therapeutic benefits and ensure that the intervention is both effective and engaging.

## Conclusion and Strategic Recommendations

The body of scientific evidence overwhelmingly supports the use of music, particularly rhythmic cues, as a powerful and effective therapeutic tool in the rehabilitation of motor function for patients with Parkinson's disease and stroke. The underlying mechanism of auditory-motor entrainment offers a compelling, neurobiologically grounded rationale for its efficacy, demonstrating that music can activate compensatory neural pathways to bypass damaged motor control centers. Documented improvements in gait parameters, balance, fine motor skills, and non-motor symptoms like mood and motivation confirm the multidimensional benefits of this approach.

However, despite these promising findings, the field remains constrained by methodological limitations and a lack of large-scale, standardized research. To move from a promising complementary therapy to a mainstream clinical intervention, a concerted effort is needed to address these gaps.

Based on the evidence reviewed, the following strategic recommendations are presented:

* **Clinical Integration:** Music-based interventions should be systematically integrated into multidisciplinary rehabilitation programs for patients with Parkinson's disease and stroke. These therapies are safe, cost-effective, and can be used in conjunction with traditional physical and occupational therapies to enhance outcomes and patient adherence.
* **Research Prioritization:** There is a critical need to fund and conduct large-scale, multi-site randomized controlled trials with standardized protocols and long-term follow-up periods. Future research should also focus on elucidating the specific dose-response relationships of different musical elements (e.g., tempo, complexity) on various motor and non-motor outcomes.
* **Technological Innovation:** Continued investment in the development of personalized, home-based, and technology-assisted interventions is paramount. Wearable devices and closed-loop systems that can adapt rhythmic cues in real-time to a patient's physiological state represent the future of precision neurorehabilitation, promising to increase therapeutic efficacy and accessibility.
* **Professional Certification and Education:** The establishment of recognized certification programs for neurologic music therapists and the widespread dissemination of research findings to clinicians, patients, and caregivers are essential for promoting the adoption of these beneficial therapies. By building a robust professional and educational infrastructure, the field can ensure the safe and effective delivery of music-based interventions to those who need them most.

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