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Construction of an AI-Enabled Closed-Loop Model for Dance Movement Therapy: Cognitive Support for Elderly Adults with Mild Cognitive Impairment

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Abstract: Elderly adults with Mild Cognitive Impairment (MCI) are situated at a critical intervention window for mitigating cognitive decline. Dance movement therapy engages cognitive processing through bodily movements, rhythmic patterns, spatial arrangement and interpersonal interaction. Nevertheless, its practical implementation is plagued by prominent challenges, including insufficient individualised adaptation, ambiguous alignment between cognitive support objectives and operational procedures, and inadequate utilisation of procedural records and outcome feedback. Grounded in embodied cognition theory, this study adopts a combined methodology of literature analysis and theoretical deduction, incorporating professional advice from cross-disciplinary experts. It highlights the pervasive auxiliary role of artificial intelligence throughout model operation, and constructs an AI-enabled closed-loop model for dance movement therapy consisting of five functional modules: participant profiling, intervention prescription generation, on-site implementation embedding, real-time monitoring and early warning, as well as feedback iteration. Guided by the core principle of practitioner leadership supplemented by AI assistance, the model translates cognitive support targets into tangible dance movement therapy workflows, with corresponding implementation prerequisites and governance boundaries proposed for practical deployment.

1. Introduction

Mild Cognitive Impairment (MCI) represents an intermediate cognitive state between normal ageing and dementia, marking a pivotal period for targeted cognitive support interventions [1,2]. Centred on bodily movement, rhythmic cadence and contextual interaction, dance movement therapy activates multi-dimensional cognitive processes via motor sequence learning, beat synchronisation, spatial navigation and collaborative engagement [6]. Cumulative empirical evidence confirms that structured dance activities yield measurable benefits for global cognitive function, memory, attention and balance among MCI older adults [3,4].

Despite these therapeutic merits, delivering tailored dance movement therapy to MCI populations faces two core limitations. First, uniform standardised activity programmes fail to accommodate heterogeneous physiological tolerance, risk profiles and personal participation preferences, leading to inadequate individualised support. Second, existing dance intervention research predominantly focuses on intervention efficacy or single programme design, while offering limited elaboration on how cognitive support objectives can be translated into activity frameworks, and how activity design, on-site execution and safety management can be systematically integrated [3,4]. Accordingly, research gaps remain to be addressed in the field of dance movement therapy for MCI older adults: how to translate individual disparities into customised implementation protocols; how to embed cognitive support goals across activity design, field execution and safety oversight; and how procedural data and feedback can inform iterative programme adjustments.

Drawing on embodied cognition as its theoretical anchor, this study synthesises literature spanning MCI cognitive intervention, dance movement therapy, digital health and AI-assisted clinical practice via literature analysis and theoretical inference. In response to operational demands covering pre-intervention preparation, in-session delivery and post-intervention optimisation, it extracts five interconnected functional stages—participant profiling, intervention prescription generation, on-site implementation embedding, real-time monitoring and early warning, and feedback iteration—to develop a holistic AI-enabled closed-loop model for dance movement therapy. To strengthen the model's practical applicability and delineate clear conceptual boundaries, revisions were conducted incorporating expert feedback from MCI and dance movement therapy disciplines, refining interpretations of cognitive mechanisms, core module configurations and risk control protocols. Such expert input solely serves structural calibration and does not constitute independent empirical data.

This study delivers three principal theoretical contributions: it integrates individual heterogeneity, cognitive support objectives, on-site activity delivery, safety surveillance and outcome feedback within a unified closed-loop framework; under the collaborative framework of practitioner primacy and AI auxiliary support, it transforms dance movement therapy from experience-dependent practice to data-driven workflows grounded in procedural documentation, feedback circulation and iterative prescription optimisation. This work provides a theoretical framework and analytical foundation for structured dance movement therapy delivery targeting MCI older adults, alongside a baseline for subsequent empirical verification research.

2. Concept Definition and Theoretical Foundation

2.1 Definition of Core Concepts

To eliminate conceptual ambiguity, operational definitions of five pivotal constructs are established as follows:

Mild Cognitive Impairment (MCI): A state of mild cognitive deterioration situated between normative senescence and dementia, characterised by subjectively and objectively detectable cognitive decline with largely preserved activities of daily living [1,2].

Dance Movement Therapy: Distinct from technical dance training and not reliant on formal clinical therapeutic alliances, this term refers to structured body-centred activities delivered by trained practitioners with relevant professional credentials. Utilising physical movement, rhythm, spatial layout and interpersonal exchange as core mediums, such activities pursue integrated physical and mental wellbeing, cognitive enhancement and emotional regulation.

Embodied Cognition: The theory posits that cognitive processing is not an isolated intracerebral operation, but a dynamic process shaped by bodily movement, sensory perception and environmental interaction [6]. This theoretical lens elucidates how dance movement therapy facilitates cognitive support for MCI older adults through kinesthetic, rhythmic, spatial and interactive experience, forming the theoretical backbone of the proposed closed-loop model.

AI Empowerment: Artificial intelligence functions as a pervasive technical infrastructure embedded across all five stages of the closed-loop dance movement therapy model, delivering auxiliary support for information collation, preliminary programme drafting, procedural data logging, risk alerting and feedback aggregation [5].

Closed-Loop Model: A cyclical operational framework linking participant profiling, intervention prescription generation, on-site implementation embedding, real-time monitoring and early warning, and feedback iteration via circulating outcome feedback. The mechanism ensures intervention outcomes inform participant profile updates and subsequent prescription revisions, reducing overreliance on subjective experiential judgement for programme adjustment.

2.2 Theoretical Foundation

Existing geriatric cognitive research establishes the foundational criteria for formulating cognitive support targets, while embodied cognition theory further substantiates that cognition cannot be decoupled from physical sensation, motor behaviour, bodily status and situational interaction [6]. Within dance movement therapy contexts, bodily motion, musical rhythm, spatial variation and peer interaction collectively constitute embodied experiential stimuli, serving as critical mediums for embedding cognitive support objectives into structured activities.

From an embodied cognition perspective, the cognitive benefits of dance movement therapy for MCI older adults can be delineated across functional domains: repetitive learning of sequential motor patterns fosters memory and learning capacity; verbal comprehension, gestural prompting, peer communication and expressive feedback enhance linguistic function; synchronous coordinated movement following rhythmic cues, imitative tasks, turn-taking and collaborative group activities stimulate complex attention, executive function, social cognition and visuospatial processing [6]. Notably, these cognitive domains do not map onto discrete movement tasks in a one-to-one correspondence; rather, they are activated simultaneously and interdependently throughout therapeutic activities.

Informed by embodied cognition theory, dance movement therapy can systematically embed cognitive support objectives via kinesthetic, rhythmic, spatial and interactive modalities, laying the groundwork for subsequent intervention prescription design and field delivery. The closed-loop model further integrates this cognitive activation mechanism into a sequential five-stage cyclical workflow.

3. Construction of the AI-Enabled Closed-Loop Model for Dance Movement Therapy

The AI-enabled closed-loop dance movement therapy model encompasses five interconnected functional stages spanning pre-intervention, in-session and post-intervention phases: participant profiling and intervention prescription generation take place pre-intervention to establish individualised therapeutic protocols; on-site implementation embedding and real-time monitoring with early warning operate concurrently during delivery to execute customised programmes while maintaining safety thresholds; post-intervention feedback iteration aggregates procedural data, practitioner observational notes and participant feedback, feeding processed insights back to refresh participant profiles and revise subsequent intervention prescriptions, forming a cyclical operational system led by human practitioners with supplementary AI support.

3.1 Participant Profiling

The core objective of participant profiling is to synthesise heterogeneous individual characteristics into structured participant profiles based on preliminary clinical screening and assessment data. This module covers both initial baseline data collection prior to programme commencement and iterative profile updates post-feedback iteration, furnishing individualised reference metrics for prescription generation, digital auxiliary tool selection and longitudinal programme optimisation.

Profiling data is categorised into four core dimensions:

Physiological tolerance and risk indicators: physical stamina, fatigue susceptibility, physical discomfort and fall/balance hazards;

Personal preference and motivational factors: preferred musical genres, group interaction formats and activity environments;

Digital technology acceptance: willingness to utilise wearable devices, system prompts, real-time recording tools and human-machine interfaces, guiding the selection of compatible digital auxiliary strategies [7,8];

Cognitive functional status derived from clinical screening records.

Within this stage, practitioners first review available clinical cognitive screening materials, then conduct baseline semi-structured interviews and brief standardised assessments covering the four dimensions above, supplemented by input from family caregivers where necessary. The AI system integrates multi-source data to generate standardised participant profiles, which practitioners validate for data accuracy; verified profiles serve as the foundational individualised dataset guiding prescription drafting, digital auxiliary configuration and iterative programme adjustment. Importantly, practitioners undertaking this profiling role bear no responsibility for formal MCI clinical diagnosis.

3.2 Intervention Prescription Generation

The term “intervention prescription” herein does not refer to clinical medical prescriptions, but customised dance movement therapy activity frameworks tailored to each participant’s profile, constructed upon a pre-established age-friendly movement library. The movement library screens, categorises and stratifies motor content by difficulty level, aligning all movement materials with defined cognitive support targets and geriatric physical safety standards, providing core material resources for AI-assisted preliminary prescription drafting.

The AI system generates initial intervention prescriptions through three layers of profile matching:

Cognitive functional status matching: the system assigns movement difficulty tiers, proposing recommendations for motor element selection, movement sequencing, rhythmic pacing and spatial choreography to align activity content with designated cognitive support goals;

Physiological tolerance and risk matching: the system specifies scheduled rest intervals, temporary suspension triggers and emergency early termination criteria based on physical risk profiles;

Personal preference and motivational matching: the system proposes group interaction structures and musical selections aligned with participant taste and engagement drivers.

Practitioners subsequently conduct two tiers of review and contextual modification on AI-generated preliminary prescriptions:

Target alignment verification: screening, restructuring and revising recommended motor sequences to ensure consistent correspondence between movement tasks and cognitive support objectives;

Safety risk calibration: adjusting movement intensity load, developing alternative low-risk motor sequences and establishing emergency contingency protocols for physical hazards;

On-site contextual adaptation: refining musical accompaniment, group interaction formats and organisational structures to accommodate real-world delivery environments.

Finalised intervention prescriptions consist of two core components: detailed activity execution scripts and emergency safety contingency protocols. After practitioner revision, complete prescriptions are synchronised to the AI system as reference benchmarks for in-session implementation and real-time safety monitoring. A supplementary execution feedback form is developed alongside each prescription to standardise procedural recording and facilitate post-intervention feedback iteration (See Figure 1).

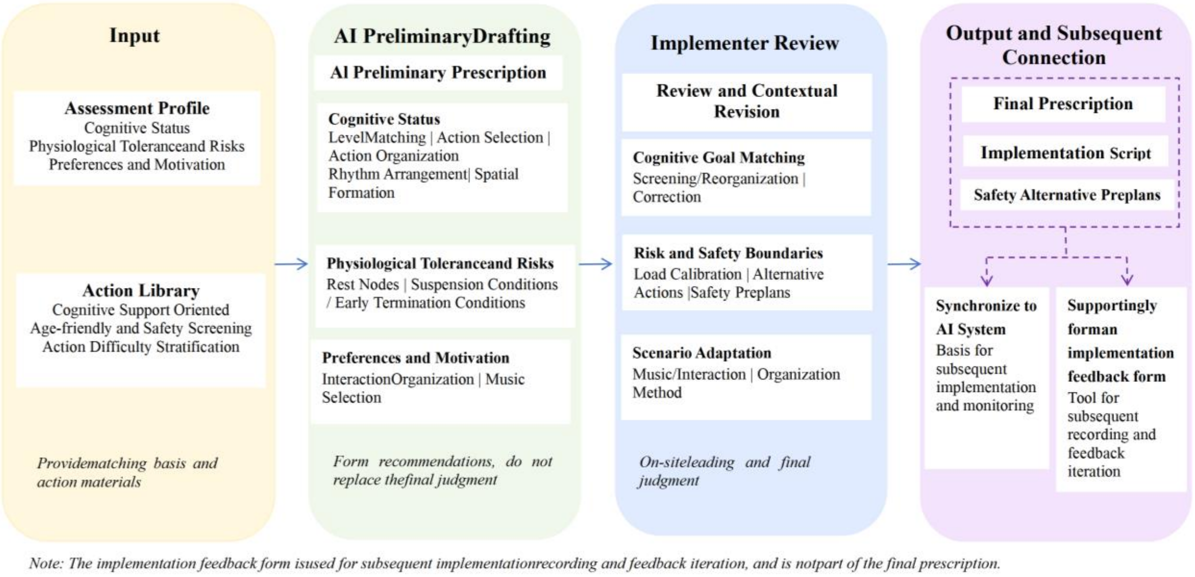

Figure 1: Flowchart of AI-powered dance therapy prescription generation process

Source: Original design by the authors

3.3 On-Site Implementation Embedding

The implementation embedding module translates formalised intervention prescriptions into tangible dance movement therapy activities, with its primary function ensuring consistent delivery of cognitive support requirements embedded within structured activity workflows. Practitioners lead group activities following standardised execution scripts, regulating overall session pacing responsively based on real-time participant performance. During delivery, wearable motion sensors and posture recognition technology capture continuous procedural data; referencing the validated intervention prescription, the AI system organises and archives all session records to form a complete dataset for subsequent feedback iteration. This module prioritises the consistent execution of cognitive support protocols and comprehensive procedural logging; identification of physical safety anomalies, risk alerting and emergency response protocols fall under the separate real-time monitoring and early warning module.

3.4 Real-Time Monitoring and Early Warning

During therapeutic sessions, the AI system continuously analyses real-time biometric and kinesthetic data collected via sensing devices, automatically flagging abnormal physiological indicators, excessive movement intensity and balance risk events as early warning alerts.

Practitioners integrate system notifications with direct on-site behavioural observation and immediate participant feedback to make comprehensive clinical judgements, implementing targeted interventions as required: extending scheduled rest periods, downgrading movement difficulty, activating pre-designed low-risk alternative motor sequences, temporarily pausing group activities or fully terminating sessions for high-risk participants.

3.5 Feedback Iteration

Serving as the concluding cyclical stage of the closed-loop model, feedback iteration updates participant profiles using complete intervention outcomes to inform subsequent prescription drafting. Within this module, the AI system aggregates all session data to summarise stable performance patterns, behavioural fluctuations and recurring safety risk events across each therapeutic cycle. Practitioners complete structured observational notes centred on cognitive functional performance and physiological risk responses, alongside brief qualitative feedback collected from participants regarding activity intensity, personal engagement preferences and satisfaction with digital auxiliary tools. All multi-source data is consolidated via the standardised execution feedback form, which serves as the decision-making basis for determining whether subsequent prescriptions should maintain current difficulty levels, advance to higher challenge tiers, regress to lower intensity or fully replace existing motor sequences. It should be clarified that the execution feedback form functions exclusively as a procedural recording tool, rather than a standardised clinical rating scale or therapeutic efficacy assessment instrument. Consolidated feedback data circulates back to the participant profiling module, updating records of cognitive functional status, physiological risk tolerance, personal motivational preferences and digital technology acceptance for each participant.

Collectively, the five functional stages operate as an interconnected synergistic system rather than isolated independent modules, embedding cognitive support objectives throughout the full dance movement therapy workflow and enabling iterative programme optimisation via outcome feedback circulation. Feedback iteration constitutes the core mechanism sustaining the closed-loop circulation by feeding post-intervention outcomes back to refresh participant profiles and adjust subsequent intervention prescriptions (See Figure 2).

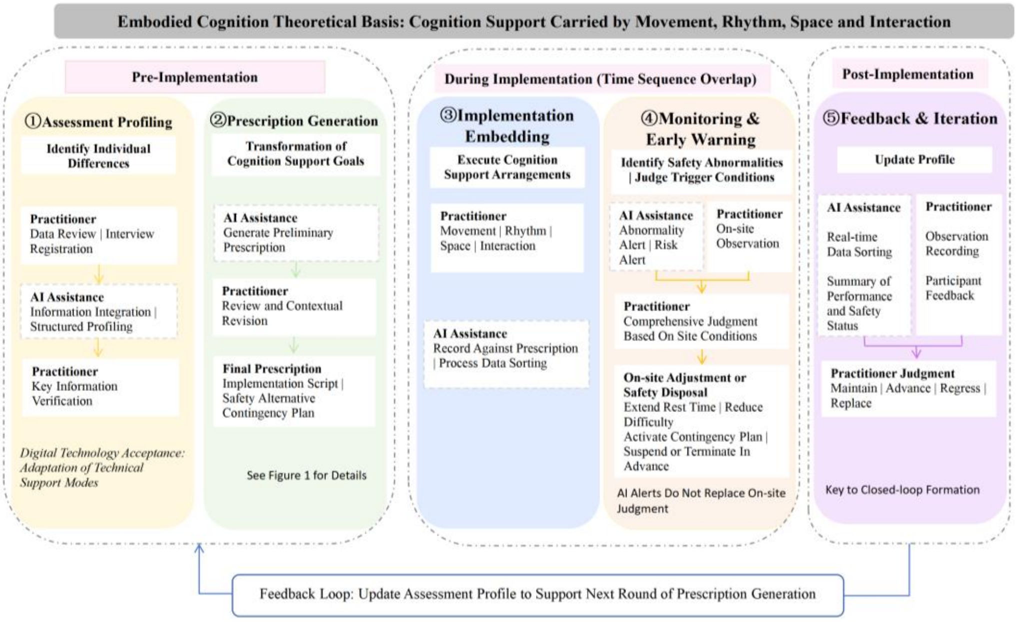

Figure 2: AI-Enabling Closed-Loop Model for Dance Therapy

4. Implementation Prerequisites and Governance Boundaries for Model Application

To deploy the AI-enabled closed-loop dance movement therapy model within real clinical and community settings, practitioners must satisfy specified staffing, procedural and technical prerequisites, while establishing clear governance boundaries covering age-friendly design, personal data governance and professional liability allocation.

4.1 Implementation Prerequisites

First, the model mandates streamlined procedural workflows. All practitioner documentation relies exclusively on the unified execution feedback form, avoiding redundant supplementary recording templates or repetitive administrative burdens. Digital auxiliary tools must serve practical therapeutic needs rather than impose excessive operational workloads on practitioners or elderly participants.

Second, the model supports flexible adaptation across diverse delivery contexts. High-cost sophisticated hardware or complex integrated digital systems are not designated as mandatory infrastructure; organisations select appropriate digital auxiliary modalities based on institutional resource availability, practitioner professional experience, group participant volume and individual MCI severity levels.

4.2 Governance Boundaries

Three core governance dimensions require formal regulation for model deployment: age-friendly digital design, personal data protection and professional liability delineation.

Age-friendly digital support frameworks: Elderly adults' willingness to engage with digital technology is shaped by interface usability, operational complexity and on-site human assistance availability [7]. Accordingly, all digital auxiliary tools integrated within the model adopt simplified, intuitive visual interfaces and streamlined operating procedures, with dedicated on-site staff providing one-on-one technical support for participants with limited digital literacy [8].

Data governance protocols: All data collection adheres to the principles of informed consent, data minimisation and restricted usage scope. Only data strictly necessary for participant profile updating, prescription iteration, safety risk identification and model operational functioning is collected and retained. All personal information processing, cross-module data circulation and analytical output utilisation comply with standard research ethics and formal data governance regulations.

Professional liability delineation: The AI system solely delivers auxiliary services including data integration, procedural archiving and risk alert notification, with all automated outputs treated as secondary reference materials for practitioner judgement. Critical clinical decisions including prescription modification, temporary session suspension and activation of emergency safety protocols remain the exclusive responsibility of on-site practitioners, who must reconcile system alerts with institutional safety standards and real-time participant status.

5. Conclusion and Future Research Outlook

Targeting the cognitive support demands of elderly adults with MCI, this study constructs an AI-enabled closed-loop dance movement therapy model grounded in embodied cognition theory and the structured procedural characteristics of dance movement therapeutic interventions. Composed of five sequential functional stages—participant profiling, intervention prescription generation, on-site implementation embedding, real-time monitoring and early warning, and feedback iteration—the model establishes a unified structured framework for embedding cognitive support objectives across pre-intervention preparation, in-session delivery and post-intervention optimisation workflows.

Several limitations of this theoretical research require acknowledgment: this study exclusively completes theoretical framework construction and operational mechanism elaboration, without developing detailed standardised activity protocols, stratified motor sequence libraries, formal intervention implementation trials or quantitative efficacy verification. Furthermore, this paper only defines the auxiliary functional positioning of AI across each model stage, without addressing specific software system development, algorithm engineering or multi-device sensing integration. Real-world deployment of the model, alongside its cross-setting applicability, remains subject to multiple contextual constraints including practitioner competency, institutional resource allocation, digital infrastructure maturity, age-friendly interface design, formal data governance frameworks and clear liability delineation. Subsequent empirical research must conduct iterative testing and structural optimisation of the model within authentic community and geriatric care delivery environments.

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