Neuropsychological Trends

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Effect of music-based training on cognitive function in older adults with and without neurological impairment: a systematic review

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ABSTRACT

Aging is associated with progressive decline in cognitive skills. Combining music-based interventions has been proposed as a strategy to enhance cognitive processing in older adults. The objective of the study was to review the effects of music-based training on cognitive outcomes in healthy and neurologically impaired older adults. A comprehensive literature search was conducted. Randomized controlled trials investigating music-based training (dual, multi-task) and reporting cognitive outcomes were included. Methodological quality and risk of bias was evaluated. Data were synthesized qualitatively. Seven randomized controlled trials were included. Interventions included music-based dual-task, and multitask music-movement programs with durations from single-session to 12-month protocols. Methodological quality ranged from fair to good, while Cochrane RoB2 assessments indicated some concerns in allocation and outcome reporting. Most studies reported improvements in specific cognitive domains. Music based intervention shows promise for improving cognitive domains in older adults. Larger, high-quality studies with standardized protocols and longer follow-up required.

Keywords: music-based training; cognition; older adults; multitask training; dual task training

1. Introduction

WHO (2024) defines aging as an accumulation of molecular and cellular changes that results in irreversible decline of biological functions and reserves. It is represented by nonlinear decrement in physiological and mental elasticity (Colita et al., 2024). Mild Cognitive Impairment (MCI) exemplifies such changes, as it is described as intermediate stage between normal aging and major neurocognitive disorder (Salari et al., 2025). Changes in cognition do not occur uniformly but rather domain specific vulnerabilities emerge, primarily three domains: processing speed, memory, and executive functioning which have been linked to separate neurobiological changes (Bettio et al., 2017).

Neuroimaging methods have experienced their most recent advancements which enable researchers to study brain activity through its complete network system instead of studying localized damaged brain areas. Earlier theories had identified the hippocampus as the sole brain region responsible for memory declines, but current research shows that MCI patients experience episodic memory declines because their hippocampal cortical circuit system has developed dysfunction (Salari et al., 2025). Researchers have discovered that executive function declines which include inhibition and cognitive flexibility now result from frontoparietal and cingulo-opercular network integrity loss instead of frontal lobe damage (Idowu et al., 2024). Through their research findings, scientists discovered that people who experience diminished visuospatial abilities and attention skills also show decreased activity in both dorsal and ventral attention networks, which is associated with alterations in functional connectivity between cortical and subcortical areas (Statsenko et al., 2022).

The development of cognitive decline demonstrates itself as a network-level occurrence which creates a need for transdiagnostic therapies that need to activate multiple brain systems at once. The use of music-based therapeutic programs in this context establishes a special treatment approach which requires patients to combine their cognitive abilities with motor skills and sensory perception during actual treatment sessions. The brain requires rhythm-based musical training to track outside sounds because the body needs to move, which results in stronger links between sensory and motor processing systems (Shimizu et al., 2018). The research findings indicate that these combined treatment methods can improve specific decline symptoms, which group music therapy has proven through its ability to enhance social skills and overall cognitive abilities of MCI patients (Raglio et al., 2013) and power and rhythm training has proven its effectiveness in boosting advanced cognitive skills of older adults living in their homes (Park et al., 2023). Music functions as a framework which activates connected systems of the brain while making it possible for brain waves and areas of the brain to communicate, which normally gets disrupted in older adults.

The objective of this study is to review the emerging evidence on cognitive-motor-sensory music-based interventions that have been used to promote healthy cognitive and functional outcomes in both clinical and non-clinical populations. This paper serves as an update to previous reviews by combining preliminary evidence on dual-task/multi-task musical interventions into one manuscript. There is a suggestion that combining two or more different systems into one intervention (dual-tasking or multi-tasking) may allow for unique therapeutic opportunities when compared to training a single domain in isolation. Due to variability in existing literature, we attempt to summarize what trends there are in efficacy and the potential reach of these interventions for future investigation.

2. Method

This systematic review was reported following the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) guidelines. The protocol of this review was registered with PROSPERO CRD420251027217 on 1 May 2025.

2.1 Eligibility criteria

To ensure methodological clarity, this review distinguishes between two primary cognitive-motor paradigms:

- Dual-Task (DT) Interventions: Defined as the simultaneous execution of two distinct tasks with separate goals, typically involving a primary motor task (e.g., walking) and a secondary musical or cognitive task (e.g., singing or rhythmic synchronization) (Fraser & Bherer, 2013).
- Multi-Task (MT) Interventions: Defined as complex, integrated activities that require the concurrent management of multiple sensory, motor, and cognitive streams within a single unified framework, such as Dalcroze Eurhythmics.

2.2 Intervention

Given the heterogeneity of music-based protocols, interventions were categorized into three distinct clusters based on their primary therapeutic mechanism:

- Rhythmic-Motor Training: Interventions focusing on sensorimotor synchronization and gait (e.g., rhythmic walking).
- Cognitive-Musical Dual-Tasking: Interventions requiring active cognitive

engagement alongside musical production (e.g., singing while walking).
- Multimodal Eurhythmics: Integrated programs combining rhythm, physical coordination, and social-cognitive demands.

2.3 Information sources

PubMed, SCOPUS, web of science databases were searched to identify relevant studies. These databases were chosen because of their comprehensive indexing of relevant journals in both basic and applied fields of research in the biomedical sciences.

2.4 Search strategy

Search strategy was developed using a structured combination of controlled vocabulary and free-text keywords related to population (e.g., older adults, elderly, neurological conditions such as dementia, Alzheimer), the intervention (e.g., music therapy, rhythmic auditory stimulation, musical dual- task training) and the outcomes (e.g., cognition, executive function, memory, attention). Search items were derived from the PICO framework and adapted for each database to ensure comprehensive retrieval. Medical subject headings (MeSH) were applied, and boolean operators were used to combine search terms and refine the results.

The final search for each database (PubMed, Scopus, Web of science) was conducted from database inception to April 2026. Filters for randomized controlled trials were applied where available, and study design eligibility was further confirmed during the screening process. The complete and reproducible search strategies for each database are provided in Supplementary File 1.

2.5 Selection process

All the identified studies were exported from their respective databases to Endnote (online) reference manager for screening. After exporting all studies, duplicate studies were removed automatically from Endnote. Two independent reviewers (MA and SP) screened the titles and abstracts based on the inclusion criteria and studies not meeting the criteria were excluded. Any discrepancies between the reviewers were resolved by the third reviewer (CAS). Full-text articles were screened through the same process and irrelevant articles were excluded.

2.6 Data items and synthesis

The following data were extracted from all included studies: 1) publication

year; 2) author; 3) country and research setting; 4) sample size and participant characteristics (healthy or neurological older adults); 5) study design; 6) intervention details for the music-based based dual-task and multi-task intervention; 7) intervention details for the control group; 8) cognitive outcome measures; 9) duration and frequency of intervention; 10) main findings related to cognition.

2.7 Quality assessment

Two independent reviewers (MA and SP) performed quality assessment on all included studies through physiotherapy Evidence Database quality assessment scale (PEDro), known for its high reliability and validity used for scoring the randomized controlled trials. Any discrepancies were resolved by the third reviewer (CAS). The quality of the studies was evaluated on the basis of 11 criteria of the PEDro scale. Each criterion was assigned a score of yes or no, except criteria 1 which assess external validity and is not included in the total score the total score were ranged from 0 to 10. Study quality was categorized as poor (PEDro score <4), fair (PEDro score 4-5), good (PEDro score 6-8), excellent (PEDro score 9-10). The reliability of PEDro scale has already established as ICC= 0.68.

2.8 Risk of bias assessment

Two independent reviewers (MA and SP) performed risk of bias assessment on all included studies through Cochrane Risk of Bias Tool version 2 (RoB2) Tool for randomized controlled trials. Any discrepancies were resolved by the Cochrane RoB2 tool through discrepancy check. The risk of bias assessment through Cochrane RoB2 consists of signaling questions categorized in 5 different domains i.e., randomization process bias, deviation from intended intervention, missing outcome data, measurement of the outcome, selection of the reported result and overall bias. The scoring of each signaling question in each domain is done on the basis of low risk, some concern and high risk.

3. Results

3.1 Search results

The databases search identifies a total of 262 records, including 180 from PubMed, 69 from Scopus and 13 from Web of Science. After removal of 7

duplicate records, 255 studies were screened based on title and abstract. Of these, 246 records were excluded. Nine full-text articles were assessed for eligibility, of which two non-randomized studies and one study with inappropriate age group were excluded. Finally, seven studies met the inclusion criteria and were included in the qualitative synthesis. The study selection process is illustrated in Figure 1.

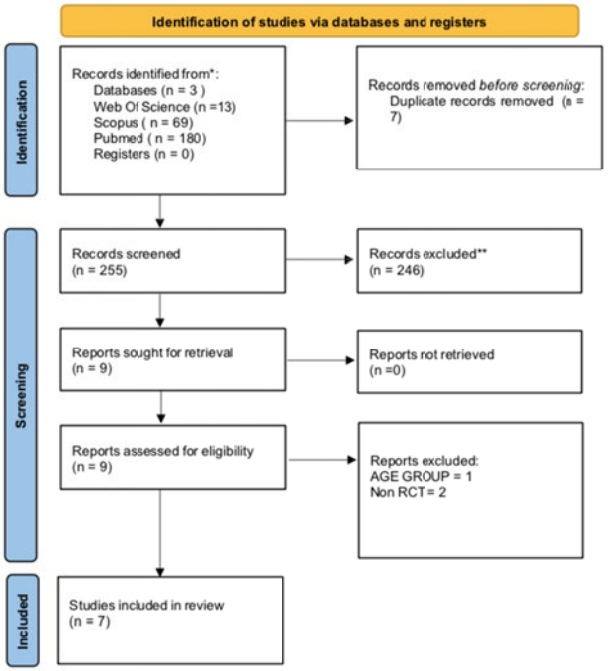


Figure 1. Prisma Flowchart: Identification of studies via databases and registers

3.2 Participants

This systematic review included studies with a total of 450 participants, with sample sizes ranging from 20 (Nieto-Guisado et al., 2024) to 142 (Hars et al., 2024). Participant's age ranged from 65 years to 88 years. Gender specification was mentioned across all studies, with female representation varying from 50%

(Chen & Pei, 2018)to 96% (Hars et al., 2014). All included participants were either healthy older adults (Hamacher et al., 2015; Hars et al., 2014, 2024; Nieto-Guisado et al., 2024) or had neurological conditions like Parkinson's disease (Pohl et al., 2020) or dementia (Chen & Pei, 2018). The characteristics of participants is given in Table 1.

Table 1. Characteristics of the included trials

Author & country	Study design	Patient characteristics	Intervention group	Control group	Outcome measures	Main findings
Hars et al., 2024 / Switzerland	RCT	142 community-dwelling older adults (>65 years, high risk of falls), 92% female; 71 in intervention, 71 in control	(DE) – exercise-music based multitask intervention, once weekly group sessions for 12 months.	Multi-component exercise (MULTI) – balance, functional and strength training, twice weekly (group + home based).	Executive function: Trail Making Test (A & B), Stroop color-word test, digit span (forward & backward), WAIS-III-digit symbol coding, (FAB), MMSE, clock drawing test.	DE group showed greater improvement in executive function vs. MULTI: TMT B, digit span backward, Stroop color-word test. No significant between-group difference for MMSE, clock drawing, or some other executive measures.
Nieto-Guisado et al., 2024 / Spain	RCT	20 older adults; EG (n=10) and CG (n=10)	8-week cognitive-motor training with postural control and proprioception exercises with music.	8-week training (postural control + proprioception) without music.	Cognitive task: categorical verbal fluency (Barcelona test).	Significant improvement in postural control and proprioception over time in both groups. Cognitive performance did not improve; music-based dual task did not provide additional benefit.

Pohl et al., 2020 / Sweden	RCT	46 patients (26 intervention, 20 control) with Parkinson's disease	Group-based music intervention – multitasking exercise, twice weekly for 12 weeks.	Usual care (offered after study).	MoCA, cognitive assessment battery, text recall, Stroop color-word test, symbol digit modalities test.	No significant between-group difference in MoCA, Stroop, text recall or delayed recall. Symbol digit modalities test showed short-term improvement in intervention group but not sustained at 3-month follow-up. No consistent improvement in cognition observed overall.
Chen et al., 2018 / Taiwan	RCT	28 participants with mild to moderate dementia (male=14, female=14); intervention n=15, control n=13	(MDTT) – walking while singing or playing simple percussion instruments under varying attention demands.	Non-musical cognitive and walking activities performed separately (not dual task).	(TMT part A) – primary outcome assessing attention control.	MDTT group showed significant improvement in attention control (better TMT part A scores). Control group showed no significant change.
Maclean, 2018 / UK	Mixed-model design (randomized 3 groups).	45 healthy older adults (28 women, 17 men), aged 65–88	Rhythmic musical training (MT) – participants trained to walk in time with music matched to their preferred walking pace.	Music playing (MP) group; No music playing group (NM).	(CCR) during 7-second subtraction in (ST) and (DT) conditions (walking while subtracting).	MT group: cognitive performance (serial 7s CCR) did not decline or improve. In MP and NM groups, no improvement in cognition.

Hamacher et al., 2015 / Germany	RCT	35 older adults; dancing group (n=19) and health-exercise group (n=16)	6-month dancing program; 2 sessions/week, 90 min/session – learning choreography, rhythms, and coordinated motor-cognitive tasks.	Health-related exercise program (endurance, strength, flexibility) with similar duration and intensity.	Cognitive performance (serial subtraction during walking), gait variability (stride time, stride length, toe clearance), gait velocity.	Significant improvement in motor-cognitive dual-task performance in dancing group; improved cognitive performance (reduced time for subtraction).
Hars et al., 2013 / Switzerland	RCT	134 community-dwelling older adults (>65 years), 96% female; 66 intervention, 68 control	Music-based multitask training, once weekly 1-hour group classes for 6 months.	Usual lifestyle.	MMSE, clock drawing test, (FAB) and subtests (especially sensitivity to interference).	MMSE: significant within-group improvement in intervention group. FAB: significant between-group improvement. Clock drawing test and other FAB subtests: no significant between-group differences.

Abbreviation: DE = Dalcroze Eurhythmics; RCT = Randomized Controlled Trial; MDTT = Musical Dual-Task Training; TMT = Trail Making Test; FAB = Frontal Assessment Battery; MMSE = Mini-Mental State Examination; MoCA = Montreal Cognitive Assessment; CCR = Correct Cognitive Response; ST = Single task; DT= Dual-task

3.3 Intervention

The included trials (N=7) employed diverse music-based strategies which, despite their heterogeneity, share the common theoretical foundation of taxing the brain's integrated network systems. The included studies were categorized according to the predefined intervention framework (rhythmic-motor training, cognitive-musical dual-tasking, and multimodal eurythmics) to improve clarity and interpretability.

3.3.1 Rhythmic-Motor and Gait-Based Training

Two studies utilized rhythmic auditory cues to influence motor-cognitive performance. Maclean et al. (2014) investigated a single-session rhythmic training protocol where healthy older adults synchronized walking pace to music, focusing on the immediate impact on dual-task cost during serial subtraction. Similarly, Pohl et al. (2020) applied a 12-week group-based music intervention for Parkinson's patients, utilizing rhythm as a temporal scaffold for multi-tasking exercises.

3.3.2 Cognitive-Musical Dual-Tasking

Chen and Pei (2018) operationalized a dual-task protocol specifically for dementia patients. This intervention required participants to practice walking while simultaneously performing musical tasks (singing or playing percussion) under varying levels of attentional demand, specifically targeting the interference between motor and vocal/musical production.

3.3.3 Multimodal Eurhythmics and Integrated Programs

The most complex interventions involved Dalcroze Eurhythmics, a multi-task approach where music is used to cue varied physical and cognitive responses. Hars et al. (2014, 2024) utilized this method in community-dwelling older adults over 6 to 12 months. These sessions required participants to adapt their movements to changing musical meters and rhythms, representing a high-level integration of sensory input and motor output.

The duration of interventions varied substantially across included studies, ranging from single-session (Maclean et al., 2014) to 12- month multimodal training programs (Hars et al., 2024). Training sessions varied across included trials, ranging from repeated short walking trails (Maclean et al., 2014) to once-weekly 1-hour classes (Hars et al., 2014, 2024) and twice-weekly sessions for 12

weeks (Pohl et al., 2020) and an 8-week program with two 30-minute sessions per week (Nieto-Guisado et al., 2024) and extended 6- month structured training programs (Hamacher et al., 2015). This reflects the heterogeneity of music-based cognitive-motor training approaches included in this review.

3.4 Control

Activities in the control group varied from study to study. In one study the control group performed multicomponent exercise training consisting of balance, functional, and strength activities delivered twice weekly in group and home-based formats (Hars et al., 2024). A study by Nieto-guisado et al. (2024), the control group performed postural control and proprioceptive exercises identical to the experimental group but without the inclusion of music, thereby receiving a purely motor training intervention without an added cognitive or auditory component. Another study employed a usual care control group with participants receiving their standard care after the study (Pohl et al., 2020). In some trials the control group engaged in non-musical walking and cognitive activities separately, without the dual-task element (Chen & Pei, 2018). In the study by Hamacher et al. (2015), the control group consisted of an active health related exercise group where participants engaged in structured sessions including endurance training, strength, endurance exercises and flexibility exercises. In another trial by Maclean et al. (2014), two control groups were included, one with music playing in the background without synchronized walking and another with no music exposure at all, and in some studies the control group maintained their usual lifestyle activities without any additional structured training (Hars et al., 2014).

3.5 Outcome measures

The outcome measures reported across the included trials were cognitive and executive function tests, global cognition scales, and dual-task performance indicators. A study by Nieto-guisado et al. (2024) the cognitive performance was evaluated using a categorical verbal fluency task derived from the Barcelona test under dual-task conditions. Two studies (Hars et al., 2014, 2024) assessed executive functions through tasks such as the trail-making test, Stroop color-word test, digit span, and frontal assessment battery. One study (Pohl et al., 2020) evaluated cognitive outcome using the Montreal Cognitive Assessment, Cognitive Assessment Battery, text recall, Stroop test, and symbol digit modalities test. Another study (Chen & Pei, 2018) primarily assessed attention control using the trail making test part A. A study by Hamacher et al. (2015) assessed both cognitive and motor dual task performance. cognitive

performance was evaluated using a serial subtraction task (subtraction by 3s), including measures such as the average time taken to respond and percentage of correct answers. Another study (Maclean et al., 2014) evaluated cognitive performance using correct cognitive response during 7s subtraction in single-task and dual-task conditions.

3.6 Quality assessment

All the included studies quality assessment was found to be fair to good, the average score came out to be 5.9. All studies met the criteria for randomization. Concealed allocation was reported in Hars et al. (2024) and Chen & Pei (2018), but not in the other studies. Baseline participant characteristics did not show a significant difference in all studies: none of the included trials achieved full blinding across subjects, therapists, and assessors. Assessor blinding was performed in Hars et al. (2024), Pohl et al. (2020), and Hars et al. (2014).

Three of the included trials adhered to an intention-to-treat protocol (Chen & Pei, 2018; Hars et al., 2024; Maclean et al., 2014). Further, all included trials provided between-group statistical comparison as well as point estimates and measures of variability. As per the PEDro criteria, two trials scored 6/10, i.e., good quality (Hars et al., 2014; Pohl et al., 2020) one trial scored 7/10, i.e., good quality (Chen & Pei, 2018); one trial scored 8/10, i.e., good quality (Hars et al., 2024); and two trial scored 5/10, i.e., fair quality (Maclean et al., 2014; Hamacher et ., 2015) and one trial scored 4/10 i.e. fair quality (Nieto-Guisado et al., 2024). Findings of the studies are shown in Table 2.

Table 2. Methodological quality assessment

	Eligibility criteria	Random allocation	Concealed allocation	Baseline comparability	Blind subject	Blind therapist	Blind assessor	Follow-up dropout <15%	Intention-to-treat analysis	Between-group comparison	Point estimate & variability	Score
Hars et al., 2024	YES	YES	YES	YES	NO	NO	YES	YES	YES	YES	YES	8/10
Nieto-Guisado et al., 2024	YES	YES	NO	YES	NO	NO	NO	NO	NO	YES	YES	4/10
Pohl et al., 2020	YES	YES	NO	YES	NO	NO	YES	YES	NO	YES	YES	6/10
Chen et al., 2018	YES	YES	YES	YES	NO	NO	NO	YES	YES	YES	YES	7/10
Maclean, 2018	YES	YES	NO	YES	NO	NO	NO	YES	NO	YES	YES	5/10
Hamacher et al., 2015	YES	YES	YES	YES	NO	NO	NO	NO	NO	YES	YES	5/10
Hars et al., 2013	YES	YES	NO	YES	NO	NO	YES	NO	YES	YES	YES	6/10

3.7 Risk of bias assessment

Most of the trials analyzed indicated some concern for the randomization process, except for 2 trials that indicated low risk(Hars et al., 2014; Pohl et al., 2020).While assessing the bias from deviation from the intended intervention, all studies indicated low risk except for Pohl et al. (2020). Whereas bias resulted from the missing outcome, the trials that indicated some concerns were Maclean et al. (2014) and Nieto-Guisado et al. (2024). All trials were classified as having some concern for risk for biasness except Hars et al., 2024, which reported low risk and Hamacher et al. (2015) that reported high risk. Regarding the bias from the selection of reported results, most of the studies indicated some concerns except for Hars et al. (2024), which had low risk. The overall risk of bias of five included trials was reported as some concern except for Maclean et al. (2014) and Hamacher et al. (2015), which reported high risk. Figure 2 illustrates findings of the studies with the intention-to- treat protocol, and Figure 3 illustrates findings of studies with the per protocol (PP) analysis.

Figure 2. Risk Of Bias Assessment using Cochrane Risk of Bias Tool 2.0 (Intention-to-treat analysis)

Intention-to-treat	Unique ID	Study ID	Experimental	Comparator	Outcome	D1	D2	D3	D4	D5	Overall
	1	Chen et al (2018)	MDT	NMT	Cognition	!	+	!	!	!	!
	4	Hars et al (2014)	MMT	Delayed intervention	cognition	!	+	!	+	!	!
	5	Hars et al (2024)	DE	MULTI exercise	cognition	+	+	+	+	+	!
	6	Nieto-Guisado et al (2024)	MDT	non music intervention	cognition	!	!	+	!	+	!
	7	Hamacher et al (2015)	music based training	NMT	cognition	+	!	-	+	+	-

+ Low risk
! Some concerns
- High risk

D1 Randomisation process
D2 Deviations from the intended interventions
D3 Missing outcome data
D4 Measurement of the outcome
D5 Selection of the reported result

Figure 2. Risk of bias assessment (intention to treat analysis)

Figure 3. Risk Of Bias Assessment using Cochrane Risk of Bias Tool 2.0 (Per-Protocol analysis)

Per-protocol	Unique ID	Study ID	Experimental	Comparator	Outcome	D1	D2	D3	D4	D5	Overall
	3	Mclean et al (2014)	Rhythmic musical training.	No music/no training	cognition	!	+	!	-	!	-
	2	Pohl et al (2020)	Group-based music intervention	Usual care	cognition	+	!	!	+	!	!

+	Low risk
!	Some concerns
-	High risk

D1	Randomisation process
D2	Deviations from the intended interventions
D3	Missing outcome data
D4	Measurement of the outcome
D5	Selection of the reported result

Figure 3. Risk of bias assessment (per protocol analysis)

4. Discussion

This review investigated the effects of music-based dual-task and multi-task training on cognitive function in older adults, including both healthy individuals and those with neurological conditions. Overall, the included studies suggest that such interventions may have beneficial effects on specific cognitive domains, particularly executive function, attention and memory, potentially through the integration of rhythmic and cognitive challenges. However, given the small number of included studies (N=7), variability in intervention protocols, and mixed findings across trials, these results should be interpreted with caution and not considered conclusive.

In healthy older adults, music-cued movement combined with memory or attentional tasks has been associated with improvements in executive functioning and processing speed in some studies. These findings are consistent with evidence reported in previous literature. For example, a study reported improvements in inhibitory control, verbal fluency, and overall quality of life following a 12-week physical-cognitive dual-task intervention in older women. Similarly, Trombetti et al., (2011) reported that among community-dwelling older adults at higher risk of falls, a six- month music-based multi-task exercise program enhanced dual-task gait performance, improved balance and lowered both the incidence of falls and falls and the overall fall risk.

Sarkamo reported that music-based interventions improved attention and episodic memory, while also reducing neuropsychiatric symptoms (Särkämö, 2018). According to one study the dual-task- based music therapy can positively influence executive functioning and attentional control in elderly individuals. According to another study, music-based dual-task exercise training can positively influence cognitive functioning, particularly attention and global cognition, in elderly individuals with Alzheimer's disease (Shokri et al., 2024; Nikkhah Bahrami et al., 2024).

Engaging in musical activities is a powerful stimulus for brain adaptation and neuroplasticity (Wan & Schlaug, 2010). The rhythmic and melodic components of music simultaneously activate motor, sensory, and emotional networks, thereby promoting brain plasticity and supporting recovery processes in conditions such as stroke and neurodegenerative disorders (Altenmüller & Schlaug, 2015).

The included studies show substantial heterogeneity because they include research which ranges from single-session rhythmic gait training to 12-month eurhythmics programs. The operational tasks show different requirements but their assignment to groups proves valid because they both depend on sensorimotor synchronization and cross-modal integration. The five studies establish fundamental difficulties for cortical hub communication because they

demand concurrent processing of both temporal auditory signals and motor cognitive responses, which targets network vulnerabilities that occur during aging and neurodegenerative disorders.

With continued musical training, stronger functional and structural coupling develops between auditory, motor, and parietal regions, reflecting enhanced neural efficiency and experience- dependent plasticity(Olszewska et al., 2021). In addition to its neural effects, music exerts widespread physiological influences, including modulation of heart rate, respiration, blood pressure, muscle tension, and biochemical responses, highlighting its capacity to regulate both emotional states and physiological processes.

Music based simultaneous cognitive-motor training, which engages both mental and physical processes concurrently, enhances cognitive-motor integration and stimulates prefrontal cortical networks involved in executive control, attention and motor planning (Stephan et al., 2002). Musical rhythm acts as an external temporal cue, facilitating sensorimotor synchronization between auditory and motor systems. The connection helps improve timing and coordination by activating the basal ganglia, supplementary motor area, and cerebellum, areas that also support executive functions and working memory (Stephan et al., 2002).

Beyond cognitive outcomes, music-based dual-tasked interventions have demonstrated broader functional benefits, Improvement in gait, balance and fall reduction have been observed in older adults participating in music cued motor-cognitive programs (Coubard et al., 2011; Trombetti et al., 2011).

These findings suggest that music-based dual-tasks not only enhance cognitive function but also contribute to mobility and functional independence, which are critical for healthy aging.

The key strength of the present review is that the included studies were primarily randomized controlled trials, providing a relatively high level of evidence. However, methodological quality varied across studies, and several demonstrated risks of bias or limited sample sizes, which should be considered when interpreting the findings. The interventions, including music-based dual-task and multi-task exercises, were implemented over varying durations, which may have allowed sufficient exposure to observe potential changes in cognitive outcomes in some studies.

Including varied groups from healthy older adults to those with dementia or Parkinson's disease, makes the results more relevant to real-world clinical practice. Overall, these strengths highlight the growing evidence that structured, engaging and task based

aerobic programs can positively influence cognitive health in aging individuals. (Coubard et al., 2011)

Nonetheless, limitations should also be considered, most studies included relatively small sample sizes, limiting generalizability, methodological quality was also found to be variable. Heterogeneity in training protocols (eg. type of music, cognitive task complexity, session duration) complicate direct comparisons across studies. Additionally, long term retention of cognitive gains remains underexplored as most interventions evaluated short-term outcomes. A major limitation of this review is the inability to conduct a meta-analysis due to substantial heterogeneity across the included studies.

Future research should focus on high-quality randomized controlled trials with larger samples to establish the efficacy of music-based dual-task across diverse populations. Standardizing intervention protocols and outcome measures will enable more robust comparisons and meta- analysis. It will also be important to explore dose-response relationships, the role of musical preference, and differential effects across healthy, mild cognitive impairments, Parkinson disease and dementia populations. Integration with neuroimaging and electrophysiological tools (eg., EEG, fNIRS) could further clarify the neural mechanisms underlying music-based cognitive gains.

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Author contribution

Conceptualizing: S.P., C.A.S., M.M.N., M.A.; Methodology: S.P., C.A.S., M.A., M.H.K; Investigation: S.P., C.A.S., M.A., M.A; Supervision: C.A.S., M.M.N, M.A; Writing – original draft: S.P., M.A, C.A.S., M.H.K; Writing – review & editing: C.A.S., M.M.N., S.P, M.A., M.Az.

Declaration of interest

The authors declare that there is no conflict of interest regarding this systematic review.

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