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REVIEW

Structural and functional neuroplasticity in music and dance-based rehabilitation: a systematic review

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Abstract

Background Music- and dance-based rehabilitation has gained prominence in promoting social engagement and improving motor, cognitive, and mood domains in individuals affected by different neurological disorders.

Aim This systematic review aims to synthesize existing evidence from randomized controlled trials (RCTs) investigating neuroimaging-based structural and functional neuroplasticity following music- and dance-based interventions among people with neurological disorders.

Methods Literature research was performed using PubMed (MEDLINE), Scopus, and Web of Science (WOS). A multidimensional approach was employed to assess the efficacy of music- and dance-based interventions, integrating neuroimaging and clinical assessments.

Results Out of a total of 2247 papers reviewed, 20 RCTs met the inclusion criteria for this review, with a total of 718 subjects. Among them, 88% underwent a neuroimaging investigation to evaluate structural or functional neuroplasticity. Six studies involved dance-based interventions, while 14 examined music-based rehabilitation. These interventions targeted cognitive, motor, and mood impairments in people at risk of dementia or with neurological disorders including Huntington's Disease, stroke, traumatic brain injury, spinal cord injury, and disorder of consciousness.

Discussion Overall, the selected studies demonstrated significant effects on behavioral and neuroimaging outcomes, showing structural and functional changes in critical areas for perception and memory in patients at risk of dementia, as well as in regions essential for language processing, emotional regulation, and motor control in patients with acute and chronic stroke. Nevertheless, several biases were identified, specifically related to neuroimaging biomarkers, such as a lack of baseline and between-group comparisons and a lack of prior registration of neuroimaging biomarkers investigated.

The protocol of this review was registered in the International Prospective Register of Systematic Reviews (PROSPERO), with registration number CRD42024574754.

Keywords Music therapy · Dance therapy · Neurodegenerative diseases · Rehabilitation · Neuroimaging · Magnetic resonance imaging · Neuronal plasticity

Introduction

In recent years, the concept of art has acquired an increasingly important role in managing and treating many physical, neurological, and psychological disorders [1, 2]. In particular, music and dance have the potential to lower the likelihood of experiencing mental health issues, enhance self-esteem [3], protect against cognitive decline [4], aid in the rehabilitation of motor functions, and skills [5–8], and promote social cohesion [9].

Music and dance are universal features of human societies for their capacity to elicit powerful emotions [10]. They have developed into forms of art and entertainment playing a pivotal role in cultural and social practices. They have been shown to influence the functionality of key brain structures associated with emotion, including the amygdala, nucleus accumbens, hypothalamus, hippocampus,

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insula, cingulate cortex, and orbitofrontal cortex [10–12], and with the development of motor expertise [13] including changes in both grey and white matter within the Mirror Neuron System [14], as well as motor and auditory areas, indicating long-term brain plasticity [15]. Music and dance, with their potential to promote sensory integration, motor coordination, emotional modulation, and memory consolidation, offer a multifaceted approach to neurorehabilitation in the treatment of psychiatric and neurological disorders [1, 4, 5, 16, 17].

Neurorehabilitation typically adopts a targeted approach focused on rehabilitating a single domain. In contrast, music- and dance-based interventions have the unique ability to simultaneously engage multiple domains within a single intervention. These include not only motor and cognitive functions but also the emotional circuitry, which plays a crucial role in enhancing the motivational aspects of treatment and promoting overall adherence and effectiveness [4–8].

Despite all the mentioned evidence, a comprehensive evaluation of the efficacy of these interventions in promoting meaningful structural and functional neuroplasticity in the treatment of neurological disorders is still lacking. This systematic review aims to fill this gap by collecting and synthesizing existing studies examining changes in neuroimaging-derived markers following music- and dance-based rehabilitation interventions among people with neurological disorders in studies using a randomized controlled trial (RCT) study design. Other study designs, such as longitudinal observational studies, case-control reports, or non-randomized trials are undoubtedly valuable for exploring a wide range of neuroplasticity mechanisms associated with music and dance therapy. However, we aimed to assess the added value of music- or dance-based treatment compared to other types of interventions. Additionally, the randomized nature of the included trials ensures that participant selection is not biased toward individuals who might, for instance, have a personal preference for or against music. This reduces selection bias and makes the results more generalizable to broader clinical populations.

Materials and methods

Protocol and registration

This systematic review was conducted and reported under the PRISMA guidelines (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) [18]. The protocol of this review was registered in the International Prospective Register of Systematic Reviews (PROSPERO), with registration number CRD42024574754.

PICOS eligibility criteria

Participants

The eligibility criteria required the recruitment of adult subjects (≥18 years old), affected by neurological disorders.

Interventions

Studies investigating music-based or dance-based rehabilitative interventions were selected.

Comparisons

This systematic review included studies with active control groups, standard care groups, and cross-over designs where both groups underwent the same rehabilitative treatment at different timepoints.

Outcomes

The main outcome was the impact of music- and dance-based interventions on neuroimaging markers. As such, studies without neuroimaging were excluded. Additionally, this review explored behavioral outcomes derived from neuropsychological and neurological assessment, as well as adherence, attendance, and safety associated with treatment modalities.

Study designs

RCTs were included in the review. Studies lacking randomization or a control group, protocol studies, or qualitative studies were excluded. Conference proceedings, reviews, book chapters, abstracts-only journals, discussion papers, case reports, editorials, letters and papers not written in English were also excluded.

Eligibility for studies was assessed in three stages: title, abstract, and full-text reading (see the Flow Diagram, Fig. 1).

Data and literature search

We systematically searched databases including MEDLINE (PubMed), Scopus, and Web of Science (all databases), and through backward citation searching by checking the reference lists. The search was performed on 24 January 2025 and was not limited in time. The search string used is reported in Supplementary Material.

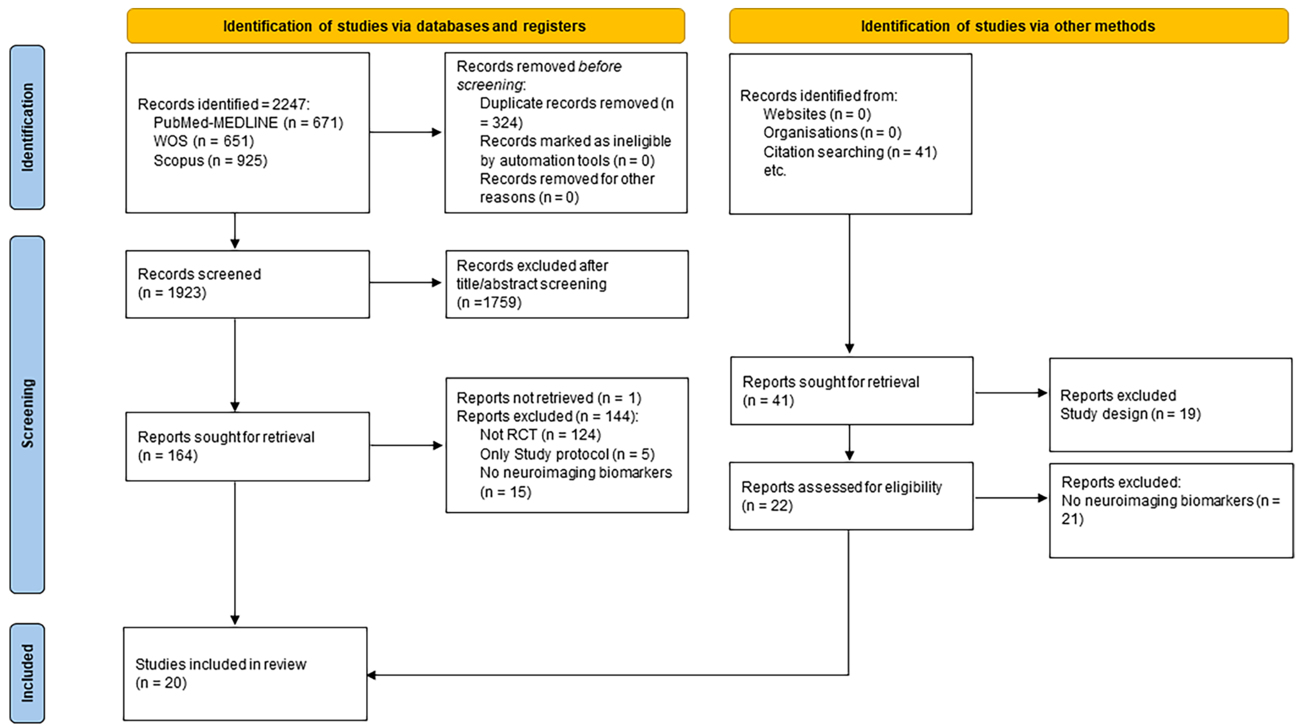


Fig. 1 PRISMA 2020 flow diagram for systematic reviews, which inclided searches, registers and other source

Study selection process

Search results were managed using the Rayyan platform [19]. After removing duplicates, two reviewers independently screened the title and abstract of studies against the eligibility criteria.

Exclusion criteria included the absence of a full paper (e.g., books, book chapters, qualitative studies, letters, comments, dissemination papers, or published abstracts without full text) and non-English language. Additionally, studies that did not refer to an RCT experimental design, such as reviews, observational studies, study protocols, or case reports, were excluded. Finally, only studies involving rehabilitation interventions with music or dance and neuroimaging-derived outcome measures were included. The full-text analysis of all relevant studies was performed to ensure compliance with the eligibility criteria. Inter-reviewer discrepancies were resolved through discussion to reach a consensus or by consulting a third reviewer when an agreement was not reached.

Study risk of bias assessment

The "Tool for the assessment of study quality and reporting in the exercise" scale (TESTEX) [20] was blindly used by two reviewers to evaluate the quality of RCT studies. Any inter-reviewer disagreements were resolved either by consensus or by the third reviewer. Each study selected for the systematic review was assessed based on 12 validity criteria, with a total score ranging from 0 to 15.

Data extraction

Two researchers conducted data extraction independently and blindly, following a standardized form. For data collection, the inter-reviewer disagreements were solved either by consensus or by the third reviewer when an agreement could not be reached.

Data collection focused on: 1) demographics and clinical characteristics of the sample (size, sex, age, and type of pathology); 2) type of treatment (music-based or dance-based rehabilitation) for both intervention and control groups; 3) intervention parameters (frequency and duration of the sessions); 4) neuroimaging markers; 5) behavioral data (neuropsychological and neurological assessment, adherence, attendance, and safety).

Results

Study selection

A total of 2247 studies were initially identified. The first screening, based on titles and abstracts, selected 164 works sought for retrieval.

Subsequently, after assessment for eligibility through a full-text reading, 19 studies were included. Conducting a backward citation search, one additional study was included (see flowchart in Fig. 1).

A total of 20 papers were included in the systematic review. Among these, 2 manuscripts involving patients with Traumatic Brain Injury (TBI) [21, 22] referred to the same RCT [22]. Similarly, among the 7 papers involving patients with acute stroke [23–29], four of them [26–28, 28, 29] referred to the same RCT [25]. In detail, the study from Sihvonen et al. [25] derived behavioral and neuroimaging findings from pooling results of 2 distinct RCTs (one not registered and one unreported). Subsequently, the other studies by Sihvonen and colleagues focused specifically on a subsample of subjects who completed the neuroimaging session. The rationale behind incorporating all three articles in this systematic review arises from their complementary contributions to the neuroimaging results. Finally, to avoid any duplication of data in our results, when calculating the total number of subjects included, we ensured that patients from the same RCT were counted only once, even if reported in multiple papers.

Risk of bias in studies

Concerning the assessment with the TESTEX score (see Table 1) [20], results showed 4 trials with high-level of quality (score > 11) [22, 30–32], 13 had a good level of quality ($7 \leq$ score ≥ 11) [21, 23, 25–28, 33–39]. Finally, two trials [24, 40] presented a low level of quality (score < 7). One study was not evaluated since only neuroimaging data were reported [29].

Participants

Table 2 reports the demographic and clinical characteristics of the sample and a description of the interventions. This review included a total of 718 people involved in the trials. Among them, 198 subjects underwent music-based interventions (89 males, mean age = 54.04; SD = 14.51) and 151 followed a dance-based program (42 males, mean age = 71.33; SD = 3.64). The control group comprised 251 subjects (95 males, mean age = 61.67; SD = 10.48), while the standard care group comprised 118 subjects (55 males, mean age = 58.62; SD = 15.31). Concerning the type of neurological

Table 1 TESTEX score for the assessment of study quality

	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]	Total
Blumen et al., 2023	1	1	0	0	1	2	1	2	1	1	1	1	12
Feng et al., 2020	1	1	1	1	0	2	1	2	1	1	0	1	12
Fotakopoulos & Kotlia, 2018	1	1	0	0	0	1	1	2	1	0	1	1	9
Jungblut et al., 2022	1	1	1	1	1	0	0	2	1	1	1	1	11
Kropacova et al., 2021	1	1	0	1	0	1	0	2	1	0	0	1	8
§ Martínez-Molina et al., 2021	1	1	0	1	1	2	0	2	1	0	1	1	11
Qi et al., 2018	1	1	0	1	1	1	0	2	1	0	1	1	10
Rektorova et al., 2019	1	1	0	1	0	1	0	2	0	0	0	1	7
Särkämö et al., 2014	1	1	0	1	0	1	0	0	0	1	0	1	6
# Sihvonen et al., 2020	1	1	1	0	1	1	0	2	1	1	0	1	10
# Sihvonen & Särkämö, 2021	Not evaluated due to the absence of between-group comparison (only regression model analysis)												
# Sihvonen, Pitkäniemi, et al., 2021	1	1	1	0	1	0	0	2	1	1	0	1	9
# Sihvonen, Ripollés, et al., 2021	1	1	0	0	1	0	0	2	1	1	0	1	8
# Sihvonen et al., 2022	1	1	1	1	1	0	0	2	1	1	0	1	10
Sihvonen et al., 2024	1	1	0	1	1	2	0	2	1	0	1	1	11
§ Siponkoski et al., 2020	1	1	0	1	1	3	1	2	1	0	1	1	13
Trinkler et al., 2019	1	1	0	0	1	1	0	2	1	0	0	1	8
Xiao et al., 2023	1	1	1	1	0	1	1	2	0	1	0	1	10
Zhang et al., 2022	1	1	1	1	0	1	1	2	0	1	0	1	10
Zhu et al., 2022	1	1	1	1	1	3	0	2	1	1	1	1	14

[1] = eligibility criteria, [2] = randomization, [3] = allocation concealment, [4] = similarity at baseline, [5] = blinding of assessor, [6] = outcome measures, [7] = Intention-to-treat, [8] = between-group statistical comparison, [9] = point measure and variability, [10] = activity monitoring in control group, [11] = exercise intensity, [12] = exercise parameters

§ Studies related to the same RCT

Studies related to the same RCT, including different subgroups

Table 2 Demographics and clinical characteristics of participants and descriptions of interventions

Reference Subjects [M/F; mean age, sd]	Pathology	Intervention Treatment	Control Treatment	Treatment Frequency and Duration	Clinical Measures
Blumen et al., 2023 IG: 13 [5/8; 77.4, 5.8] CG: 12 [6/6; 75.4, 5.8]	Risk of dementia	Ballroom dancing	Treadmill walking	IG and CG: 90 minutes, 2 days a week, for 24 weeks	Executive functions (DSST, FIT, WWT)
Feng et al., 2020 IG: 47 [11/36; 71, 5.7] CG: 46 [9/37; 69.4, 5.3]		Choral singing	Health education program	IG: 60 minutes, 1 day a week, for 104 weeks	Cognitive functions (CCTS, RAVLT, DST, Block Design, CCT, SDMT, BNT)
Kropacova et al., 2019 IG: 15 MCI + 34 HS [8/41; 69.2; 5.4] CG: 19 MCI + 31 HS [15/35; 68.4; 6.1]	MCI	Irish, African, Greek, and tango dance choreography	Life as usual	IG: 60 minutes, 3 days a week, for 24 weeks	Cognitive functions (MoCA, TCF, WMS III: LogPam, WAIS III: symbols and digit span, ToH, FPT, JLO) Self-dependency (BADLS-CZ) Mood (BDI-II)
Qi et al., 2019 IG: 16 [5/11; 70.6, 6.2] SC: 16 [4/12; 69.1, 8.1]		Specially designed moderate-intensity aerobic dance	Standard Care	IG: 35 minutes, 3 days a week, for 12 weeks	Cognitive functions (MMSE, MoCA, WMS-RLM, DST, TMT, SDMT) Motor function (BBS)
Rektorova et al., 2019 IG: 8 MCI + 23 HS [7/24; 68, 4.9] CG: 11 MCI + 20 HS [10/21; 67.2, 6.7]		Learning a dance choreography	Life as usual	IG: 60 minutes, 3 days a week, for 24 weeks	Cognitive functions (FPT)
Zhu et al., 2022 IG: 35 [17/1; 71.5, 6.6] CG: 33 [10/23; 69.8, 7.7]		Group aerobic dance program	Health education program	IG: 35 minutes, 3 days a week, for 12 weeks CG: 120 minutes in total	Cognitive functions (MMSE, MoCA, WMS-RLM, TMT, SDMT, DST, FAQ, SF-36, GDS)
Trinkler et al., 2019 IG: 7 [not available] SC: 7 [not available]	Huntington's Disease	Contemporary dance classes	Standard Care	IG: 120 minutes per week, for 20 weeks	Motor function (UHDRS motor score) Cognitive functions (UHDRS cognitive score: fluency, Stroop test, Symbol Digit Code, MDRS, TMT) Quality of Life (LARS, PBA-S)
Fotakopoulos & Kotlia, 2018 IG: 24 [14/10; 73.3, 4] SC: 41 [19/22; 76, 3]	Acute stroke	Physical exercise program while listening to experiential and traditional music	Standard Care	IG: 45 minutes, 4 days a week, for 24 weeks	Cognitive functions (mini-Mental Test) Daily functioning (Barthel Index)

Table 2 (continued)

Reference Subjects [M/F; mean age, sd]	Pathology	Intervention Treatment	Control Treatment	Treatment Frequency and Duration	Clinical Measures
Särkämö et al., 2014 IG: 16 [9/7; 57.4, 9.4] CG: 18 [8/10; 58.6, 8.2] SC: 15 [8/7; 61.7, 6.8]		Passive listening to the favorite songs of the patients	CG: Audio-book listening SC: Standard Care	IG and CG: 60 minutes, 7 days a week, for 8 weeks	Memory (RBMT, auditory list-learning task, DST, memory interference task) Language (word and sentence repetition, verbal fluency, naming test, Token test) Visuospatial cognition (clock task, copying task, BVRT, Balloons Test) Music cognition (scale and rhythm subtests from MBEA) Executive functions (FAB, mental subtraction, Stroop test, vigilance subtest) Mood (POMS) Quality of Life (SAQOL)
# Sihvonen et al., 2020 IG1: 27 [5/12; 54.9, 13.4] IG2: 23 [15/8); 56.7, 10.3] CG: 33 [16/17; 59.8, 11.6]		IG1: Home-based vocal music listening IG2: Home-based instrumental music listening	Home-based narrated audio-book listening	IG1, IG2, and CG: 60 minutes, 7 days a week, for 8 weeks	Verbal memory (RBMT, auditory-verbal learning) Language (Token test, verbal fluency, BNT) Focused attention (Stroop, Mental Subtraction Subtest) Mood (POMS)
# Sihvonen & Särkämö, 2021 IG1 + IG2: 31 [18/13; 55.4, 13.4]		IG1: Home-based vocal music listening IG2: Home-based instrumental music listening	NA	IG1 and IG2: 60 minutes, 7 days a week, for 8 weeks	NA
# Sihvonen, Pitkäniemi, et al., 2021 IG1: 27 [15/12; 54.9, 13.4] IG2: 23 [15/8; 56.7, 10.3] CG: 33 [16/17; 59.8, 11.6]		IG1: Home-based vocal music listening IG2: Home-based instrumental music listening	Home-based narrated audio-book listening	IG1, IG2, and CG: 60 minutes, 7 days a week, for 8 weeks	NA
# Sihvonen, Ripollés, et al., 2021 IG1: 27 [15/12; 54.9, 13.4] IG2: 23 [15/8; 56.7, 10.3] CG: 33 [16/17; 59.8, 11.6]		IG1: Home-based vocal music listening IG2: Home-based instrumental music listening	Home-based narrated audio-book listening	IG1, IG2, and CG: 60 minutes, 7 days a week, for 8 weeks	NA
# Sihvonen et al., 2022 IG1: 27 [15/12; 54.9, 13.4] IG2: 23 [15/8; 56.7, 10.3] CG: 33 [16/17; 59.8, 11.6]		IG1: Home-based vocal music listening IG2: Home-based instrumental music listening	Home-based narrated audio-book listening	IG1, IG2, and CG: 60 minutes, 7 days a week, for 8 weeks	NA

Table 2 (continued)

Reference Subjects [M/F; mean age, sd]	Pathology	Intervention Treatment	Control Treatment	Treatment Frequency and Duration	Clinical Measures
Jungblut et al., 2022 IG: 10 [6/4; 55.3, 7.15] CG: 10 [7/3; 57.2, 6.39]	Chronic post-stroke aphasia	Rhythmic-melodic voice training	Speech therapy	IG and CG: 45 minutes, 2 days a week, for 16 weeks	Language (AAT)
Sihvonen et al., 2024 IG: 13 [7/6; 64.1, 8.8] SC: 15 [7/8; 65.2, 8.3]		Group singing with Melodic Intonation Therapy and home self-training	Standard Care	IG: 90 minutes, 1 day a week (group singing) + 30 minutes 3 days a week (self-training), for 16 weeks	Language (naming and repetition)
§ Martínez-Molina et al., 2021 IG: 15 [8/7; 41.1, 14.4] SC: 8 [5/3; 42.1, 11.6]	TBI	Neurological Music Therapy, with active musical production with drums or piano	Standard Care	IG: 60 minutes, 2 days a week, for 10 weeks	NA
§ Siponkoski et al., 2020 IG: 20 [10/10; 41.6, 14.7] SC: 19 [13/6; 40.9, 12]		Neurological Music Therapy, with active musical production with drums or piano	Standard Care	IG: 60 minutes, 2 days a week, for 10 weeks	Executive functions (FAB) Cognitive functions (NLT, ANT, ST, SART, WMS, DST) Motor function (Box and Block Test, ARAT, PPBT)
Xiao et al., 2023 IG: 5 [2/3; 26.8, 11.2] CG: 5 [3/2; 50.8, 10.1] SC: 5 [4/1; 38.8, 15.1]	Minimal conscious state	Passive live music listening therapy	CG: Passive listening of familial auditory stimulation; SC: Regular medication and routine care	IG and CG: 30 minutes, 5 days a week, for 4 weeks	Coma (GCS)
Zhang et al., 2022 IG: 13 [10/3; 39.3, 17.8] CG: 13 [11/2; 40.5, 19.9]	Spinal cord injury	Vocal Respiratory Training, with singing	Respiratory physiotherapy	IG and CG: 30 minutes, 5 days a week, for 12 weeks	Respiratory functions (vital capacity, total lung capacity, inspiratory capacity, residual volume, forced respiratory volume in one second, and forced vital capacity)

AAT = Aachener Aphasia Test, *ANT* = Auditory N-back Task, *ARAT* = Action Research Arm Test, *BADLS-CZ* = Bristol Activities of Daily Living Scale, *BBS* = Berg Balance Scale, *BDI* = Beck Depression Inventory, *BNT* = Boston Naming Test, *BVRT* = Benton Visual Retention Test, *CCT* = Colour Trails Test, *CCTS* = Composite Cognitive Test Score, *CG* = Control Group, *DSST* = Digit Symbol Substitution Test, *DST* = Digit Span Test, *F* = Female, *FAB* = Frontal Assessment Battery, *FIT* = Flanker Interference Test, *FPT* = Five-Point Test, *GCS* = Glasgow Coma Scale, *GDS* = Geriatric Depression Scale, *HS* = Healthy Sample, *IG* = Intervention Group, *JLO* = Judgement of Line Orientation, *LARS* = Lille Apathy Rating Scale, *M* = Male, *MBEA* = Montreal Battery of Evaluation of Amusia, *MCI* = Mild, Cognitive Impairment, *MDRS* = Mattis Dementia Rating Scale, *MMSE* = Mini-Mental State Examination, *MoCA* = Montreal Cognitive Assessment, *NA* = Not Applicable, *NLT* = Number Letter Task, *PBAS* = Pain-related Beliefs and Attitudes, *POMS* = Profile of Mood State, *PPBT* = Purdue Peg Board Test, *RAVLT* = Rey Auditory Verbal Learning Test, *RBMT* = Rivermead Behavioural Memory Test, *SAQOL* = Stroke and Aphasia Quality of Life, *SART* = Sustained Attention to Response Task, *SC* = Standard Care, *SD* = Standard Deviation, *SDMT* = Symbol Digit Modalities Test, *SF-36* = Short Form-36, *ST* = Simon Task, *TBI* = Traumatic Brain Injury, *TCF* = Taylor Figure Test, *TMT* = Trail Making Test, *ToH* = Tower of Hanoi, *UHDRS* = Unified Huntington's Disease Rating Scale, *WAIS* = Wechsler Adult Intelligence Scale, *WMS* = Wechsler Memory Scale, *WMS III: LogPam* = Logical memory subtest from Wechsler Memory Scale III, *WMS-RLM* = Wechsler Memory Scale-Revised Logical Memory, *WWT* = Walking-While-Talking Test.

§ Studies related to the same RCT

Studies related to the same RCT, including different subgroups

disorders analyzed, the sample included: 271 people at risk of dementia (Subjective memory/cognitive complaint and/or Mild Cognitive Impairment, MCI), 245 stroke patients (197 in the acute and 48 in the chronic phase), 108 healthy aging subjects, 39 subjects who underwent, 26 with spinal cord injury (SCI), 15 patients with minimal conscious state (MCS), and 14 people with Huntington's Disease (HD).

Outcome measures

Neuroimaging markers

Considering the human brain as a network, neuroplasticity mechanisms can be investigated at different levels. The first level pertains to the fundamental units of the network, namely brain regions or white matter tracts. The second level examines the interactions between brain areas, specifically pairwise connectivity. The third level focuses on the topological properties of the entire brain network (i.e., graph-based property analysis) using indices of global efficiency. The majority of the studies included in this review investigated neuroplasticity at the first level, that is, at the level of individual brain areas, in terms of functional activation, morphometric indices (e.g., volumetric measures and cortical thickness), and microstructural integrity of white matter tracts. Only a few studies explored the second level, assessing how brain areas communicate or are functionally connected, whereas no studies have evaluated the impact of rehabilitative interventions on the global functioning of the brain network (third level). Table 3 summarizes the principal neuroimaging biomarkers investigated.

Examining in detail, all selected trials used Magnetic Resonance Imaging (MRI) to evaluate different biomarkers except one study [23] in which Cerebral Blood Flow (CBF) was derived by Computed Tomography Perfusion (CTP). Eleven studies employed T1-3D to measure Grey Matter Volume (GMV), White Matter (WM) Volume, and cortical thickness [22, 24, 25, 30–32, 34, 36, 37, 39, 40], while 8 measured metrics derived from diffusion-weighted imaging (DWI) such as Fractional Anisotropy (FA), Quantitative Anisotropy (QA), Radial Diffusivity (RD), and Mean Diffusivity (MD) [26, 28, 30, 31, 36, 38–40]. Task-based functional MRI (task-fMRI) was used in 5 studies, employing tasks related to executive functions (EF) [30], language processing and music stimulation [25, 28, 29, 33]. Finally, 3 trials used resting-state fMRI (rs-fMRI) to investigate functional connectivity (FC) [21, 25, 27] and Amplitude of Low-Frequency Fluctuations (ALFF) [35]. However, data analysis varied, with some studies conducting whole-brain analyses and others focusing on specific pathology markers, such as the hippocampus volume in people at risk of dementia. DWI was employed either for tract-based spatial statistics (TBSS) or other tract-based or whole-brain analyses. Additionally, 2 studies [38, 39] relied on qualitative descriptions of neuroimaging findings, without the support of quantitative measures. Other limitations of MRI included the absence of between-group analyses in 4 studies [23, 29, 34, 35]. Finally, the baseline comparisons between groups for neuroimaging biomarkers were reported only in 6 trials [21, 23, 26, 34, 35, 40], while a full description of postprocessing with information relative to the normalization of data was fully reported only in 2 studies [25, 34]. No studies introduced adherence or attendance to the rehabilitation intervention as a variable of interest or covariate.

Clinical outcomes

The clinical outcomes included EF, language, memory, attention, and global cognition, as well as motor function, aphasia recovery, respiratory function, state of consciousness, quality of life, and mood. This aspect witnesses the potentialities of music- and dance-based interventions.

Neurological disorders

Table 4 summarizes neuroimaging and behavioral results.

Neurodegenerative disorders

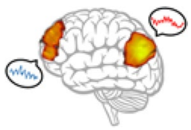
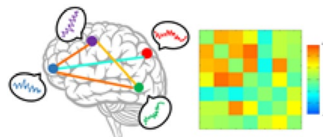
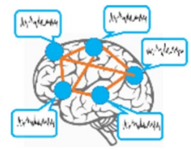
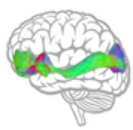
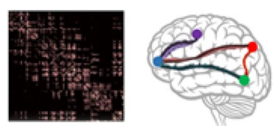
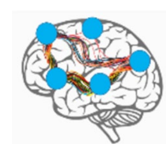
Six studies reported data from subjects suffering from MCI or other risk factors for dementia [30–32, 34, 35, 40], and one study reported data from subjects with HD [37].

Among these, only one study [31] used a singing intervention; all the others involved dance-based programs. Overall, the trials involved 271 subjects at risk of dementia and 108 healthy aging subjects. These studies had a mean duration of 56.67 minutes (SD = 20.41, min = 35, max = 90), with a frequency of twice a week (mean = 2.50, SD = 0.84, min = 1, max = 3), for an average of 33.34 weeks (SD = 35.11, min = 12, max = 104). The trial involving HD patients consisted of contemporary dance classes, with a duration of 120 minutes per week, for 20 weeks.

Concerning clinical outcomes, the trials reported significant improvement in several cognitive domains, including EF, memory, global cognition, and mood. In HD patients, dance-based intervention was effective in reducing motor impairment and improving EF [37].

Structural neuroplasticity biomarkers Two studies observed a positive impact of dance-based intervention over control condition on structural neuroplasticity in the hippocampus [30, 32], while in one trial [34] hippocampal volume was used to predict intervention outcome, without a significant effect. Rektorova et al. [40] found changes in cortical thick-

Table 3 Summary of neuroimaging biomarkers and clinical outcomes investigated

	Neuroimaging analyses		
	Fundamental units: changes within specific brain regions/networks (1st level analyses)	Connectivity patterns: changes between network nodes (2nd level analyses)	Whole network properties: changes in graph-based indices within whole brain (3rd level analyses)
Functional neuroplasticity			
task-fMRI [studies]	Changes in the activation of brain regions involved in a specific task after rehabilitation intervention [25, 28–30, 33]	Changes in connectivity pattern of fMRI-task after treatment [n.a.]	
rs-fMRI [studies]	Changes in the activation of a specific network during rest after the rehabilitation intervention [35]	Changes in the pattern of connectivity between brain regions after rehabilitation intervention [21, 25, 27]	Changes in global and local indices of functional network topology [n.a.]
CT-perfusion [studies]	Role of CBF and lesion size in predicting recovery [23]		
Structural neuroplasticity			
T1-3D [studies]	Changes in morphometric indices (volumetry or cortical thickness) of specific brain regions or whole brain [22, 24, 25, 30–32, 34, 36, 37, 39, 40]		
DWI [studies]	Changes in indices of white matter integrity (FA, MD, RD, QA) within single WM brain area/specific tract [26, 28, 30, 31, 36, 38–40]	Changes in structural connectivity such as the strength of structural wiring between network nodes [n.a.]	Changes in global and local indices of structural network topology [n.a.]

CBF = cerebral blood flow, *DWI* = Diffusion-Weighted Imaging, *FA* = fractional anisotropy, *fMRI* = functional Magnetic Resonance Imaging, *MD* = mean diffusivity, *n.a.* = not available, *QA* = quantitative anisotropy, *RD* = radial diffusivity, *rs-fMRI* = resting-state fMRI, *T1-3D* = T1 weighted 3D imaging, *WM* = White Matter

ness of the fusiform and occipital cortex and increased microstructural integrity of white matter bundles (superior longitudinal fasciculus, corpus callosum, and corticospinal tract). Trinkler et al. [37] found a GMV increment in left somatosensory and spatial body processing areas, related to dance-based intervention. One study [31] did not report significant results related to the singing-based intervention (see Table 3).

Functional neuroplasticity biomarkers Only one study [35] investigated variation in ALFF related to dance-based rehabilitation, showing increased brain activity in the bilateral frontotemporal, entorhinal, anterior cingulate, and para-hippocampal cortex (Table 4).

Stroke

Seven studies involved patients with acute stroke (197 patients). In five of them, all related to the same RCT [25], patients underwent two types of experimental intervention: listening to vocal (VML) or instrumental music (IML) [25–29]. Moreover, two trials [23, 24] used passive music listening. The rehabilitative sessions had an average duration of 55 minutes (SD = 8.66; min = 45; max = 60), conducted 6 days a week (SD = 1.73; min = 4; max = 7), over 13 weeks (mean = 13.33; SD = 9.24; min = 8; max = 24).

Two studies addressed chronic post-stroke aphasia [33, 36] with melodic singing (48 patients).

Table 4 Summary of neuroimaging and behavioral results

Refs.	Subjects with neuroimaging	Pathology	MRI	Neuroimaging biomarker	MRI results: between-group comparison	MRI results: other analysis	Clinical results
[30]	IG: 7 CG: 5	Risk of dementia	T1-3D DWI task-fMRI	Structural neuroplasticity: changes in hippocampal volume, CT, and WM integrity (FA) Functional neuroplasticity: during fMRI with EF tasks	Structural neuroplasticity IG > CG: ↓ right hippocampal atrophy; CG > IG: pre-post ↑ in CT in pars triangularis, pars orbitalis, and rostral anterior cingulate; FA no significant results Functional neuroplasticity IG Vs CG: no significant differences	NA	IG>CG: ↑ DSST
[31]	IG: 47 CG: 46 (T1-3D: 83 DWI: 79)		T1-3D DWI	Structural brain reserve: total brain volume, total GMV, total WMV, total ventricular volume, and hippocampal volume (FreeSurfer analysis) Structural neuroplasticity: changes in global and regional FA and MD (TBSS)	No significant effects in all metrics	NA	IG: ↑ CCTS No between-group differences
[32]	IG: 29 CG: 25		T1-3D	Structural neuroplasticity: changes in hippocampal volume	IG > CG: ↑ right and total hippocampal volume	NA	IG > CG: ↑ MoCA, ↑ WMS-RLM, ↑ TMT
[34]	IG: 42 CG: 44	MCI	T1-3D	Structural brain reserve: Hippocampus/cortex volume predicts DMI-induced cognitive changes	NA	No evidence of any association between the baseline MRI and the DMI-induced cognitive aftereffects	IG: ↑ TCF, ↑ ToH, ↑ FPT IG>CG: ↑ FPT
[35]	IG: 16 SC: 16		rs-fMRI	Functional neuroplasticity: changes in ALFF during rs-fMRI	NA	Within IG: ↑ ALFF in the bilateral frontotemporal, entorhinal, anterior cingulate, and para-hippocampal cortex (no significant correlation between ALFF and NPS) Within SC: ↑ ALFF in the right temporal and posterior cingulate cortex	IG>SC: ↑ WMS-RLM IG (T0 Vs T1): ↑ MMSE, ↑ MoCA, ↑ WMS-RLM, ↑ SDMT
[40]	IG: 28 CG: 27		T1-3D DWI	Structural neuroplasticity: changes in CT and micro-structural integrity of WM with DTI-based FA, MD, AD, RD maps	IG > CG: ↑ CT in IG in the right inferior temporal fusiform, lateral occipital cortex	Within IG: ↑ RD bilaterally in the SLF, left CC, and left CST; ↑ MD bilaterally in the SLF, left CC, and bilateral CST	IG: ↑ FPT
[37]	IG: 7 SC: 7	Huntington's Disease	T1-3D	Structural neuroplasticity: changes in VBM-based GMV in areas of somatosensory and spatial body processing	IG > SC: ↑ GMV in left medial superior parietal lobe, paracentral lobule and medial superior occipital gyrus	Within IG: ↑ GMV in one voxel in medial superior parietal lobule	IG < SC: ↓ UHDRS motor scale IG > SC: ↑ TMT-B

Table 4 (continued)

Refs.	Subjects with neuroimaging	Pathology	MRI	Neuroimaging biomarker	MRI results: between-group comparison	MRI results: other analysis	Clinical results
[23]	IG: 24 SC: 41	Acute stroke	CTP	Functional brain reserve: the role of CBF in predicting recovery post-stroke of cognitive and motor skills	NA	Group and lesion size are independent predictors of recovery; mean CBF of > 18.8 cm/s had 100% sensitivity and 85% specificity for predicting recovery	No significant results
[24]	IG: 16 CG: 18 SC: 15		T1-3D	Structural neuroplasticity: changes in VBM related to the recovery of cognition (language, verbal memory, and attention) and mood	IG > CG & SC left hemisphere lesion: ↑ GMV bilateral superior frontal, right medial gyrus, limbic areas, and right ventral striatum IG > CG & SC right hemisphere lesion: no significant results	IG left hemisphere lesion: ↑ GMV in frontal regions significantly correlated with verbal memory, language, and attention; ↑ GMV in limbic regions correlated with decrement in depression, tension, fatigue, forgetfulness, and irritability IG right hemisphere lesion: ↑ GMV in the left insula correlated with improvement in language	Not reported
#[25]	IG1: 27 IG2: 23 CG: 33 (fMRI: 35; T1-3D: 75)		T1-3D rs-fMRI task-fMRI	Neuroplasticity mechanisms related to cognitive, language, and mood recovery Structural neuroplasticity: changes in VBM-based GMV Functional neuroplasticity: changes in FC (rs-fMRI-based) particularly in DMN; changes in activation during passive listening of auditory stimuli	Structural neuroplasticity IG1 > CG: ↑ GMV in one cluster of left STG, left middle MTG, and left inferior ITG; aphasics patients ↑ WMV in right medial parieto-occipital lingual gyrus, cuneus, MOG aphasics patients IG2 > CG: ↑ GMV in one cluster in right MTG and MOG Functional neuroplasticity IG1 > IG2 & CG: ↑ FC between left STG and MTG areas and the rest of the DMN IG1 > IG2: ↑ FC between right temporal STG, HG areas, and the rest of the DMN IG1 > CG: ↑ activation in DMN	Within aphasics: ↑ WMV in right medial parieto-occipital lingual gyrus, cuneus, MOG correlated with improvement in language and verbal memory; IG2: ↑ GMV in one cluster in right MTG and MOG correlated with improvement in language IG1: ↑ FC between left STG and MTG areas and the rest of the DMN correlated with memory and language recovery	IG1 > IG2 (T0-T1): ↑ verbal memory IG1 > CG (T0-T2): ↑ verbal memory IG1 > CG (T0-T1): ↑ language recovery

Table 4 (continued)

Refs.	Subjects with neuroimaging	Pathology	MRI	Neuroimaging biomarker	MRI results: between-group comparison	MRI results: other analysis	Clinical results
#[26]	IG1: 12 IG2: 15 CG: 11		DWI	Structural neuroplasticity: changes in QA in both hemispheres	IG1 > CG: ↑ QA in left ventral (UF, IFOF, extreme capsule) and dorsal (AF, FAT) pathways, in the left cingulum, thalamic radiation, and CST as well as in the right dorsal (AF, SLF) pathways, in the right cingulum, thalamic radiation, and CST and the CC IG2 > CG: ↑ QA in left ventral (UF, IFOF, ILF) and dorsal pathways (AF), in the left thalamic radiation and corticospinal and pontine tracts as well as in the right dorsal pathway (AF, SLF), and the CC IG1 vs IG2: no differences	NA	NA
#[27]	IG1: 12 IG2: 15 CG: 11		rs-fMRI	Functional neuroplasticity: rs-fMRI to determine changes in FC, related to language and verbal memory recovery	IG1 > CG and IG2 > CG: ↑ FC between left inferior parietal and postcentral areas and the language network IG2 > CG: ↑ FC between the left supramarginal gyrus and the language network	IG1 > CG: ↑ FC between left inferior parietal and postcentral areas and the language network, correlated with improvement in verbal memory IG2 > CG: ↑ FC between the left supramarginal gyrus and the language network correlated with improvement in verbal	NA
#[28]	IG1: 12 IG2: 15 CG: 11		DWI task-fMRI	Structural neuroplasticity: tract-based changes in FA in left AF, IFOF, and FAT Functional neuroplasticity: changes in brain activation during music and speech listening tasks	Structural neuroplasticity IG1 > CG: ↑ in FA values over time in the left FAT Functional neuroplasticity IG1 > CG: ↑ activation in the left superior/middle frontal gyrus and the precentral gyrus	IG1: the FA change in the left FAT correlated with improved language skills IG1: the activation in this area correlated with the ↑ FA in the left FAT across the whole sample	NA
#[29]	IG1 + IG2: 31		task-fMRI	Functional neuroplasticity: brain activation in predicting treatment response both at single regions and network levels, related to language and verbal memory recovery	NA	IG1: ↑ activity in the left parietal areas (inferior parietal lobule, supramarginal gyrus, and postcentral gyrus) as bilaterally in medial frontal areas (supplementary motor and cingulate gyrus) predicted greater improvement in language skills IG2: ↑ engagement of the auditory network predicted greater improvement in language and verbal memory skills	NA

Table 4 (continued)

Refs.	Subjects with neuroimaging	Pathology	MRI	Neuroimaging biomarker	MRI results: between-group comparison	MRI results: other analysis	Clinical results
[33]	IG: 6 CG: 6	Chronic post-stroke aphasia	task-fMRI	Functional neuroplasticity: during task-fMRI with repetition of chanted vowels, related to language recovery	No significant results	NA	IG > CG: ↑ articulation and prosody, ↑ repetition, ↑ naming, ↑ comprehension (auditory and reading), ↑ profile level
[36]	IG: 13 SC: 15		T1-3D DWI	Structural neuroplasticity: changes in VBM-based GMV in all brain and ROIs; changes in DWI-derived QA with seed-based analysis	IG > SC: ↑ QA in the left AF, FAT, superior longitudinal fasciculus, cortico-striatal tract, and in the right FAT, SLF, cortico-striatal tract, as well as in the corpus callosum IG > SC: ↑ in GMV in the left BA44, left BA45, and left vPMC	IG: ↑ QA in left FAT and AF correlated with improvement in naming; ↑ GMV in left BA44 correlated with improvement in naming	IG > SC: ↑ naming
§[21]	IG: 15 SC: 8	TBI	rs-fMRI	Functional neuroplasticity: FC (rs-fMRI-based) changes within and between networks related to the music-based intervention	IG > SC: ↓ FC between DMN and sensory networks; ↓ FC within FPN and SAL; EF correlated with FC within FPN and between DMN and SMN	IG: ↑ FC between FPN, SMN, and DAN; ↑ FC between left FPN with right DAN and right primary sensory networks	NA
§[22]	IG: 16 SC: 9	TBI	T1-3D	Structural neuroplasticity: changes in VBM-based GMV	IG > SC: ↑ GMV in the right IFG, right MFG, left cerebellum, and left fusiform gyrus; ↑ GMV in the right IFG correlated with NLT performance	NA	IG > SC: ↑ FAB; ↑ NLT
[38]	IG: 5 CG: 5 SC: 5	Minimal conscious state	DWI	Structural neuroplasticity: changes in DTI-based FA, FN, Path length	Only qualitative evaluation IG > CG > SC: ↑ the neural fibers and FA, FN, and Path Length	NA	IG > CG > SC: ↑ GCS
[39]	IG: 13 CG: 13	Spinal cord injury	T1-3D DWI	Structural neuroplasticity: changes in DTI-based (FA, FN, Path length) in the respiratory center	Only qualitative evaluation IG > CG: ↑ FA, FN, and Path length in connectivity between the thalamus and occipital lobe, lingual gyrus, rostral area of the cuneate gyrus, spinothalamic tract	NA	IG > CG in all respiratory function measures

AD = Axial Diffusivity, *AF* = Arcuate Fasciculus, *ALFF* = Amplitude of Low Frequency Fluctuations, *BA* = Brodmann Area, *CBF* = Cerebral Blood Flow, *CC* = Corpus Callosum, *CCTS* = Composite Cognitive Test Score, *CG* = Control Group, *cm/s* = centimeters/seconds, *CST* = Cortico-Spinal Tract, *CT* = Cortical Thickness, *CTP* = Computed tomographic perfusion, *DAN* = Dorsal Attention Network, *DMI* = Dance-Movement Intervention, *DMN* = Default Mode Network, *DSST* = Digit Symbol Substitution Test, *DTI* = Diffusion Tensor Imaging, *DWI* = Diffusion-Weighted Imaging, *EF* = Executive Functions, *F* = Female, *FA* = Functional Anisotropy, *FAB* = Frontal Assessment Battery, *FAT* = Frontal Aslant Tract, *FC* = Functional Connectivity, *fMRI* = functional Magnetic Resonance Imaging, *FN* = Fiber Number, *FPN* = Fronto-Parietal Network, *FPT* = Five-Point Test, *GCS* = Glasgow Coma Scale, *GMV* = Grey Matter Volume, *HG* = Heschl's Gyrus, *IFG* = Inferior Frontal Gyrus, *IFOF* = Inferior Fronto-Occipital Fasciculus, *IG* = Intervention Group, *ITG* = Inferior Temporal Gyrus, *M* = Male, *MCI* = Mild Cognitive Impairment, *MD* = Mean Diffusivity, *MFG* = Middle Frontal Gyrus, *MMSE* = Mini-Mental State Examination, *MoCA* = Montreal Cognitive Assessment, *MOG* = Middle Occipital Gyrus, *MRI* = Magnetic Resonance Imaging, *MTG* = Middle Temporal Gyrus, *NA* = Not Applicable, *NLT* = Number Letter Task, *NPS* = Neuropsychological Test Scores, *QA* = Quantitative Anisotropy, *RD* = Radial Diffusivity, *ROI* = Region Of Interest, *rs-fMRI* = resting-state functional Magnetic Resonance Imaging, *SAL* = Salience network, *SC* = Standard Care, *SDMT* = Symbol Digit Modalities Test, *SLF* = Superior Longitudinal Fasciculus, *SMN* = Sensori-Motor Network, *STG* = Superior Temporal Gyrus, *T1-3D* = T1 weighted 3D imaging, *TBBS* = Tract-based Spatial Statistics, *TCF* = Taylor figure Test, *TMT* = Trail Making Test, *ToH* = Tower of Hanoi, *UF* = Uncinate Fasciculus, *UHDRS* = Unified Huntington's Disease Rating Scale, *VBM* = Voxel Based Morphometry, *vPMC* = ventral Premotor Cortex, *WM* = White matter, *WMS-RLM* = Wechsler Memory Scale-Revised Logical Memory, *WMV* = White Matter Volume

§ Studies related to the same RCT

Studies related to the same RCT, including different subgroups

The session duration ranged from 90 to 120 minutes per week for 16 consecutive weeks.

All studies reported significant effects on language [25, 33, 36] and verbal memory [25], except for one study [23], in which no significant effects on cognitive (Mini-Mental State Examination - MMSE) or daily functioning (Barthel Index) were found.

Structural neuroplasticity biomarkers Five studies [25–29] showed a significant impact of music-based interventions on structural neuroplasticity related to language and verbal memory. In particular, an increase in GMV in the left and right frontal areas [25], and in the right insula [24], related to language recovery was shown. Moreover, an increment in GMV in limbic regions was associated with mood changes [24]. Furthermore, the study conducted by Sihvonen, Ripollés, et al. [28] showed an increase in the FA of the Frontal Aslant Tract (FAT) and the QA of the ventral and dorsal pathways in both music-based interventions [26, 36].

Functional neuroplasticity biomarkers Two studies [28, 33] showed increased activation of left frontal areas related to aphasia recovery, while Sihvonen and Särkämö [29] predicted language recovery with pre-treatment level of activation in parietal areas. Finally, related to language recovery, Sihvonen et al. [25] showed increased FC between language and DMN, while Sihvonen, Pitkäniemi et al. [27] confirmed an increased FC within the language network. Finally, Fotakopoulos and Kotlia [23] identified CBF levels as predictors of recovery of cognitive and motor abilities (Table 4).

Other neurological disorders

The two studies on TBI [21, 22] focused on 39 TBI patients using Neurological Music Therapy, where subjects played musical instruments like drums or piano for 60 minutes, twice a week, over 10 weeks. Moreover, Xiao et al. [38] worked with 15 patients with MCS, who passively listened to live music (30 minutes a day, 5 days a week, over 4 weeks). Finally, Zhang et al. [39] examined 26 patients with cervical SCI who underwent Vocal Respiratory Training (VRT) involving singing (30 minutes, 5 days a week, for 12 weeks).

Behavioral results showed improvements in executive and motor functions, with active music playing in TBI patients [22]. Concerning patients with MCS [38], passive music listening was associated with better outcomes at the Glasgow Coma Scale (GCS) scoring compared to standard care. Finally, VRT with singing was more effective than regular physiotherapy in improving respiratory function [39] in patients with SCI.

Structural neuroplasticity biomarkers Siponkoski et al. [22] showed an increase of GMV in the right inferior and middle frontal gyri, left cerebellum, and fusiform gyrus, related to active music playing. Two studies qualitatively described increased fiber numbers, FA, and path length, related to music-based interventions in patients with MCS [38], and in patients with SCI [39].

Functional neuroplasticity biomarkers One study [21] showed a decrease in functional connectivity between DMN and Sensory Network, and between FPN and SAL in the intervention group compared to the control group.

Adherence, attendance and safety

Table 5 summarizes data for each study. Adherence to the intervention, in terms of the number of subjects who completed the rehabilitation program, was 92.07% (SD = 10.59) of the total participants. Moreover, only four studies [21, 22, 30, 32] reported attendance (mean = 79.70%; SD = 14.05). Finally, only one study [30] reported adverse events related to the intervention, including shortness of breath, musculoskeletal injury, and high blood pressure. In three studies, adverse events not related to the intervention were reported, while in twelve studies, adverse events were not mentioned.

Discussion

This systematic review aims to summarize evidence related to the effects of music- and dance-based rehabilitation on neuroplasticity mechanisms in people with neurological disorders.

Despite the extensive evidences on the behavioral effects of music- and dance-based interventions [4, 5, 16, 17, 41], to our knowledge, this is the first systematic review assessing evidence from neuroimaging techniques.

Overall, the observed results showed significant effects in both behavioral and neuroimaging outcomes, demonstrating impacts across multiple measures. Nevertheless, several limitations have been found, restricting the possibility to formulate an overall conclusion.

Methodological considerations and potential bias

Designing studies on MRI markers in rehabilitation faces several challenges. A major issue is the lack of prior registration of the neuroimaging markers to be investigated. This can introduce relevant bias, as each neuroimaging technique allows the investigation of multiple markers. The small number of participants, together with lack of power analyses on imaging data, pose additional challenge.

Table 5 Adherence, attendance, and adverse events report in RCT studies

Reference	Total adherence*	Attendance**	Adverse events
Blumen et al., 2023	64%	63.50%	3
Fotakopoulos & Kotlia, 2018	100%	/	/
Feng et al., 2020	100%	/	0
Jungblut et al., 2022	81%	/	2
Kropacova et al., 2019	96%	/	/
§ Martínez-Molina et al., 2021	85%	87%	/
Qi et al., 2018	84%	/	1
Rektorova et al., 2019	100%	/	/
Särkämö et al., 2014	90%	/	/
# Sihvonen et al., 2020	98%	/	/
# Sihvonen & Särkämö, 2021	/	/	/
# Sihvonen, Pitkäniemi, et al., 2021	76%	/	/
# Sihvonen, Ripollés, et al., 2021	76%	/	/
# Sihvonen et al., 2022	76%	/	/
Sihvonen et al., 2024	85%	/	2
§ Siponkoski et al., 2020	85%	87%	0
Trinkler et al., 2019	100%	/	/
Xiao et al., 2023	100%	/	/
Zhang et al., 2022	100%	/	/
Zhu et al., 2022	91%	88.6%	0

*Adherence corresponds to the number of subjects who completed the rehabilitation program; **Attendance is the percentage of sessions completed by the participants

/ = data not reported

§ Studies related to the same RCT

Studies related to the same RCT, including different subgroups

Addressing these issues is crucial to improve study design and ensure the reliability of neuroimaging data in future rehabilitation research.

Neurological condition and type of intervention

Neurodegenerative disorders

Dance-based interventions were mainly aimed at people at risk for dementia to improve general cognition, memory, mood, quality of life, and EF [30, 32, 34, 35, 40] as well as subjects with motor disabilities, such as HD patients [37]. These programs had an extended duration, ranging from 16 to 104 weeks, allowing for gradual and sustained improvement in behavioral outcomes while promoting changes in structural neuroplasticity. Specifically, the potential of dance-based interventions [30, 32], but not of singing [31], to counteract hippocampal atrophy was shown coupled with improvements in memory abilities. This discrepancy could be due to lack of aerobic exercise in singing intervention, which is associated with improvement in memory and hippocampus volume, a biomarker of dementia [42]. Additionally, findings indicate increases in cortical thickness in regions essential for face and object recognition [40], as well as improved microstructural integrity of WM bundles essential for integrating sensorimotor information, interhemispheric communication, and cognitive and motor control, such as superior longitudinal fasciculus, corpus callosum and cortico-spinal tract [40]. These structural neuroplastic changes were congruent with the observed improvements in frontal EFs. In Trinkler et al. [37], dance was effective in improving motor and EF in patients with HD, with an increment in GMV in areas related to the behavioral outcome, important for spatial and body representation and sensorimotor integration such as superior parietal, paracentral lobule, and occipital areas. These observations suggest that dance-based rehabilitation can promote widespread neuroplasticity, extended beyond localized hippocampal changes.

Concerning functional neuroplasticity, Qi et al. [35] observed increased brain activity in regions associated with EF, social cognition, memory encoding, emotional regulation, and spatial navigation (bilateral frontotemporal, entorhinal, anterior cingulate, and para-hippocampal cortex).

Overall, neural reorganization was associated with behavioral outcomes related to memory, global cognitive function, emotional regulation, and EF. These findings are partially consistent with a recent meta-analysis [43] on the efficacy of dance-based interventions in older adults with mild cognitive impairment, Alzheimer's disease, and dementia. The meta-analysis reported significant improvements in global cognition, memory, and depression, but no significant effects on executive function. Differences in the clinical populations studied and the small sample sizes in the studies included in this review may account for these discrepancies.

Ultimately, in studies involving subjects with neurodegenerative disorders, interventions predominantly focus on dance. Despite considerable variability in the intensity and duration of these treatments, nearly all studies have demonstrated neuroplasticity effects. However, this variability makes it difficult to determine the optimal duration and intensity of the intervention.

Stroke

Passive music listening was primarily directed at individuals who had acute stroke [23–29]. while singing was used in chronic post-stroke aphasia [33, 36]. Four studies [26–29] reported secondary analyses of the same RCT [25], which showed significant effects of music listening on language and verbal memory recovery [25, 36]. These studies revealed GMV increases in left and right frontal regions, anterior cingulate cortex, and ventral striatum in patients with left hemisphere lesions. Notably, these changes in GMV correlated with language, verbal memory, and attention recovery [24]. Moreover, increment in GMV in the left insula in patients with right hemisphere lesions, correlated with language improvement [24]. Enhancements of FA and QA as indicators of the integrity of white matter pathways (FAT, AF, SLF, corpus callosum, and CST) were observed in both acute and chronic stroke [28, 36]. These pathways are essential for facilitating communication between hemispheres and regions involved in language and motor function [43–45].

Functional neuroplasticity biomarkers were also associated with music listening interventions [24, 27, 36], and rhythmic-melodic voice training [33], showing increased activation in left frontal areas and enhanced FC within language network areas. Moreover, activity in the left parietal areas, bilateral medial frontal areas, and bilateral auditory network areas predicted language recovery and verbal memory skills [29].

In the two studies on patients with chronic post-stroke aphasia, the music-based treatment had the same duration but differed in intensity. Neuroplasticity effects were observed only in the study with higher intensity [36]suggesting that intensity plays a role in driving long-term neural reorganization. The language improvements reported in these two studies align with the findings of the recent meta-analysis by [47], which concluded that music therapy significantly enhances functional communication, repetition, and naming in patients with post-stroke aphasia. However, the results of [33] study also indicate an improvement in comprehension, which was not found to be significant in the aforementioned meta-analysis. Once again, it is important to note that the sample size in Jungblut's study was very small, and it cannot be ruled out that the participants may have differed in terms of aphasia severity or other characteristics compared to those analyzed in the meta-analysis.

Other neurological diseases

Two studies [21, 22], related to the same RCT [22], reported on interventions using active musical production in patients with TBI. Behaviorally, the music-based intervention had a significant impact on the recovery of EF, aligning with a recent meta-analysis that confirms the importance of music in treating EF deficits—an aspect of critical relevance in this type of pathology [48].

Structural neuroplasticity was shown as an increment of GMV in right frontal areas, left fusiform, and cerebellum [22], while Martínez-Molina et al. [21] reported a decrement in FC between DMN and sensory network, and within the FPN and SAL. Furthermore, improvement in general EF after training was correlated with a reduction in connectivity within the FPN and between the DMN and SMN. These data, in agreement with a previous work [46], suggest a shifting from a compensatory hyperconnected state to a sensory-integrative functioning related to music-based intervention.

One study reported on passive live music listening in a small number of patients with MCS [38]. Increment in the GCS in patients compared to the control group was reported, together with a qualitative evaluation of FA in several WM bundles related to the ascending reticular activation system [38].

The last study [39] demonstrated that music intervention outperformed standard respiratory physiotherapy in improving respiratory function outcomes. However, DWI biomarkers were qualitatively reported, indicating increased FA, FN, and path length in connectivity in areas associated with respiratory movements.

Limitations

In this section, we aim to highlight some limitations of the present review. First, it is important to emphasize that the primary outcomes considered — namely, neuroimaging-derived structural and functional changes — represent highly restrictive selection criteria. These criteria were chosen to address a gap in the literature by focusing on the neurobiological mechanisms underlying these interventions, with the specific goal of elucidating neuroplasticity mechanisms, including structural and functional brain changes. As a result, numerous studies examining variables such as gait, balance, movement, voice, and quality of life—factors that are crucial for understanding the broader clinical impact of music- and dance-based interventions—were not included in this review. For this reason, studies on conditions such as Parkinson’s disease, in which music- and dance-based treatments have been extensively investigated and have demonstrated significant clinical effects on motor symptoms, balance, functional mobility, and cognitive function, were not discussed [49]. Despite these limitations, our study remains relevant as it aims to complement existing literature by providing novel insights into the underlying brain mechanisms, which are often underexplored.

Below, a structured overview of the limitations of the studies included in this review is provided.

Sample

Despite the wide variability in the neurological disorders of the studies included in this systematic review, some trials have enrolled a relatively small number of participants. This limitation is due to the fact that some studies focus on rare pathologies or conditions, such as HD and MCS [37, 38], which limits the possibility of recruiting large samples.

Replicability

The studies in this systematic review covered various neurological pathologies and provided interventions targeting different circuits and functions. A common limitation was that imaging analyses were conducted on sub-samples from the original behavioral RCT, often lacking comprehensive clinical data and data analyses reports. This discrepancy can hinder the replicability and robustness of the findings.

Follow-up

Only one study included in this systematic review reported data on follow-up [22]; limiting the ability to draw robust conclusions about the efficacy of the treatment over time.

Variability of biomarkers

Virtually each included study investigated a different neuroimaging marker, including GMV, WM integrity, anisotropy, FC, and brain activation, complicating the synthesis of findings about the overall effectiveness of music- and dance-based interventions on neuroplasticity. Compounding this issue is the absence of standardized assessment scales for evaluating the quality of neuroimaging measurements. Without such objective criteria, it becomes difficult to systematically assess and compare the reliability of the neuroimaging findings across studies.

Data analysis

One significant limitation was the lack of baseline comparisons for neuroimaging biomarkers, which were reported in only six trials [21, 23, 26, 34, 35, 40], thus limiting the ability to conduct robust between-group analyses. The latter were absent in four studies [23, 29, 34, 35]. Furthermore, a detailed description of postprocessing methods, including data normalization, was fully provided in only two studies [25, 34]. Finally, none of the studies incorporated adherence or attendance to the rehabilitation intervention as a variable of interest or covariate. To overcome these limitations, it would be advisable that, when neuroimaging biomarkers are used as outcome measures in RCTs, they are first declared in the trial protocol registration and subsequently included among the randomization criteria for the sample or, at the very least, carefully assessed prior to conducting between-group analyses. Moreover, a detailed description of the methods used to analyze neuroimaging biomarkers is absolutely essential to evaluate their reliability and to ensure their reproducibility. Finally, considering that the majority of studies have evaluated how the structure and/or function of the brain changed at the level of individual areas or white matter tracts involved, and that only three studies have analyzed connectivity variations between them, it is desirable that future studies investigate the impact of music- and dance-based rehabilitation also at the level of the overall functioning of the brain network.

Clinical implications

Despite these limitations, some findings, if confirmed by further studies, could have important clinical implications. For example, neuroplasticity effects have been observed in the hippocampus of patients at risk of dementia and in the frontal language areas of patients with post-stroke aphasia, both in the acute and chronic phases. These effects occur in brain regions that are crucial for the disabilities associated with these conditions. Therefore, a significant impact of rehabilitative interventions in these areas could play a key role in preserving or restoring functions, ultimately helping to counteract disability and improve patients' quality of life.

Conclusion

This systematic review highlights the potential of music- and dance-based interventions to induce neuroplastic changes in individuals with neurological disorders, as evidenced by both behavioral and neuroimaging findings. In individuals at risk for dementia, dance interventions emphasize mood, cognitive, and motor function, promoting neuroplasticity in regions crucial for memory and cognitive functions. On the other hand, music-based interventions, particularly in stroke rehabilitation, demonstrated significant impacts on structural and functional neuroplasticity linked to language recovery, memory, and mood regulation through increased connectivity in key brain networks. However, the heterogeneity in intervention protocols and neuroimaging biomarkers across studies limits the ability to draw definitive conclusions regarding their overall efficacy.

To enhance the quality and reproducibility of future research, it is crucial to address key methodological challenges. In particular, greater standardization is needed in the selection and analysis of neuroimaging biomarkers, with a clear a priori definition of outcome measures in study protocols. Additionally, the adoption of shared criteria for neuroimaging data analysis and quality assessment could improve comparability across studies.

Further research should also focus on optimizing intervention parameters, such as duration and intensity, and on including follow-up assessments to evaluate long-term neuroplasticity effects. By addressing these gaps, future studies can contribute to a more robust understanding of the mechanisms underlying music- and dance-based rehabilitation and their potential clinical applications.

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Data availability The strings used for the present systematic review are included in the supplementarymaterial, further inquiries can be directed to the corresponding author.

Declarations

Conflicts of interest The authors declare they have no competing interests.

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