# The Musician's Brain as a Model for Use-Dependent Plasticity and Multisensory Neuro-Rehabilitation

**Evelyn Mire**[1]

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Musical training is associated with use-dependent neuroplasticity due to its intensive multisensory and sensorimotor demands. Beyond its psychological benefits, playing a musical instrument requires continuous integration of motor, auditory, and visual feedback, which is associated with experience-dependent plasticity. For example, motor coordination and auditory feedback circuits engaged during musical practice may overlap with networks involved in movement and speech. Literature was identified through searches of PubMed and Google Scholar conducted between February and June 2026 and supplemented by relevant theoretical and rehabilitation studies. Included studies consisted primarily of peer-reviewed human research reporting objective neuroimaging, neurophysiological, or rehabilitation outcomes. Using advanced neuroimaging and electrophysiological techniques, researchers have reported associations between musical training and differences in brain structure, auditory processing, and certain cognitive functions. While the structural differences among musicians are documented, the translation of these findings into neuro-rehabilitation methods remains largely unexplored. Prior voxel-based morphometry (a neuroimaging method that measures local brain tissue volume) studies have reported associations between long-term musical training and increased gray matter volume in the Heschl's gyrus, premotor cortex, and cerebellum. These findings suggest that long-term musical training is associated with auditory-motor networks that may be relevant to future rehabilitation research in stroke and TBI. This narrative review summarizes recent advances in gray matter morphology and examines their possible implications for multisensory neuro-rehabilitation. It further considers rhythmic auditory entrainment as a potential avenue for future research on cortical reorganization.

**Keywords:** neuroplasticity, cortical reorganization, gray matter density, musical training, cross-modal plasticity, neuro-rehabilitation, therapeutic intervention, executive function, voxel-based morphometry, rhythmic auditory stimulation, music therapy

## Introduction

Neurological motor impairments, resulting from conditions like stroke or traumatic brain injury, place a substantial socioeconomic and psychological burden on patients and healthcare systems worldwide. Traditional rehabilitation approaches may be limited by physical, logistical, or financial constraints, highlighting the need for engaging, cost-effective, and scalable therapeutic strategies. Multisensory training paradigms are particularly promising in this context, as they simultaneously engage auditory, visual, and motor networks and may promote neuroplastic changes relevant to functional recovery.

Musical training involves intensive feedback loops that may engage overlapping auditory, motor, and visual networks associated with cortical reorganization. Use-dependent plasticity refers to the functional and structural changes associated with repeated motor activity[1,2]. These adaptations may occur across distributed sensorimotor systems, involving changes in cortical maps, connectivity, excitability, and learning processes beyond simple motor repetition[2]. Experimental studies in healthy adults have shown that repeated movement practice can induce behavioral directional movement consistent with a use-dependent plasticity framework[1,2]. Current theories suggest that motor learning arises from multiple interacting processes, including use-dependent plasticity, adaptation, and reinforcement, rather than from a single mechanism alone[2]. While simple repetitions induce measurable directional biases, musical training provides a particularly useful model of use-dependent plasticity because it requires the integration of precise motor sequences with auditory and multisensory feedback over prolonged periods of practice. The relative contribution of visual, tactile, and proprioceptive feedback varies across instruments. In musicians, these persistent motor demands have been associated with increased gray matter density within specialized sensorimotor-auditory networks[3]. Because mu-

[1] *Jasper High School, Texas, USA*

**Table 1** Structural Neuroimaging Studies of Musician Brains

| Study | Population (N) | Musician Criteria | Design | Measure | Key Finding | Limitation |
|---|---|---|---|---|---|---|
| Gaser & Schlaug (2003) | 18-40 year old males (N = 80) | Professionals: $\geq$1 h/day practice; amateurs: regular players with non-musical occupations | Cross-sectional | VBM | Training intensity associated with distinct gray matter patterns | Male-only sample; causality uncertain |
| Bermudez et al. (2009) | Adult musicians and non-musicians (N = 135) | $\geq$10 years formal training; right-handed; neurologically healthy | Cross-sectional | VBM; cortical thickness | Greater auditory and frontotemporal gray matter in musicians | Cross-sectional; absolute pitch subgroup variability |
| Gärtner et al. (2013) | Adult volunteers (N = 39) | Middle-aged professional musicians with at least subsidiary piano training | Cross-sectional | DBM | Larger sensorimotor volumes associated with better motor performance | Modest sample size; causality uncertain |
| James et al. (2014) | Healthy young adults (N = 59) | Professionals: $\sim$5 hours daily; amateurs $>$10 hours weekly | Cross-sectional | VBM; gray matter density | Training intensity associated with differential gray matter patterns across networks | Cross-sectional associations only |
| Groussard et al. (2014) | Young adult volunteers (N = 44) | Amateur musicians with varying years of practice | Cross-sectional | Structural MRI | Longer practice associated with regional gray matter differences | Cross sectional; heterogeneous training |
| Kleber et al. (2016) | Healthy volunteers (N = 55) | Professional trained classical singer | Cross-sectional | VBM | Greater somatosensory and auditory cortex gray matter in singers | Small sample; limited generalizability |
| Yamashita et al. (2021) | Older adults (N = 60) | $\geq$20 years training; active performers | Cross-sectional | VBM, fMRI | Larger cerebellar volume and stronger cerebellar-hippocampal connectivity in older musicians | Small sample; uncontrolled confounders |

sical performance relies heavily on rhythm and sensorimotor integration, the cerebellar and premotor cortices have attracted interest as potential targets for music-based rehabilitation strategies. This review synthesizes evidence from studies of musician brain morphology, longitudinal music-training paradigms, and music-based rehabilitation interventions to examine the musician's brain as a model of use-dependent plasticity and to explore the potential relevance of these findings to neuro-rehabilitation.

## Methodology

This narrative literature review was conducted between February and June 2026, with the final search completed on June 18, 2026. Searches were performed in PubMed and Google Scholar using Boolean combinations of terms related to musical training, music-based intervention, neuroplasticity, gray matter, motor-auditory networks, cerebellar involvement, and premotor cortex involvement.

- ("music" OR "musical training" OR "musicians") AND ("neuroplastic" OR "gray matter" OR "brain structure") AND ("motor" OR "auditory" OR "cerebellum" OR "premotor")
- ("music therapy" OR "musical training" OR "rhythmic auditory stimulation") AND ("rehabilitation" OR "stroke" OR "Parkinson") AND ("motor" OR "gait" OR "movement")
- ("musical training" OR "music intervention") AND ("longitudinal" OR "pre-post" OR "training study") AND ("brain" OR "neuroplasticity" OR "MRI" OR "fMRI")
- ("digital therapeutic" OR "DTx" OR "gamified" OR "electronic drums") AND ("music" OR "rhythmic") AND ("motor" OR "neurorehabilitation")

Title and abstract screening were performed first, followed by full-text review of studies relevant to the objectives of the review. Following screening, 26 articles met the objectives of this narrative review and were synthesized qualitatively.

Studies were included if they consisted of peer-reviewed primary research involving human participants and patients, with adult studies prioritized and selected developmental studies included when relevant to longitudinal neuroplasticity. Only articles published in English were considered. Eligible studies were published between 1996 and 2026 and reported objective outcomes related to brain structure, brain function, or rehabilitation, including MRI, fMRI, TMS, electrophysiological measures, gait analysis, and standardized clinical assessments. Selected peer-reviewed review articles and theoretical papers were included to provide mechanistic and conceptual context. Opinion pieces, non-peer-reviewed sources,

**Table 2** Rhythm-Based Rehabilitation Studies (RAS)

| Study | Population | Intervention | Design | Outcome Measure | Key Finding | Limitation |
|---|---|---|---|---|---|---|
| Thaut et al. (1996) | PD patients (N = 26) | Rhythmic auditory stimulation (RAS) gait training | Controlled trial | Gait parameters; EMG | RAS improved gait velocity, stride length, and cadence | Small sample; short intervention duration |
| Curzel et al. (2021) | Healthy volunteers (N = 34) | Rhythmic auditory cueing (e-drum) training | Short-term training study | Behavioral tapping; fNIRS | Participants synchronized to external rhythms during training | Healthy sample; short-term intervention |
| Tamplin et al. (2019) | PD patients (N = 75) | Weekly ParkinSong singing therapy | Controlled clinical trial | Voice measures; respiratory measures; quality of life | Singing therapy improved vocal and respiratory function | No neuroimaging outcomes; limited mechanistic insight |

animal studies, and studies lacking relevant outcomes were excluded.

Studies were grouped into five distinct literature categories and summarized in Tables 1–5 according to participant characteristics, study design, sample size, and outcome measures. Because definitions of musician varied across studies, each study's original operational criteria were retained and recorded in the summary table. Related theoretical and neuroscience studies on motor-auditory networks were used to provide mechanistic context and were not considered part of the primary empirical evidence base.

As a narrative literature review, studies were selected to address the objectives of the review rather than according to formal systematic-review procedures. No quantitative synthesis or formal risk-of-bias assessment was performed. Consequently, findings should be interpreted as a qualitative synthesis of the literature rather than a systematic evaluation of evidence quality.

## The Musician's Brain: Structural Adaptations

### Motor-Auditory Networks and Cerebellar Adaptations

Table 1 summarizes the principal neuroimaging studies discussed in this section examining structural adaptations in musician brains.

In a 2003 study, Gaser and Schlaug used voxel-by-voxel morphometric analysis to compare gray matter volume between professional keyboard players and a matched group of amateur musicians and non-musicians[3]. The study found that gray matter volume was highest in professional musicians, intermediate in amateur musicians, and lowest in non-musicians. Additionally, gray matter volume in the left cerebellum, left Heschl's gyrus (the primary auditory cortex), and the left inferior frontal gyrus, areas critical for auditory processing and motor control, was found to be positively correlated with musician status. The graded differences observed between professional musicians, amateur musicians, and non-musicians are consistent with use-dependent plasticity, as greater training intensity was associated with larger structural differences in regions engaged during musical performance.

These results support the idea that motor-related brain regions (such as the premotor and cerebellar cortices) play a critical role in the planning, execution, and control of bimanual sequential finger movements. The cerebellar component of this network corresponds to the cerebellar finger-hand representation[4]. Additionally, studies have found activation in these regions during repeatedly practiced auditory-musical tasks[5,6], suggesting that repeated functional engagement may be associated with the structural differences observed by Gaser and Schlaug. Functional imaging studies have further demonstrated that pitch and duration sequence processing recruit a shared bilateral network involving the cerebellum, posterior temporal lobes, and inferior frontal regions, supporting the role of distributed frontotemporal-cerebellar circuits in auditory pattern processing[5]. Similarly, studies of professional musicians have reported associations between structural differences in sensorimotor regions and corticospinal pathways that corresponded with superior motor performance[7]. Several studies have shown that the cerebellum is an important contributor to cognitive skill learning[8] and music processing[5,6], suggesting that these aspects of musical training could contribute to structural differences in the cerebellum. Reviews of neuroimaging and neurological studies have further suggested that music performance and perception rely on distributed networks spanning both cerebral and cerebellar regions rather than isolated structures alone[8]. Similarly, Groussard et al. reported associations between the duration of musical practice and regional differences in the hippocampus, supplementary motor area, and temporal regions, suggesting that distinct aspects of training may be associated with different patterns of structural adaptation[9]. Furthermore, studies of older musicians have reported larger cerebellar volumes and stronger cerebellar-hippocampal connectivity, suggesting that some structural differences associated with long-term musical experience may persist into later adulthood[10].

Collectively, these studies suggest that musical training is

**Table 3** Music-Supported Therapy and Stroke Rehabilitation

| Study | Population | Intervention | Design | Outcome Measure | Key Finding | Limitation |
|---|---|---|---|---|---|---|
| Amengual et al. (2013) | Chronic stroke patients (N = 20) | Music-supported therapy (MST) | Pre-post study with matched controls | TMS; motor performance; 3D movement analysis | MST improved motor performance and increased corticospinal excitability | Small sample; non-randomized design |
| Segura et al. (2024) | Chronic stroke patients (N = 58) | Enriched MST | Randomized controlled trial | Upper-limb motor scales; quality-of-life measures | MST improved upper-limb function and quality of life | Moderate sample size; chronic stroke population only |

associated with structural and functional adaptations across interconnected auditory, motor, and cerebellar networks. The convergence of neuroimaging and behavioral findings supports the view that prolonged multisensory practice may engage distributed systems involved in sensorimotor integration rather than isolated cortical regions, which may merit further investigation into the possible therapeutic relevance of musical expertise. However, because the majority of these studies are cross-sectional, they cannot determine whether the observed differences resulted from musical training itself or from preexisting individual predispositions.

### Frontotemporal Networks and Executive Function

Beyond primary sensory processing, James et al. reported that increasing musical expertise was associated with increased gray matter density in cognitive and auditory regions but decreased gray matter density in portions of the sensorimotor system [11]. The authors proposed that these opposing patterns may reflect different forms of neural adaptation associated with long-term training. These findings suggest that musical expertise may be associated with region-specific structural remodeling rather than uniform increases in gray matter volume. Conversely, the observed decrease in striatal gray matter density may reflect neural refinement associated with long-term practice, potentially supporting more efficient execution of complex motor sequences. Together, these findings suggest that long-term training may be associated with structural adaptations that extend beyond primary motor and auditory regions to support complex executive functions.

Furthermore, Bermudez et al. (2009) [12] utilized a multimodal neuroimaging approach to reveal that musicians exhibit greater cortical thickness with peaks in superior temporal and dorsolateral frontal regions. Their findings showed a specific increase in gray matter concentration in the right auditory cortex, emphasizing the importance of the frontotemporal network of areas relied upon in musical performance and the interplay between multisensory and motor behaviors. These findings further suggest that prolonged engagement of auditory-cognitive networks may be associated with experience-dependent structural adaptation. Similar findings have been reported in trained singers, who exhibit differences in auditory and somatosensory gray matter compared with non-singers, suggesting that structural associations with musical expertise are not limited to instrumental performance alone [13]. Functional imaging studies have further demonstrated that auditory working memory and pitch memory engage distributed networks involving frontal, temporal, parietal, and cerebellar regions, supporting the role of widespread neural systems in higher-order auditory processing [6]. The expansion of these frontotemporal networks suggests that musical training may be associated with both sensory processing and cognitive control networks [11,12]. These findings suggest that musical training is associated with adaptations extending beyond primary auditory and sensorimotor systems. Such distributed network changes have prompted interest in whether similar mechanisms might be leveraged in neurorehabilitation settings.

## Theoretical Applications in Neuro-Rehabilitation

The cerebellar and premotor cortices are important contributors to rhythmic motor synchronization [14]. Causal evidence for the role of the right dorsal premotor cortex in auditory-motor timing comes from rTMS studies, which show that transient disruption of this region impairs synchronization accuracy during rhythmic tasks. Musicians frequently utilize these circuits to execute precise, bimanual finger movements during instrument performance. In the context of neuro-rehabilitation, this constant engagement suggests that musical training may be associated with neuroplasticity processes that could be relevant to future studies on motor function in stroke or TBI patients. In the context of stroke rehabilitation, rhythm-based interventions such as rhythmic auditory stimulation (RAS) may modulate residual motor networks involved in movement timing, although the underlying mechanisms remain incompletely understood [15]. Current evidence is strongest for Parkinson's disease and stroke, while additional randomized controlled trials are needed to clarify efficacy in other neurological popula-

**Table 4** Mechanistic and Theoretical Frameworks

| Study | Type | Proposed Mechanism | Relevance | Limitations |
|---|---|---|---|---|
| Diedrichsen (2010) | Theoretical | Optimal feedback control may coordinate movement through hierarchical error correction and sensorimotor integration | Provides framework for understanding motor coordination in music-based training | Theoretical; no original data |
| Huang et al. (2011) | Theoretical | Motor learning may arise from multiple processes, including adaptation, reinforcement, and use-dependent plasticity | Explains how repeated musical practice may shape motor behavior | Theoretical; no original data |
| Giovannelli et al. (2012) | Experimental rTMS study | Right dorsal premotor cortex may contribute to rhythmic auditory-motor synchronization | Supports neural basis of rhythm synchronization and auditory cueing | Small sample size |
| Grodd et al. (2001) | fMRI study | Cerebellum contains somatotopic motor representations involved in movement coordination | Provides mechanistic basis for cerebellar involvement in musical training | Healthy subjects only |
| Griffiths et al. (1999) | PET study | Shared frontotemporal-cerebellar networks may support pitch and timing processing | Suggests common neural substrates for music perception | Small sample size |
| Gaab et al. (2003) | fMRI study | Auditory working memory is associated with activity in temporal, frontal, parietal, and cerebellar regions | Suggests neural basis of pitch memory and auditory processing | Small sample; healthy subjects only |
| Parsons et al. (2006) | Review | Music processing relies on distributed cerebral and cerebellar networks | Background for pitch, rhythm, and cerebellar involvement | Review; no original data |
| Zatorre (2013) | Review | Experience-dependent plasticity interacts with pre-existing predispositions | Provides framework for interpreting causality limitations | Review; no original data |
| Patel (2011) | Theoretical | OPERA hypothesis proposes conditions under which musical training may enhance speech encoding | Proposed mechanism linking music and speech plasticity | Theoretical; no original data |
| Dalla Bella (2018) | Translational Review | Rhythmic abilities may facilitate auditory-motor rehabilitation | Suggests translation of rhythmic cueing to clinical populations | Review; mechanisms remain incompletely understood |
| Janzen et al. (2021) | Review | Rhythm-based interventions may modulate motor networks and promote plasticity | Background for RAS and music-supported therapy | Review; evidence strongest for PD and stroke |

tions.

A recent ecological study using electronic drums demonstrated successful synchronization to external rhythmic cues and highlighted the viability of monitoring rhythmic training in naturalistic settings, although the underlying neural mechanisms remain incompletely understood [16]. These findings support further investigation into the potential clinical applications of music-based protocols for motor dysfunction. Beyond motor synchronization, a translational approach to music-based intervention utilizes fundamental theories of beat perception to remediate cognitive and linguistic functions across diverse clinical populations [15,17]. For example, rhythmic auditory cueing has been identified as a promising approach for improving gait in Parkinson's disease (PD) patients. In one of the earliest clinical studies of rhythmic auditory stimulation, Thaut et al. reported improvements in gait velocity, stride length, and cadence compared with self-paced and no-training controls, supporting the use of external rhythmic cues to facilitate gait performance in Parkinson's disease [18] (Table 2). Rhythmic cueing has been proposed to engage cerebello-thalamo-cortical and related motor networks involved in movement timing, although the precise mechanisms remain incompletely understood. Research indicates that baseline rhythmic abilities may influence responsiveness to these interventions, with patients demonstrating relatively preserved rhythmic processing showing greater benefit from cueing protocols [17].

Furthermore, the integration of Digital Therapeutics (DTx), such as gamified rhythmic entrainment platforms, may provide a portable and accessible delivery system for these therapies. Recent reviews have highlighted the need for further investigation into such approaches as rhythm-based therapies continue to evolve beyond traditional clinical settings [15]. Although evidence outside Parkinson's disease and stroke remains limited, rhythm-based approaches may have potential relevance for future research involving neurodevelopmental disorders and speech-language deficits through targeted auditory-motor entrainment. Integrating music-based approaches into neuro-rehabilitation may warrant further investigation as a low-risk strategy that could potentially support motor, speech, and respiratory function in patients with neurological conditions. For example, Tamplin et al. reported that singing-based therapy improved vocal intensity, respiratory measures, and voice-related quality of life in individuals

**Table 5** Longitudinal Musical Training Studies

| Study | Population | Participant Criteria | Design | Measure | Key Finding | Limitation |
|---|---|---|---|---|---|---|
| Nutley et al. (2013) | Children and young adults ages 6 to 25 (N = 352, MRI subset N = 64) | Self-reported instrumental practice | Longitudinal developmental | Structural MRI; VBM | Music practice associated with improved cognition and larger regional gray matter volume | Observational design; developmental confounders |
| Worschech et al. (2023) | Healthy older adults (N = 156) | ≤6 months lifetime musical experience | Matched-pairs RCT | MRI; behavioral measures | Piano training improved fine motor performance over 12 months | Healthy sample; limited generalizability |

with Parkinson's disease, suggesting that music-based interventions may have applications extending beyond gait rehabilitation[19].

## Music-Supported Therapy in Stroke Rehabilitation

Although musician neuroimaging studies do not directly examine rehabilitation outcomes, they provide a natural model of long-term multisensory training. Identifying the neural systems consistently associated with musical expertise may help inform the design of interventions intended to engage similar auditory-motor networks in clinical populations.

Unlike rhythmic auditory stimulation, which primarily targets gait and movement timing, music-supported therapy (MST) incorporates active instrument-based training to promote upper-extremity recovery after stroke. These interventions engage auditory, sensory, and motor systems simultaneously and may provide a framework for facilitating motor relearning through repetitive, goal-directed movement.

Amengual et al. investigated the effects of music-supported therapy in individuals with chronic stroke and reported improvements in motor performance accompanied by increased corticospinal excitability and shifts in motor cortex representation measured using transcranial magnetic stimulation (TMS)[20]. These findings suggest that music-supported therapy may be associated with neuroplastic changes within residual motor networks, although the precise mechanisms underlying these effects remain incompletely understood.

More recently, Segura et al. conducted a randomized controlled trial and found that enriched music-supported therapy resulted in greater improvements in upper-limb motor function and motor impairment compared with conventional rehabilitation, with benefits persisting at follow-up. Participants also demonstrated improvements in several quality-of-life measures[21]. Together, these findings provide preliminary evidence that music-supported therapy may have potential as an adjunct to conventional stroke rehabilitation, particularly for upper-limb recovery (Table 3), although additional randomized controlled trials are needed to establish long-term efficacy and optimal treatment protocols.

## Limitations

While current neuroimaging literature suggests a link between musical training and gray matter differences, several critical limitations warrant consideration. A primary concern is the direction of causality: whether the observed structural differences are a result of intensive long-term practice or if individuals with specific pre-existing anatomical and functional differences are simply more likely to pursue and excel in musical training[22]. Evidence reviewed by Zatorre suggests that both experience-dependent plasticity and pre-existing anatomical and functional differences contribute to music learning and performance, indicating that these explanations are not mutually exclusive. Table 4 summarizes the mechanistic and theoretical frameworks drawn on throughout this review.

However, the presence of a dose-response relationship, where gray matter volume correlates linearly with the intensity and duration of practice, is consistent with the possibility that some of these adaptations are experience-dependent, although pre-existing individual differences may also contribute[3]. Recent studies have emphasized the importance of longitudinal studies, such as Nutley et al. (2013)[23], which reported that greater musical practice was associated with greater working-memory development across childhood and adolescence, in order to quantify the long-term efficacy of musical training for neuro-rehabilitation. Similarly, Worschech et al. demonstrated that previously untrained older adults who underwent 12 months of piano instruction exhibited improvements in fine motor performance, providing further evidence that longitudinal and randomized training paradigms may help clarify the relationship between musical practice and functional change[24]. Longitudinal interventions provide stronger evidence for experience-dependent plasticity because they evaluate neural and behavioral changes within the same individuals over time (Table 5). Such designs help distinguish training-related effects from pre-existing anatomical differences.

A significant challenge in neuro-rehabilitative research is the lack of definitive evidence supporting far-transfer effects, the extent to which music-induced anatomical changes enhance unrelated functional domains, such as gait or linguistic articulation. In a 2017 study[25], Sala and Gobet performed a meta-analysis to assess the effects of working memory training, a cognitive skill correlated with music. The results revealed small to moderate effects, arguing that structural plasticity may be task-specific rather than systemic. In a 2011 review[26], Patel hypothesized that there is an overlap in the brain networks that process an acoustic feature used in both music and speech. Patel's OPERA hypothesis proposes that if music and language share overlapping cortical and subcortical resources, particularly within the inferior frontal gyrus and superior temporal gyrus, intensive musical training may enhance neural encoding within these shared circuits under specific conditions involving overlap, precision, emotion, repetition, and attention. Although theoretical, the OPERA hypothesis provides one possible framework through which shared neural resources between music and speech may contribute to cross-modal plasticity

## Conclusion

The structural and functional adaptations observed in the musician's brain are broadly consistent with mechanisms of use-dependent plasticity. Evidence reviewed here consistently reports associations between musical training and structural and functional adaptations across auditory, motor, cerebellar, and executive-control networks.

These multiregional differences demonstrate that intensive training may influence distributed neural systems relevant to future rehabilitation research. The evidence suggests that rhythmic entrainment and multimodal integration may have potential relevance for future research on motor and cognitive function in patients with stroke, TBI, Parkinson's disease, and neurodevelopmental disorders. However, much of the available literature remains cross-sectional, and additional longitudinal and randomized controlled studies are necessary to clarify causality and establish therapeutic efficacy. Emerging evidence from music-supported therapy studies in stroke populations further suggests that music-based interventions may influence both motor performance and underlying neural function, although larger clinical trials remain necessary.

Future research should move beyond cross-sectional observations toward longitudinal randomized controlled trials to determine the long-term efficacy and therapeutic ceiling of these interventions. Additionally, optimizing Digital Therapeutics (DTx) and serious games will be beneficial for personalizing protocols based on an individual's baseline rhythmic profile. Integrating music-based approaches into neuro-rehabilitation may warrant further investigation as a potential way to engage the brain's plasticity for motor and cognitive rehabilitation.

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