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REVIEW

The sound of longevity: music and technology for healthy ageing

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Abstract
A growing body of research is focusing on how music, technology, and neuroscience can converge to promote healthy ageing and counteract pathological decline. In particular, music interventions for older adults have been garnering increasing attention, with numerous reports showing positive effects of music on various health outcomes, including psychological well-being, cognitive function, physiological responses, quality of life, and overall well-being. In this context, the European Interdisciplinary Council on Ageing (EICA) in collaboration with the "Age-It" project (Ageing well in an Ageing Society), specifically, the work package 1 of Spoke 8, run by the University of Bari, and the "RAISE" project (Robotic and Artificial Intelligence for Socio-economic Empowerment) run by the E.O. Galliera Hospitals, Genoa, Italy, convened a 2-day meeting in June 2025 to review the state of the evidence on the relationship between music and health. Speakers were tasked with exploring how music, neuroscience, technology, and environmental design contribute to understanding ageing and to developing interventions that support healthy ageing. This report presents the Executive Summary of the proceedings of this meeting.

Keywords music · music interventions · technology · soundscape · longevity · healthy ageing

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Introduction

Ageing is a multidimensional process shaped by biological, psychological, social, and environmental factors. Across recent decades, research has increasingly focused on how music, technology, and neuroscience can converge to promote healthy ageing and counteract pathological decline. Healthy ageing is broadly and heterogeneously defined in the literature, reflecting its multidimensional and context-dependent nature, but is generally understood as a dynamic process shaped by personal characteristics, resources, goals, and the broader social, cultural, economic, and environmental context across multiple dimensions of life [1]. It involves both maintaining health and function as much as possible, and adapting effectively over time through supportive interactions between the person and their environment [1].

In this context, music interventions for older adults have been garnering increasing attention in recent years, with a number of published reviews that have shown positive effects of music on various health outcomes, including psychological well-being, cognitive function, physiological responses, quality of life, and overall well-being [2, 3]. There is a growing consensus that music interventions may enhance biopsychosocial health outcomes in older adults, although overall confidence in the evidence remains quite low. According to a white paper by Jespersen and colleagues, the current evidence corresponds to Level 2 in the Oxford Centre for Evidence-Based Medicine hierarchy, indicating support from randomized or large observational studies but insufficient systematic synthesis to draw definitive conclusions [4]. Similarly, while mechanistic models of the rehabilitative impact of music on neurological disorders have been put forward in the literature, a consensus is still lacking on the actual mechanisms driving the beneficial effects of music on health, especially in older adults [5–7]. Nevertheless, music is a valuable and highly versatile support for the well-being of older adults. In today's world, where life expectancy is rising, technological advancements have transformed how we experience music, and thus the role of both music and technology in the daily life of older individuals deserves greater scientific attention.

To this end, the European Interdisciplinary Council on Ageing (EICA) in collaboration with the "Age-It" project (Ageing well in an Ageing Society), specifically the work package 1 of Spoke 8 run by the University of Bari, and the "RAISE" project (Robotic and Artificial Intelligence for Socio-economic Empowerment) run by the E.O. Galliera Hospitals, Genoa, Italy, convened a 2-day international meeting entitled "The Sound of Longevity: Music and Technology for a Healthy Ageing"(including a live streaming webinar, available at https://www.youtube.com/watch?v=Cz2CpZkMrIE, and a workshop) in June 2025. The scope of the meeting was to review the state of the evidence on the relationship between music, technology, and health, thus, speakers were tasked with exploring how music, technology, neuroscience, and environmental design contribute to understanding ageing and to developing interventions that support healthy ageing (see Fig. 1). We present here the Executive Summary of the proceedings of this meeting.

A multidimensional approach to ageing: technology and music

Overview of multidimensional assessment models

A multidimensional understanding of ageing is essential for designing and evaluating effective interventions. While it is known that biological age alone does not adequately capture the great heterogeneity of ageing trajectories, the Comprehensive Geriatric Assessment (CGA) is recognized as a cornerstone of geriatric medicine and the gold standard for evaluating medical, cognitive, functional, nutritional, and psychosocial domains in older adults [8]. A central tool derived from the CGA is the Multidimensional Prognostic Index (MPI). By integrating standardized measurements across domains, the MPI predicts mortality and other adverse outcomes with high accuracy. Importantly, the MPI supports clinical decision-making by identifying risk profiles and informing personalized care plans [9]. A great number of studies have confirmed its validity and utility across hospital, primary care, and telemedicine contexts [10].

Several major ongoing projects illustrate how CGA and the MPI can be combined with technology and lifestyle interventions. The MULTIPLAT-AGE project linked multiple technological platforms to create interoperable data systems supporting personalized treatment pathways [11]. Examples of such platforms include an adapted physical activity programme supported by information and communication technologies, or at-home cognitive telerehabilitation / remote cognitive stimulation [11]. The Pro-Home project further demonstrated how home-based monitoring, incorporating domotics, robotics, and music training, can help maintain mobility, reduce frailty, and sustain improvements, up to several months after the intervention ends [12].

Role of technology and music in supporting healthy ageing

Music appears as an emerging component in multidomain interventions. Evidence from numerous systematic reviews suggests that music listening, exercise with music, and structured music therapy improve mood, physical activity, socialization, and aspects of cognitive function [13]. The

Fig. 1 Leaflet of the meeting "The Sound of Longevity: Music and Technology for a Healthy Ageing", Venice, June 3rd 2025

mechanisms remain under investigation [5–7], but involve interactions among motor networks, emotional regulation circuits, and neuroendocrine pathways. The integration of music into CGA-based interventions is conceptually aligned with person-centred geriatric care: it targets multiple domains simultaneously, supports adherence, and enhances quality of life.

Neural perspectives on music across the lifespan

The importance of music for humans resides in the phenomenon of group coherence. Indeed, it creates an ambiance conducive to cooperation, and fosters group coordination and promote prosocial behaviour [14, 15]. Previous research has shown that interpersonal synchrony, in the form of synchronized drumming, enhances activity in the caudate nucleus in the brain [16]. This activates reward-like signals that have the potential to shape future behaviour, specifically by promoting prosocial commitment [17]. It has also been shown that temporally aligned movements enhance social bonding, and this in turn was associated with higher empathy during movement interactions that featured music [18, 19].

The question of why humans spontaneously move when they hear music has been the subject of intense research, and there is evidence that most humans can move to the beat, musicians and non-musicians alike, albeit with some exceptions [20, 21]. This concept is known as "groove", namely the "feel" of the rhythm, or the subtle quality of music that compels people to dance or move along [22]. The balance achieved between the degree of syncopation of the music, and the feelings of pleasure and wanting to move, indicate that both motor and pleasure systems (like dopamine) are stimulated when a human listens to music. These findings regarding activation of the associated brain areas have been corroborated by functional magnetic resonance imaging studies performed while musicians and non-musicians listened to and rated experimentally controlled music [23]. The study showed that rhythms with a medium level of complexity elicited greater pleasure and a greater sensation of desire to move [23]. Cultural differences and musicianship experience may affect these responses [24, 25]. Interestingly, the disruption to the dopaminergic system resulting from drug addiction can cause individuals with substance use disorders to experience stronger groove with high rhythmic and harmonic complexities [26]. High rhythmic complexity means the beat is hard to predict or follow, i.e. due to the use of unusual time signatures, syncopation, overlapping patterns, or sudden accents. Harmonic complexity means the chords and note combinations are richer or less familiar than in simpler songs, i.e. the music may change key unexpectedly, use dense or dissonant chords, or move through chord progressions that create ambiguity or tension. Furthermore, individuals with Parkinson's disease have also been shown to have a significantly flattened response for both pleasure and the urge to move [27].

Current thinking suggests that the violation and confirmation of temporal predictions is the key driver behind the pleasurable effect of music. Accordingly, the inverted U-shaped relation between the urge to dance and rhythmic complexity is purported to represent a balance between predictability and uncertainty when listening to the music [28]. In this regard, the predictive coding theory proposes that prediction is a fundamental principle of brain processing [29].

Auditory memory, which encompasses melody and harmony in addition to rhythm, has also been shown to be affected by ageing. In one study, it was shown that ageing differentially affects the various dimensions of auditory memory, whereby more musical training conferred a significant advantage on certain specific tasks [30]. Overall, it was shown that younger participants (<25 years of age) outperformed their older counterparts (>60 years) in terms of short term memory for rhythmic sequences and long-term memory for novel sequences [30]. Conversely, for previously memorized music, older adults displayed stronger activity in auditory regions. Therefore, there is clearly a difference in strategy, with older people relying more on auditory cortices, while younger people rely more on hippocampal areas [31]. When it comes to encoding new melodies, older adults have reduced activity in regions relating to decision making processes, related to novelty, and display reduced performance compared to younger adults. Such age-related differences in neural strategies for processing music underscore that brain function across the lifespan reflects both experiential learning and foundational developmental influences, making it essential to consider how epigenetic mechanisms shape these trajectories from the earliest stages.

Epigenetic risk factors in neurodevelopment

Engaging with the multisensory stimulus that music represents can prompt structural and functional adaptations within the brain, and ultimately influence neural pathways and neuroplasticity [32]. In this regard, it has been proposed that resilience, i.e., the ability of the brain to maintain or recover function after stress or insult, emerges from the lifelong interaction between biological predisposition and the environmental context. Accordingly, if resilience depends on the plastic potential of neural circuits, genetic variability, and environmental inputs [33], then music could be leveraged as a tool to promote resilience. Within this context, the Italian National Research Council (CNR) has developed LOTUS³ - a unifying initiative linking diverse research clusters focused on brain health, environmental exposure, and neuroplasticity. Directed by Professor Michela Fagiolini (CNR and Harvard Medical School), LOTUS³ unites research on molecular neuroscience, behavioral interventions, and environmental toxicology under a single vision, namely optimizing brain trajectories from early development to old age.

Music-related brain changes in ageing

Building on this framework of environmentally driven brain trajectories, music offers a compelling example of how specific experiences can modulate neural systems throughout adulthood and into older age. Accumulating evidence supports the role of musical engagement in enhancing brain plasticity, supporting cognitive reserve, and slowing structural decline. A comprehensive review by James et al.

demonstrated broad cognitive protection through musical interventions, with the strongest effects observed in combined cognitive and physical training paradigms [34]. Here, cognitive training paradigms include interventions targeting functions such as memory, attention, executive control, reasoning, and spatial navigation, often delivered through computerized tasks, games, language learning, or music-based activities; physical training paradigms include aerobic exercise and non-aerobic coordinative or sensorimotor activities such as walking, cycling, dancing, resistance training, tai chi, and balance-based exercise [34]. Similarly, Marie et al. reported that both piano training and active music listening led to increases in cerebellar grey matter volume and auditory working memory, despite ongoing age-related atrophy [35]. Of note, both piano training and active music listening had effects. Mack et al. found that one year of piano training enhanced cognitive flexibility and sustained attention in older adults [36], while Jünemann et al. demonstrated stabilization of white-matter integrity in the fornix—a key memory-related structure—after six months of piano training [37]. These converging results highlight the promising neuroprotective effects of music in ageing, with benefits from everyday cognitive functioning to structural brain integrity.

Musical engagement may also slow progression in pathological conditions such as Alzheimer's disease (AD). Despite profound impairment of episodic and semantic memory, individuals with AD often retain the ability to recognize familiar melodies and even learn new ones. AD patients have been shown capable of distinguishing familiar from novel melodies, detecting wrong notes, and singing familiar tunes accurately [38]. Elsewhere, it was reported that AD patients who learned sung lyrics had better word retention than spoken presentation, underscoring the mnemonic power of melodic structure [39]. Moreover, music has been shown to enhance autobiographical recall: patients recalled life episodes more vividly when listening to familiar music, even when the pieces were unrelated to those experiences [40–42]. Current thinking suggests that a separate musical memory exists that can exert positive effects, whereby learning and retention of musical information is mediated by brain networks distinct from those involved in other types of episodic and semantic memory [43, 44]. Moreover, the acquisition and recall of complex musical information could remain as intact cognitive activities, even in the presence of other memory impairment [45]. Together, these findings suggest that neural systems supporting musical memory might be resistant to neurodegeneration until its latest stages [46, 47].

Music-based interventions in pathological ageing

Music-based interventions represent a low-cost, accessible, and neurobiologically grounded approach to mitigating cognitive and emotional decline in ageing. By preserving hippocampal volume, stimulating dopaminergic circuits, and enhancing emotional well-being, music therapy and music-based interventions might complement physical and cognitive training strategies in the prevention and management of dementia.

Recent systematic reviews and meta-analyses indicate that music-based interventions may offer modest cognitive benefits for individuals with dementia, although findings remain mixed. Fusar-Poli et al. reported no overall significant effects of music therapy across outcomes, but subgroup analyses suggested a small positive effect of active interventions on global cognition [48]. Similarly, Dorris et al. found that music-making produced a small yet statistically significant improvement in cognitive functioning among older adults with mild cognitive impairment or dementia [49]. Despite these signals of benefit, the broader evidence base is constrained by substantial methodological weaknesses. Reviews highlight consistently small sample sizes, heterogeneous and often non-standardized intervention protocols, and variability in outcome measures, all of which limit interpretability [50–52]. There remains a compelling need for rigorously designed, larger randomized controlled trials that incorporate well-defined and stage-appropriate intervention protocols, assess both cognitive and positive emotional or social outcomes, and evaluate treatment duration and persistence of effects [51, 53].

Beyond AD, multiple other studies have documented music's influence on physiological markers such as heart rate, heart-rate variability (HRV), respiration, blood pressure, and sleep quality. Krabs and colleagues demonstrated that both pleasant and unpleasant music, and even isochronous tones devoid of melody, reduce HRV compared to silence [54]. The similarity of responses across emotional valences indicates that rhythm and temporal regularity play dominant roles in autonomic regulation. Orini et al. further confirmed that the tactus or beat alone is sufficient to elicit measurable autonomic responses, emphasizing entrainment as a key mechanism [55]. Yet, as in the field of AD research, clinical application of music therapy faces methodological challenges, since the choice of tempo, familiarity with the music, the presence of lyrics, and the delivery mode (headphones, live, etc.) are all factors that may influence outcomes. Furthermore, distinguishing between active music-making and passive listening is essential, as active participation engages motor and cognitive circuits that enhance plasticity and reward processing.

Among the potential benefits of active musical engagement, the capacity to synchronize movement to an external beat can be strategically harnessed for rehabilitation purposes. Rhythmic abilities may be thought to be characteristic of experts or musicians, but in fact, the capacity to couple movement to rhythm is very widespread and natural in the general population [21, 56]. This ability is supported by dedicated neural circuitry, encompassing networks of cortical and subcortical regions whose interactions enable the temporal alignment of motor actions with rhythmic auditory cues [57, 58]. A particularly noteworthy point is that the neural regions engaged in rhythm processing are primarily those responsible for motor control, rather than areas specialized exclusively for rhythm. Even tasks that require only the perception or identification of a beat, without overt movement, elicit robust activation of motor circuits [59–61]. This phenomenon reflects the strong functional coupling between rhythm perception and motor control, whereby auditory rhythmic input can stimulate motor networks even in the absence of actual movement. Building on these findings, a translational approach has emerged, moving from basic research to applied rehabilitation by developing theory-driven interventions [62].

A useful model for studying rhythm-based interventions in rehabilitation is Parkinson's disease (PD), where motor impairments and disrupted timing processes provide a clear framework for testing the effects of rhythmic stimulation [63, 64]. PD is a neurodegenerative disease that results from neuronal depletion in the substantia nigra and deregulation of the dopaminergic system with characteristic symptoms: akinesia (few initiated movements), bradykinesia (slow movements), rigidity, and tremor at rest. PD is also characterized by rhythm disturbances, often referred to as a general dysrhythmia [65], manifesting behaviorally as impaired rhythmic motor timing. For example, this is visible in a tendency to "hasten" during paced tapping when auditory cues are removed and timing must be internally maintained. More recently, in a study by Puyjarinet et al. [66], it was found that general dysrhythmia is visible in patients with PD on the production side across different motor tasks such as finger tapping, oro-facial coordination, and gait, as well as in rhythm perception (e.g., in rhythm discrimination, the detection of tempo changes, and the detection of a misaligned beat). Notably, rhythm deficits in gait, vocal production, and manual motor control can be predicted by deficits in rhythmic perception. Another major challenge in PD is the presence of gait disturbances, which are associated with a high burden but respond poorly to standard pharmacological treatment, such as L-dopa [67]. Evidence indicates, however, that rhythmic stimulation can significantly improve gait performance. Rhythmic auditory cueing, particularly when delivered through music, for example following the neurological music-therapy protocol named Rhythmic Auditory Stimulation (RAS), enables patients to walk faster, with longer steps and a more natural gait pattern [62, 68–71]. The effects are often immediate, but they typically dissipate once the stimulus is removed. Nevertheless, when cueing-based training is applied consistently over a period of one to two months, benefits can persist even in the absence of ongoing external stimulation [63, 72, 73].

Music- and dance-based technological advances for rehabilitation

Music and dance occupy a unique space at the intersection of art, neuroscience, and technology. At the InfoMus–Casa Paganini Research Centre of the University of Genoa, Antonio Camurri and colleagues have developed a transdisciplinary framework that merges artistic practice, computational modeling, and human-centered design. The therapeutic applications of Casa Paganini's research extend from clinical rehabilitation to cultural well-being. In the "CARE HERE" project [74], patients with PD used their bodies as 'brushes' to paint projected walls, with fluid motion generating visual and sonic feedback. This aesthetic and motivational approach quantitatively reduced movement hesitation, illustrating how beauty and play can enhance motor recovery.

The "DanzArTe" Emotional Well-being Technology, developed in collaboration with geriatricians, merges interactive sonification, visual art, and virtual agents to foster emotional and physical engagement among older adults. Participants reconstruct classical paintings through expressive movement; their gestures, analyzed in real time, 'reveal' the artwork as movement becomes fluid. Recent evaluations reported significant improvements in subjective well-being and resilience, validating the paradigm of aesthetic resonance, i.e. the emotional alignment between performer, movement, and sensory environment [75, 76]. By capturing the nuances of expressive gesture and translating them into multisensory feedback, music- and dance-based systems foster empathy, motivation, and neuroplastic recovery.

Another example of application of technology to enhance an aesthetic experience for rehabilitative purposes comes from a recent proof-of-concept study by Carlomagno and colleagues [77]. They used immersive virtual reality (VR) combined with evocative, aesthetically engaging visual content (calming, pleasant landscapes) and music (culturally resonant songs) as a mini-intervention for 21 older individuals with varying levels of cognitive decline, including mild cognitive impairment and dementia. The primary goals were to assess whether this audiovisual intervention could enhance mood, evoke autobiographical memories, and improve overall emotional well-being, regardless of participants' cognitive status. Findings indicate that most participants experienced high immersion and predominantly positive emotional responses, with many reporting calmness and recollection of meaningful personal memories during the sessions. Moreover, self-rated mood significantly improved from before to after VR exposure. Some minor side effects—such as mild anxiety or physical discomfort from the headset—were noted, but overall, the experience was engaging and well received.

Beyond immersive art and VR, digital rehabilitation technologies, such as rhythmic serious games and adaptive mobile solutions [72], offer an alternative way to make rhythm-based training scalable, engaging, and personalized for people with PD. For example, serious games exploit gamification to increase motivation while enabling multisensory engagement, real-time monitoring, and individualized control of training parameters, in a format that is affordable and deployable on tablets or smartphones. For example, in a proof-of-concept study Puyjarinet et al., implemented a six-week home program (3 sessions/week) using a serious rhythmic game in which patients tapped in synchrony with music to gain points and progress [66]. The intervention was associated with improvements in trained rhythmic functions (e.g., reduced tapping variability) and speech articulation, alongside improved beat perception that correlated with motor outcomes, consistent with the idea that strengthening a central rhythmic system can support broader motor function.

Overall, these exemplary studies illustrate how the fusion of art and technology can transform rehabilitation into an aesthetic experience, supporting and empowering patients across diverse functional domains [78].

The role of soundscapes in healthy ageing

The relationship between sound and health is paradoxical: sound can both injure and heal. At the intersection of musical composition and sound design, the notion of the 'soundscape', i.e. the total acoustic environment in which we are immersed, was first introduced in Raymond Murray Schafer's seminal work, "The Tuning of the World" [79]. The soundscape has emerged as an important perspective in the domain of healthcare, notably to investigate how sonic environments might influence physiological and emotional well-being, especially among vulnerable and ageing populations.

In hospital settings, the sounds in the ambient acoustic environment, e.g., ventilators, footsteps, or distant voices, can alternately either comfort or distress patients. Studies in intensive care units have shown that acoustic insulation may paradoxically create environments that are 'too silent', leading to disorientation or anxiety [80]. Recent research has shown that the use of artificial keynotes (i.e., soft, continuous background sounds) can restore a sense of spatial and temporal orientation. Conversely, signals such as alarms are often too intrusive. Customizing alarm tones to match staff preferences and attentional thresholds can reduce cognitive fatigue, an idea supported by research on auditory ergonomics [80–82]. Other soundscape interventions in healthcare can range from environmental design to individualized therapy. For example, one study performed in a French long-term care facility for people with AD, experimented with diffused soundscapes tailored to specific spaces: church bells in communal areas, birdsong near gardens, and personalized music in patient rooms. These subtle sonic cues provided cognitive and emotional anchors, stimulating memory and reducing agitation [83]. This work echoes findings by Voisin et al. [83] showing that familiar environmental sounds improve orientation and emotional stability in dementia care.

Future directions and emerging opportunities

Future work should place greater emphasis on clarifying the mechanisms through which music may support healthy ageing. In particular, predictive processing offers a useful framework for understanding how the balance between expectation and surprise in music may shape pleasure, movement, attention, and learning, and how these effects may differ according to musical experience, ageing trajectory, and neurological status. At the same time, further research should explore the potential of personalized and technology-supported interventions across the lifespan, including adaptive music training, home-based digital programmes, immersive multisensory environments, and rehabilitation strategies integrated with multidimensional geriatric care. Methodological priorities include larger and better characterized cohorts, greater harmonization of intervention protocols and outcome measures, longer follow-up, and multimodal designs combining behavioural, clinical, and neural markers to better define both efficacy and underlying mechanisms.

Conclusion

The proceedings of the "Sound of Longevity" meeting summarized here highlight the growing recognition of music as a powerful, multidimensional resource for promoting healthy ageing according to an interdisciplinary and proactive methodological approach (see Fig. 2). Across

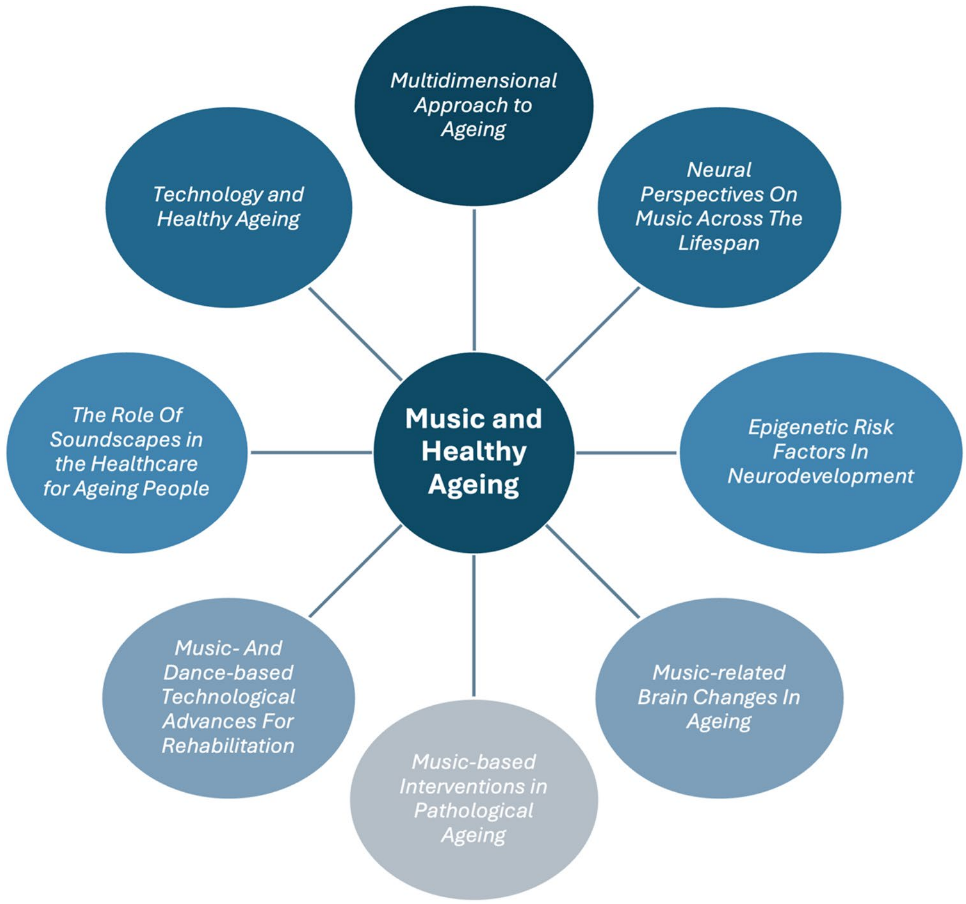

Fig. 2 Interdisciplinary approach to the role of music in promoting and preserving healthy ageing

biological, cognitive, emotional, and social domains, musical engagement, whether in the form of listening, active music-making, movement, technology-mediated musical experiences or carefully designed soundscapes, emerges as a low-cost, accessible, and person-centred intervention. Advances in neuroscience have begun to elucidate the neural mechanisms through which music supports plasticity, resilience, and preserved function, even in the presence of neurodegenerative disease. At the same time, technological innovations now enable music- and dance-based interventions to be personalized, scalable, and integrated into clinical, home, and care settings.

Despite encouraging evidence, substantial methodological challenges remain, underscoring the need for rigorous, large-scale trials and standardized outcome measures. Future research should adopt a lifespan and systems-based perspective, embedding music within comprehensive geriatric assessment frameworks to fully harness its potential in supporting longevity, well-being, and dignity in ageing populations.

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Data availability No datasets were generated or analysed during the current study.

Declarations

Competing interests The authors declare no competing interests.

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