A Self-Optimizing Artificial Intelligence–assisted Early Music Intervention Training Framework for Delaying Alzheimer's Disease Onset

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Abstract

Alzheimer's disease (AD) is a progressive neurodegenerative disorder that imposes substantial personal, societal, and economic burdens worldwide. Given the limited effectiveness of treatments after significant cognitive decline has occurred, increasing attention has been directed toward preventive and early-intervention strategies that can delay disease onset and preserve cognitive function. Music-based interventions have emerged as a promising non-pharmacological approach due to their ability to engage multiple neural networks involved in memory, attention, emotion, and executive function. Despite encouraging evidence, conventional music-training programs remain largely static, offering limited personalization and lacking mechanisms for continuous adaptation based on individual responses. To address these limitations, this paper proposes an Artificial Intelligence–assisted Early Music Intervention Training platform, a closed-loop self-optimizing framework that integrates digital biomarker assessment, machine learning, generative artificial intelligence, and personalized music training into a unified intervention platform. The proposed framework has the potential to improve participant engagement, enhance intervention effectiveness, support longitudinal monitoring, and ultimately contribute to delaying the onset of cognitive decline and reducing the long-term burden of dementia.

Introduction

Dementia, of which Alzheimer's disease (AD) accounts for approximately 60–80% of cases, is one of the most expensive chronic conditions for Medicare and Medicaid. The average annual cost of health care for a senior with Alzheimer's disease in the United States is roughly three times higher than for those without dementia. Nationwide healthcare expenditures for Alzheimer's disease are projected to increase from $409 billion in 2026 to nearly $1 trillion by 2050 [1]. The Medicare Hospital Insurance Trust Fund is projected to be financially insolvent by 2050 [2]. How should we address this big financial crisis?

Published research has shown that even modest delays in Alzheimer's disease could have a substantial economic impact on reducing the long-term care cost. One modeling study estimated that for seniors aged 70 and older, delaying the onset of Alzheimer's disease by one year could reduce total caregiving costs by approximately 14%. The study further projected that a three-year delay would reduce costs by 27%, while a five-year delay could lead to a 39% reduction in caregiving expenditures [3]. The projection suggests that delaying Alzheimer's disease onset by a few years could save the United States government hundreds of billions of dollars over coming decades to mitigate the financial crisis.

Therefore, this work is proposing a non-pharmacological AI-assisted music training framework aimed at the early detection and early intervention for Alzheimer's disease, which is designed to be engaging for users, low-cost to implement, and associated with minimal risk of side effects.

Music Training: a promising utility for early intervention of Alzheimer's Disease

Koelsch's Five-Component Model proposes that music can influence attention, emotion, cognition, behavior, and communication through distinct neuropsychological pathways [4]. Consequently, music training engages multiple cognitive systems simultaneously, supporting memory, emotional well-being, social interaction, and the maintenance of cognitive reserve. Although music training cannot prevent or cure Alzheimer's disease, growing evidence suggests that it may help preserve cognitive functioning and improve quality of life during the early stages of cognitive decline.

Recent neuroimaging studies provide biological support for this potential. A 2025 study reported that older adults at risk of dementia who actively played musical instruments exhibited greater grey matter density than non-musicians [5]. Since grey matter contains neuronal cell bodies and synaptic connections essential for memory, learning, and information processing, greater grey matter density may indicate enhanced cognitive reserve and resilience against age-related neurodegeneration.

Additionally, music-based interventions may provide greater intrinsic reward compared to other neurocognitive training approaches, such as language learning or puzzle-solving. From a neurobiological perspective, music engagement has been shown to activate the brain's reward circuitry, including dopaminergic pathways involving the ventral striatum and mesolimbic system, which are closely associated with pleasure, motivation, and reinforcement learning [6]. This self-rewarding response may enhance sustained engagement, particularly in older adults who are at risk of reduced adherence to cognitively demanding interventions.

Furthermore, music preference is highly culture-based and can be tailored by individual characteristics across genres, styles, rhythms, and levels of complexity. According to self-determination theory and behavioral engagement frameworks, interventions that foster intrinsic motivation are more likely to achieve long-term adherence than those driven primarily by extrinsic goals [7]. Therefore, the enjoyable and personalized nature of music-based training may enhance engagement and intervention effectiveness. In conclusion, these neurocognitive, neurobiological, and behavioral advantages make music a promising utility for AI-driven early intervention strategies aimed at delaying cognitive decline and reducing dementia risk.

Framework of AI-assisted Early Music Intervention Training platform

Based on the preceding discussion, this work proposes the AI-Based Early Music Intervention Training framework, which integrates artificial intelligence with music-based cognitive intervention through two complementary modules as shown in Figure.1 below: Early Detection Module and Music Training Module. The two modules work collaboratively with each other to form a closed-loop system

that continuously assesses cognitive status and dynamically personalizes music-based training to support Alzheimer's disease prevention and early intervention.

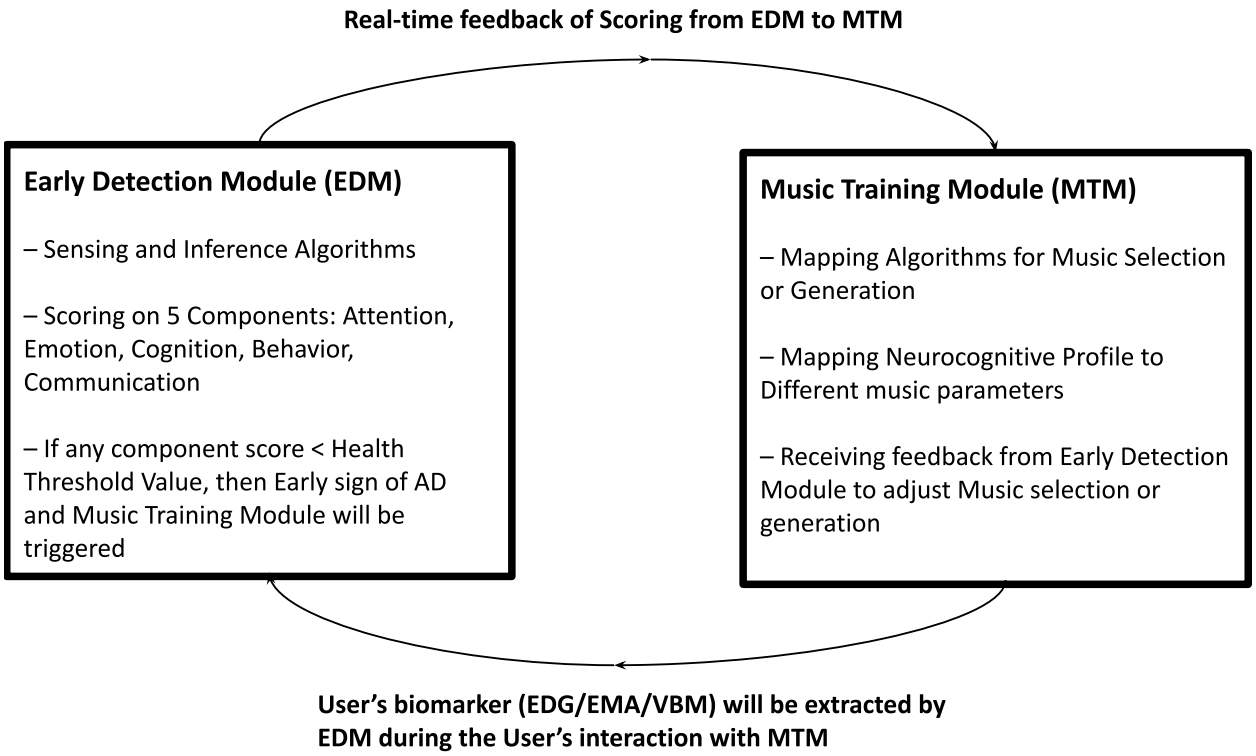

Figure.1 Framework of AI assisted Early Music Intervention Training platform

Early Detection module, comprises two main techniques to sense and infer the early sign of Alzheimer's disease: Machine Learning based biometrical data extraction and AI-driven vocal data extraction.

Machine Learning (ML) models help to quantify the biometrical data, such as Electrodermal Activity (EDA) (skin conductance) and facial Electromyography (EMG) (muscle movement) [8]. Music-based diagnostic approaches for Alzheimer's disease leverage the analysis of individuals' involuntary physiological, behavioral, and cognitive responses to familiar melodies. These responses are often mediated by distributed neural systems involved in auditory processing, emotional regulation, and autobiographical memory retrieval, which may remain relatively preserved in the early stages of neurodegeneration. As a result, music-evoked responses can serve as sensitive indicators of subtle cognitive changes that may not yet be detectable through conventional assessments.

AI-driven vocal biomarkers (VBM) extracts non-semantic acoustic features—like pitch, pauses, shimmer, and speech rate. Because speech and singing share complex neurological pathways, integrating vocal samples can yield up to 95% accuracy in distinguishing cognitively normal individuals from those in preclinical stages. [9]

Based on ML or AI analysis, the early detection module will create a neurocognitive profile for each user based on Koelsch's "Five-Component Model" of attention, emotion, cognition, behavior, and communication. Each component will be scored, and the Five-Component scores will be used to evaluate if the early signs of Alzheimer's disease emerge. Users identified as at risk will then proceed to the Music Training module.

Music Training Module, the core component of the AI assisted Early Music Intervention Training platform. Its primary function is to deliver personalized music-based interventions through an adaptive, AI-driven framework. The module utilizes machine learning algorithms to map an individual's Five-Component Score to specific musical parameters, including pitch, rhythm, tempo, dynamics, harmony, and melodic complexity. Based on these mappings, the system selects or generates customized music-training programs tailored to the user's neurocognitive profile. [10]

Through a closed-loop feedback mechanism, digital biomarkers generated by the Early Detection Module are used to periodically reassess and update Five-Component scores. These updated scores are then transmitted to the Music Training Module, where they initiate the dynamic adjustment of musical parameters, training intensity, and task complexity to optimize engagement and therapeutic effectiveness.

Generative AI techniques further enhance personalization by automatically composing or adapting musical content based on an individual's evolving cognitive profile. By targeting specific domains of neurocognitive profile requiring improvement, the system can deliver increasingly tailored interventions that respond to changes in user performance and clinical status over time. This continuous cycle of assessment, adaptation, and intervention establishes a self-optimizing framework that integrates early detection with personalized music training for Alzheimer's disease prevention and early intervention.

Conclusion and Future Research

This paper proposes the Artificial Intelligence–assisted Early Music Intervention Training platform, a novel framework that integrates music-based cognitive training, digital biomarker assessment, machine learning, and generative artificial intelligence into a unified closed-loop self-optimizing system. By continuously monitoring cognitive, behavioral, and physiological indicators, the AI assisted platform can dynamically personalize music interventions according to an individual's evolving cognitive profiles. Unlike traditional music-training programs, which are typically static and predetermined, the proposed framework enables real-time adaptation, scalable deployment, and longitudinal outcome tracking, which could contribute to delaying cognitive decline, improving quality of life, and reducing the long-term societal and economic burden associated with dementia.

Future research should systematically investigate and validate the causal relationships between specific cognitive profiles and musical parameters, including rhythm, tempo, melody, harmony, dynamics, and complexity. In addition, the scoring methodology of the Early Detection Module requires further refinement and validation. Ultimately, these efforts could enable the development of a self-optimizing platform for precision prevention and early intervention, with the goal of delaying the onset of Alzheimer's disease at both individual and population levels.

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