Extended Reality (XR) vs. Virtual Reality (VR) for Artificial Intelligence (AI)-Driven Balance Improvement in Older Adults

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***Abstract*—Balance impairment in older adults significantly increases fall risk, leading to decreased mobility, higher healthcare expenditures, and reduced quality of life. The emergence of rehabilitation technologies such as Virtual Reality (VR) and Extended Reality (XR), enhanced with Artificial Intelligence (AI), offers promising interventions to mitigate these risks. VR provides immersive, controlled environments suitable for structured rehabilitation programs, whereas XR integrates real-world scenarios, facilitating functional mobility training applicable in home and community settings. Despite their potential, evidence comparing the effectiveness, adaptability, and clinical applicability of AI-enhanced VR and XR interventions for balance rehabilitation remains limited. This rapid systematic review protocol outlines a structured approach to evaluating existing literature through comprehensive database searches, clearly defined inclusion criteria, and systematic narrative synthesis informed by the Metaverse Equitable Rehabilitation Therapy (MERTH) framework. The findings of this research will not only clarify the comparative advantages, barriers, and limitations of VR and XR technologies but also identify evidence-based best practices and propose recommendations to guide future clinical practice and technology development in balance rehabilitation for older adults. This research is crucial in shaping the future of rehabilitation for older adults and is of significant interest to the healthcare community.**

Keywords- Balance; Artificial Intelligence; Virtual Reality; Extended Reality; Aging; Fall Prevention; Older Adults; Review.

I. INTRODUCTION

Balance impairments among older adults present significant risks, including increased incidence of falls, reduced mobility, and a greater probability of hospitalization due to injuries [1]. As the global population ages, the potential of innovative technologies to enhance balance rehabilitation and mitigate fall risks among older adults is becoming increasingly clear [1]. Virtual Reality (VR) and Extended Reality (XR) are effective technologies that provide immersive, interactive, and engaging environments for tailored balance rehabilitation programs [2][3][4]. VR utilizes fully immersive, computer-generated environments to isolate users from real-world distractions, enabling structured and precisely controlled rehabilitation experiences. In contrast, XR technology combines real-world settings with virtual augmentations, providing a hybrid environment that supports functional and context-driven rehabilitation exercises relevant to daily activities [2]. The integration of Artificial Intelligence (AI) further enhances these technologies, enabling personalized exercise programs, real-time movement analysis, adaptive feedback, and dynamic adjustment of exercises tailored to individual performance and needs [5]. Despite their potential, VR and XR's comparative effectiveness, adaptability, and clinical applicability within AI-enhanced balance rehabilitation interventions have not been sufficiently studied. This abstract summarizes a proposal to conduct a rapid, systematic review of recent literature to evaluate and compare the effectiveness, adaptability, and clinical utility of VR and XR technologies integrated with AI for balance rehabilitation among older adults. The goal is to identify the optimal technology for improving balance and reducing fall risk across different environments. The structure of the paper is as follows: Section II details the methodology used to perform this rapid review, including search strategy, inclusion and exclusion criteria, data extraction processes, and quality assessment considerations. Section III outlines the planned synthesis and presentation of results, including the comparison criteria of effectiveness, adaptability, and clinical applicability. Section IV discusses how the findings from this review can inform the design and implementation of future AI-enhanced VR and XR rehabilitation programs. Finally, Section V presents the conclusion, summarizing key understandings, identifying existing gaps in the current literature, and proposing future research to improve technology-enhanced balance rehabilitation interventions for older adults.

II. METHODS

This rapid systematic review will utilize the Population, Intervention, Comparison, and Outcomes (PICO) framework [6] to define the study's scope, clearly identifying the population, intervention, comparison, and outcomes of interest. Specifically, the population includes older adults ($\geq$ 65 years) experiencing balance impairment or increased fall risk. Compared with traditional or non-AI-assisted rehabilitation methods, the interventions under consideration are AI-enhanced Virtual Reality (VR) and Extended Reality (XR) rehabilitation technologies. The outcomes assessed include balance improvement, fall risk reduction, personalized adaptation, pa-

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tient engagement and compliance, clinical feasibility, cost-effectiveness, and sustained functional gains.

To guide a comprehensive analysis, the review will apply the Metaverse Equitable Rehabilitation Therapy (MERTH) framework [7], which consists of five domains: Equity, Health Services Integration, Technological Adaptation, Global Governance, and Humanization, each domain is further divided into relevant subdomains (Figure 1). The MERTH framework will ensure that the systematic review addresses critical issues of accessibility, inclusivity, diversity, fairness, cultural relevance, adaptability, clinical feasibility, patient engagement, and the broader ethical considerations of implementing VR and XR rehabilitation interventions in clinical practice.

A systematic literature search will be conducted in several databases, such as PubMed, Scopus, and IEEE Xplore, focusing on peer-reviewed studies published within the past five years. The search will specifically target studies evaluating AI-driven VR or XR balance rehabilitation interventions compared to traditional rehabilitation programs or those without AI enhancements. Data extraction will focus on intervention characteristics (exercise programs, real-time movement analysis, adaptive feedback, and dynamic adjustments tailored to individual performance and needs), study design, patient demographics, and outcomes (Table I).

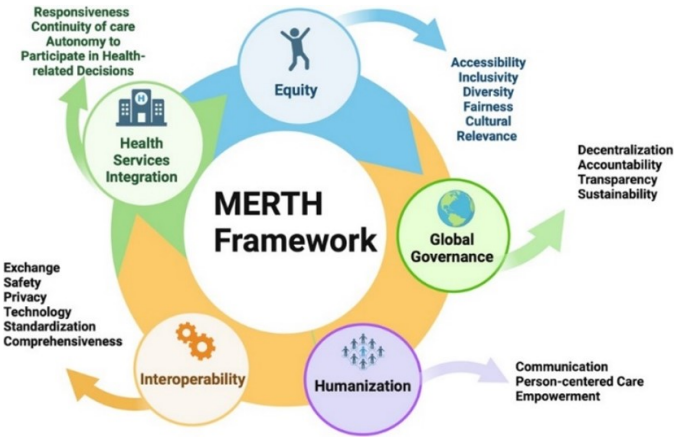

Figure 1: Metaverse Equitable Rehabilitation Therapy (MERTH) framework.

A. *Screening and Data Extraction*

Two independent reviewers will conduct study screening, full-text review, data extraction, and quality assessment, guided by the predefined categories of the MERTH framework and the PICO structure. In discrepancies, consensus will be sought through reviewer discussion, with the involvement of a third reviewer when necessary. Data extracted will include key study characteristics such as AI tools used, intervention type (VR or XR), study population, research design, measured outcomes, and primary results. A standardized extraction template will document additional data on study settings, sample characteristics, and methodological rigor. Equity, ethics, safety, confidentiality, and privacy considerations associated with AI-driven rehabilitation interventions will also be evaluated systematically. Extracted data will be managed and coded using the Covidence Software [8], facilitating comprehensive and accurate analysis.

TABLE I: POTENTIAL OUTCOMES IN VR AND XR AI-DRIVEN BALANCE REHABILITATION.

Outcome	Description	Measurement/Indicator
Balance Improvement	Assess the impact of VR and XR technologies on postural stability, fall prevention, and functional balance in older adults.	Berg Balance Scale (BBS), Timed Up and Go (TUG) test, Functional Reach Test (FRT), reduction in fall frequency.
Personalized Adaptation	Evaluate how effectively VR/XR technologies tailor rehabilitation exercises based on individual motor function, cognitive status, and progression.	AI-driven progression metrics, modified exercise difficulty levels, user-reported adaptability via standardized questionnaires (e.g., System Usability Scale)
Clinical Feasibility	Determine the practicality of implementing VR/XR in rehabilitation, long-term care, and home rehabilitation settings.	Healthcare provider feedback (standardized surveys), cost-effectiveness analysis, adherence rates in real-world use
User Engagement and Compliance	Measure patient engagement, motivation, and VR/XR rehabilitation protocol adherence.	Participant-reported engagement scores (e.g., Intrinsic Motivation Inventory), session completion rates, dropout rates
Cost-effectiveness	Compare the financial viability of VR/XR-based rehabilitation against traditional rehabilitation interventions.	Cost-benefit analysis, direct treatment costs, healthcare savings from fall prevention
Sustained Functional Gains	Assess long-term retention of balance and mobility improvements post-intervention.	Follow-up assessments at 6 months and 1 year using BBS, TUG, Activities-specific Balance Confidence (ABC) scale, incidence of falls

B. *Assessment of the Risk of Bias (RoB)*

Two reviewers will independently assess the Risk of Bias (RoB) of the included systematic reviews and primary studies. Discrepancies between reviewers will be resolved through discussion. For the systematic reviews, the AMSTAR-2 Checklist [9] will be applied, evaluating critical methodological domains, including eligibility criteria, comprehensiveness of literature searches, data extraction, quality of study appraisal, and clarity of findings synthesis. Each domain will be categorized as having low, unclear, or high RoB. For primary studies, randomized controlled trials (RCTs) will be assessed using the Cochrane Risk of Bias 2 (RoB 2) tool [10], and observational or non-randomized studies will be evaluated using the Risk of Bias in Non-randomized Studies of Interventions (ROBINS-I) tool [11].

III. RESULTS

Findings from this rapid review will be narratively synthesized following the five domains of the MERTH framework,

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encompassing equity, integration of health services, technological adaptation, global governance, and humanization. Results will systematically evaluate AI-enhanced VR and XR rehabilitation interventions' effectiveness, adaptability, clinical applicability, and equity considerations. Subgroup analyses will explore variations according to population characteristics (e.g. age, gender, socioeconomic status), intervention types (exercise programs, assessment tools, gamification strategies), and equity dimensions (accessibility, inclusivity, cultural relevance). The review will highlight strengths, limitations, implementation barriers, and equity issues aligned with MERTH domains, ensuring a comprehensive assessment. The reporting will follow the PRISMA-AI [12] guidelines to maintain rigor, transparency, and clarity.

IV. Discussion

The methodology of this rapid systematic review presents potential challenges that can affect the feasibility, data reliability, and overall strength of the findings. One limitation is the availability and quality of existing literature, as AI-enhanced VR and XR applications for balance rehabilitation remain an emerging field with limited high-quality randomized controlled trials. Many studies may have small sample sizes, inconsistent methodologies, or lack rigorous comparative analysis between VR, XR, and traditional rehabilitation approaches. Standardizing outcome measures remains challenging since researchers use varied clinical tools, motion analysis systems, and patient-reported outcomes to assess balance improvement and fall risk reduction, complicating data synthesis across studies. Risk of bias assessment can highlight inconsistencies, particularly in non-randomized studies, where uncontrolled factors such as participant adherence, therapist involvement, or environmental settings may influence intervention effects. Relying on databases such as PubMed, Scopus, and IEEE Xplore can also introduce publication bias by underrepresenting studies with negative or neutral findings. Feasibility concerns affect AI-driven VR and XR interventions' broader clinical and real-world applicability. These technologies perform well in controlled environments, but cost, accessibility, clinician training, and patient adoption create barriers to real-world implementation. The team applies its expertise in knowledge synthesis to rigorously mitigate these challenges.

V. Conclusion and Future work

This rapid review protocol summarizes a methodology to systematically evaluate the integration of AI with Virtual Reality and Extended Reality technologies in balance rehabilitation interventions for older adults. The synthesis of current evidence will clarify these technologies' comparative effectiveness, adaptability, feasibility, and clinical applicability. Furthermore, the review will identify the strengths, limitations, and implementation barriers of VR and XR interventions, explicitly addressing equity considerations guided by the MERTH framework. The findings from this analysis will help guide future research, inform clinical practice, and support the development of equitable, accessible, and evidence-based rehabilitation interventions to reduce fall risks and enhance functional mobility among older adults.

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