Alayidi *et al. Journal of NeuroEngineering and Rehabilitation* (2025) 22:75
https://doi.org/10.1186/s12984-025-01612-0

Journal of NeuroEngineering and Rehabilitation

REVIEW **Open Access**

Exploring balance control mechanisms in people with multiple sclerosis in virtual reality environment: a systematic review

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Abstract

Background Multiple sclerosis (MS) impairs balance control, affecting mobility and quality of life. Virtual reality (VR) offers a novel way to study balance mechanisms and potential rehabilitation. This review examines balance control in MS patients using VR, comparing responses in VR and non-VR settings with those of healthy controls.

Methods This systematic review adhered to PRISMA guidelines. Comprehensive searches were conducted across databases including PubMed, Web of Science, Scopus, CINAHL, and ScienceDirect. Studies involving individuals with MS were analyzed to explore population characteristics and types of VR environments employed. Data extraction focused on participant demographics, clinical profiles, VR configurations, and reported outcomes.

Results The potential value of VR training in this population was explored via systematic review. 23 studies highlighted the potential of VR environments to explore balance mechanisms in MS. Diverse VR types, ranging from immersive to semi-immersive systems, were used to assess postural control, functional balance outcomes, gait, and mobility. Despite variability in methodologies and reported outcomes, changes in functional measures such as gait and balance were frequently observed. This variability underscores the need for standardized protocols to enhance the comparability and application of VR in MS rehabilitation.

Conclusion This systematic review highlights the variability in assessed balance response outcomes in PwMS.

Keywords Balance control mechanisms, Multiple sclerosis, Postural balance, Postural control, Virtual reality

Background

Multiple sclerosis (MS) is a neurodegenerative inflammatory condition that affects the central nervous system (CNS) [1]. It affects more than 2.8 million individuals globally and is typically diagnosed between the ages of 20 and 40 years [2, 3]. Over 13,000 people with MS (PwMS) are estimated to be living in the United Kingdom, where nearly 7,000 new diagnoses are made each year [4]. Balance impairment affects up to 80% of individuals with MS [5]. This can significantly undermine quality of life (QoL) and lead to difficulties in walking, falls, and social isolation [6–8].

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Achieving and maintaining balance in the lives of individuals with multiple MS requires a nuanced understanding of the multifaceted disruptions caused by the disease. In this context, balance encompasses not only physical stability but also the integration of physical, cognitive, emotional, and social dimensions of well-being [9]. Demyelination and neurodegeneration within the CNS pathways disrupt motor coordination, sensory processing, and vestibular function in MS [3, 10]. These disruptions lead to common impairments such as muscle weakness, spasticity, sensory deficits, visual disturbances, and fatigue, all of which contribute to significant balance problems [11]. Balance impairment affects up to 80% of individuals with MS [5]. This can significantly undermine quality of life (QoL) and lead to difficulties in walking, falls, and social isolation [6–8]. To understand the balance in the lives of individuals with MS, it is essential to consider the multidimensional disruptions caused by the disease. MS disrupts this equilibrium through chronic fatigue, mobility challenges, and physical limitations that constrain participation in daily activities.

Balance is not uniformly affected in PwMS [5]. Variability arises from differences in disease progression, whether relapsing-remitting or gradually progressive, as well as the heterogeneity among MS subtypes. This heterogeneity reflects the impact of neurodegeneration-related deficits on key neurological centers responsible for balance regulation [5]. To fully understand the adverse impact of MS on balance [12–14], it is essential to evaluate the mechanisms that maintain postural stability and examine how the disease process disrupts them [15].

Balance deficits among PwMS can have considerable, wide-ranging impacts on their functioning and well-being [16], interfering with functional gait and daily activities. These challenges often lead to limited mobility, restricting access to diverse family and social activities and diminishing overall quality of life [17]. Approaches to rehabilitation and balance training have shown some success in PwMS, by reducing both the severity of symptoms and disease progression [14]. VR has been recognized as a potentially advantageous approach for facilitating rehabilitation in people with movement disorders [17, 18], and VR has the potential to create physical spaces in a virtual setting. It allows flexibility in joint mobility and movement patterns, while controlling for visual stimuli in an immersive environment, which has obvious advantages for rehabilitation [19, 20]. The degree of immersion available with VR can vary from minimally/nonimmersive to fully immersive, depending on the degree to which the senses (e.g., vision) may be stimulated by the external environment (rather than the VR environment per se) [21]. As PwMS have cognitive and motor deficits, fully immersive VR has the potential to provide additional benefits in movement control during rehabilitation. This has made it an attractive approach in practice [21].

Studies have shown that the use of VR in a balance training program significantly improved balance and mobility in PwMS, reduced falls [22], and improved gait, and QoL [23, 24]. Although such findings suggest that the use of VREs holds promise in evaluating balance control in PwMS, there is a lack of consensus on optimal evaluation methods [24, 25].

Previous systematic literature reviews have indicated that VR rehabilitation offers potential benefits in the management of MS [23, 26–31]; however, its efficacy as compared with traditional rehabilitation and the optimal features of VR programs remain unclear [19, 20]. Despite its promising potential, how individuals with MS control their balance in virtual reality environments (VREs) compared to conventional settings remains unclear. Understanding these differences could shed light on balance control mechanisms in MS, help explain variabilities observed in intervention studies, and inform the development of more effective, tailored rehabilitation strategies.

This systematic review, registered in the PROSPERO database (CRD42023363516), aims to address this gap by comparing balance responses in PwMS operating within VREs and non-VREs. Additionally, it will evaluate these responses in comparison to healthy controls, analyzing the clinical significance of VR's impact on balance and its potential for assessment and rehabilitation in this population.

Methods

Search strategy

A systematic search was conducted using the following journal databases: MEDLINE (OVID), EMBASE (OVID), AMED (OVID), CINAHL, Scopus, and Web of Science. The search covered studies published between 1996 and 29 October 2024. The PICO model guided the search strategy, defining 'MS' as the population, 'VR' and 'exergaming' as the intervention, and 'balance,' 'postural control,' 'postural,' and 'balance response' as the outcomes. These terms were systematically combined across databases to ensure comprehensive literature coverage [32]. The detailed MEDLINE search strategy is provided in [Additional File 1], and the same approach was applied across all the databases to minimize bias [33]. No specific comparison was set, allowing for a broad evaluation This review examines balance responses in PwMS operating within VREs and non-VREs and, where applicable, compares these responses to those of healthy controls. The research question guiding this review is: 'How do VR and exergaming influence balance and postural control in PwMS, and how do these responses compare between VREs and non-VREs, as well as with HCs?'.

Eligibility criteria

Studies fulfilling the following criteria were considered eligible for inclusion: (1) those that required participants (male or female) to be aged at least 18 years and have a formal diagnosis of MS according to the McDonald criteria [34, 35], (2) those including any form of VR with varying degrees of immersion that were aimed at evaluating balance responses in PwMS, (3) those that required balance responses to be evaluated in both static and dynamic contexts, and (4) those that explored the mechanism of action of VR in influencing balance responses. Studies were excluded if they were not available in English, were not in full-text format, used a non-MS population, or failed to use VREs as a treatment strategy.

Study selection

The search results were imported into the EndNote reference management software package (desktop version X9) to organize the references and eliminate duplicates. Two independent reviewers completed the search in the designated databases and used a systematic approach to refine the data according to the PRISMA statement [36]. The articles were refined sequentially based on the content of their titles and abstracts; full-text evaluation was then performed to confirm adherence to the designated inclusion criteria. In cases of disagreement, a third reviewer was consulted to resolve the issue regarding inclusion. The final dataset then underwent quality appraisal and formal data extraction and synthesis.

Data extraction

Data extraction was performed using a tabulated approach; a specially modified spreadsheet based on the recommendations of the Cochrane Handbook for Systematic Reviews of Interventions was used. The key data included the details of the study population, intervention approach, outcome measures, and findings reported [33, 37]. The data relating to variables of interest were extracted on the basis of the condition of assessment. Two independent reviewers performed the data extraction in to decrease subjectivity of the findings and interpretations [33, 37].

Methodological quality assessment

A quality appraisal was conducted using the Physiotherapy Evidence Database (PEDro) scale [38] and the Revised Cochrane Risk-of-Bias Tool for Randomized Trials (RoB 2) [33]. These tools were chosen for their reliability in identifying bias in randomized study designs and their ability to assess study suitability for inclusion, minimizing bias in the review [37].

The PEDro scale consists of 11 items evaluating the internal validity of clinical trials [37, 39]. Studies with scores above 6 are classified as Level I evidence (6–8: good; 8–10: excellent), whereas those with scores below 5 are classified as Level II evidence (4–5: deficient; < 4: poor). The classification was based on a consensus between the reviewers [38].

The RoB 2 tool assesses bias in five domains: randomization, deviations from intended interventions, missing data, outcome measurement, and reporting bias. It categorizes risk as low, high, or with some concerns [37].

Data analysis and synthesis

A narrative synthesis was conducted to interpret and integrate findings across the included studies, with a focus on key themes and patterns within the data. This approach provided a structured framework for describing the variability in outcomes and methodological differences between studies. Given the diversity in variables and measurement tools used to assess balance control, a narrative approach allowed for a detailed exploration of commonalities and differences across studies. This method has been recommended as a transparent and rigorous alternative when statistical meta-analysis is not feasible or appropriate, particularly to minimize bias and ensure reliable conclusions [37, 39].

The synthesis identified variability in the methods and outcomes reported, highlighting challenges in direct comparisons. Key themes emerged, such as differences in balance control between PwMS and healthy controls (HCs), the impact of study-specific conditions, and the range of tools used to evaluate balance. While heterogeneity was notable across studies, the narrative approach enabled a more generalized interpretation of findings by accounting for the variability in populations, interventions, and settings. The use of rigorous methods to explore this heterogeneity is essential to ensure the robustness of conclusions [37, 39].

By synthesizing results narratively, the study provided valuable insights into balance control differences without relying solely on statistical comparisons. This approach facilitated a deeper exploration of the context and nuances of the findings, offering a more interpretative and descriptive analysis of the dataset [37, 39].

Results

Search results

The initial search strategy identified 1754 citations across all the databases; after removing duplicates, 1423 citations remained. Following a thorough evaluation, only 23 studies were included in the final dataset. Figure 1 illustrates the process of screening of the studies based on the PRISMA criteria [36]. A total of 21 studies adopted an RCT design; 2 were experimental studies with no control groups. The studies were conducted in different nations including the United States ($n = 5$), Italy ($n = 4$), Iran

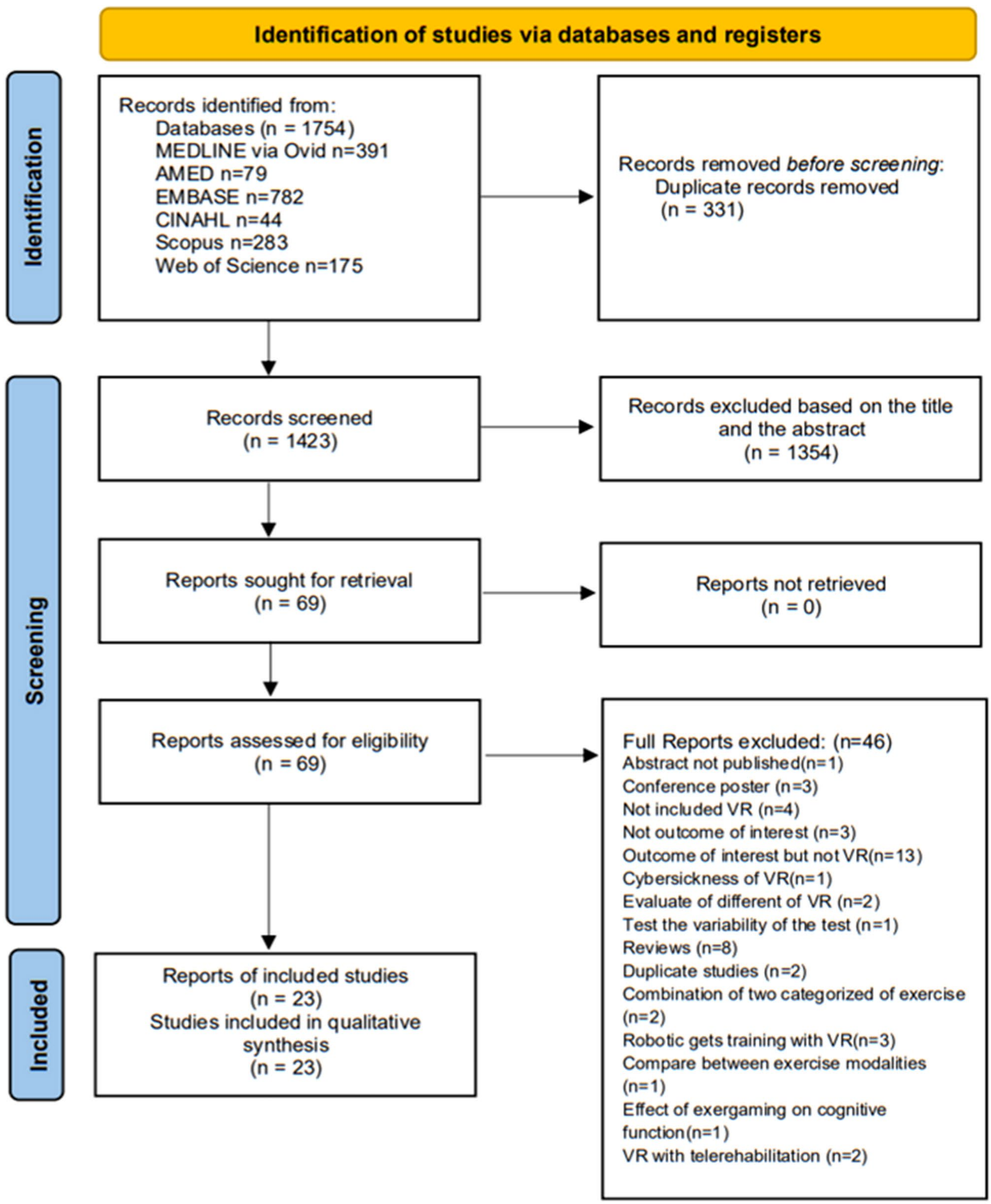

Fig. 1 PRISMA flow diagram of study selection process [36]

($n = 2$), Spain ($n = 2$), Turkey ($n = 2$), and various other countries (with a single study each).

Methodological quality assessment

The PEDro scale was used to assess the quality of 23 studies (Table 1); the scores ranged from 3 to 8, with an average value of 5.91. A total of 14 and 9 studies were classified as level I evidence (fair to excellent) [40–53] and level II evidence (fair) [54–62], respectively.

In this context, it is important to note at the outset that these scores indicate relatively low-quality studies. Most of the studies had a low risk of selective reporting bias; however, a high risk of bias was observed in the blinding of participants/assessors and analysis (reporting bias) domains in most studies. Figures 2 and 3 show the summary and study-by-study risk of bias, respectively. Although the reviewers had occasional disagreements regarding domain 2, a consensus was always reached.

Population characteristics

PwMS

The number of included PwMS ranged from 6 to 42 per study, with a total of 453 participants across all studies; the number of HCs ranged from 5 to 42, with a total of 355 participants across all studies. The reported ages of the PwMS and HCs were 38.6 ± 3.5 years and 36.5 ± 4.1 years, respectively, representing the mean ± SD for each group. All studies included male and female participants; however, they were not distributed equally (263 and 570 participants, respectively). This reflected the higher prevalence of MS among females (the ratio in this cohort was 2.17:1). The mean Expanded Disability Status Scale score for PwMS was reported by most of the included studies and ranged from 1 to 6. The mean duration of MS ranged from 8 to 24 years across the studies that reported this characteristic.

MS phenotypes

Except for nine studies that did not specify the MS phenotype, all included patients with the relapsing-remitting type [43, 45, 53, 54, 56, 58, 59, 61, 62]. Only two studies included participants with all MS phenotypes [42, 60], whereas the others included those with certain types. Although these studies implicitly included other MS phenotypes, they were not necessarily represented to the same extent. As certain phenotype populations were either over- or under-represented, it is possible that these studies had potential selection bias.

VR characteristics and types

The VR systems utilized in the studies varied in type, immersion level, and setting. The majority of studies have used non-immersive systems, such as the Nintendo Wii Fit™ [40–43, 45, 53, 55, 57–60], Xbox Kinect™ [50, 51, 54], BIODEX Balance System [44] and home video game-based VR setups [46]. In contrast, immersive systems were used in only two studies, including the CAREN VR platform [47] and Oculus VR [53]. Treadmill-based VR systems have also been implemented in some studies [48, 50, 52, 61, 62]. Overall, non-immersive VR systems were more commonly utilized, whereas immersive systems, despite their potential for greater sensory engagement, were used in fewer studies.

Narrative synthesis

Six main themes emerged from the analysis of findings, reflecting the primary reported outcomes of balance mechanisms in PwMS compared with HCs within both VR and non-VR contexts: (1) postural control; (2) functional balance outcomes; (3) the role of VR in postural control and functional balance outcomes; (4) sensory integration strategies; (5) gait and mobility outcomes; and (6) patient experience, safety, and adverse events in VR environments for PwMS.

The results highlight the variability in adaptive responses across tasks, with VR environments uniquely engaging the sensory and motor systems in PwMS. Mechanisms of balance control were explored, revealing how sensory integration, motor coordination, and adaptive strategies differ between individuals. While some PwMS demonstrate effective compensatory mechanisms, others face challenges in integrating sensory feedback and coordinating motor responses, particularly during dynamic tasks. These findings emphasize the importance of understanding how task-specific demands and individual characteristics influence postural control, functional performance, and mobility mechanisms within both VR and non-VR settings.

Postural control

Postural control under static balance conditions was evaluated through postural sway variability and Centre of Pressure (CoP) measurements. Robinson et al. [45] reported significantly larger anterior-posterior (AP) and mediolateral (ML) sway ranges in PwMS during VR tasks than in those during conventional tasks ($p = 0.04$), indicating that VR environments pose additional challenges to postural stability under static conditions. Similarly, Kalron et al. [47] reported greater CoP path lengths during eyes-open VR tasks than during non-VR tasks ($p < 0.05$), reflecting a compensatory reliance on visual feedback to maintain stability.

Contrasting findings were observed by Pau et al. [58], who demonstrated reductions in sway variability following VR exposure, suggesting adaptive postural strategies in PwMS. In addition, Shahnewaz et al. [53] reported no significant differences in CoP path lengths between PwMS and HCs during static VR conditions, indicating

Table 1 Assessment based on PEDro scale items

Study	1	2	3	4	5	6	7	8	9	10	11	Score (/10)
[40] Nilsagård et al. (2012)	Y	Y	Y	Y	N	N	Y	Y	N	Y	Y	7
[41] Prosperini et al. (2013)	Y	Y	Y	Y	N	N	Y	Y	N	Y	Y	6
[42] Prosperini et al. (2014)	Y	Y	Y	Y	N	N	Y	Y	N	Y	Y	8
[43] Brichetto et al. (2015)	Y	Y	Y	Y	N	N	Y	N	Y	Y	Y	7
[44] Eftekharsadat et al. (2015)	Y	Y	N	Y	N	N	Y	Y	N	Y	Y	6
[45] Robinson et al. (2015)	Y	Y	Y	Y	N	N	N	N	Y	Y	Y	8
[46] Hoang et al. (2016)	Y	Y	Y	Y	N	N	Y	Y	Y	Y	Y	7
[47] Kalron et al. (2016)	Y	Y	Y	Y	N	N	Y	Y	N	Y	Y	7
[48] Peruzzi et al. (2017)	Y	Y	Y	Y	Y	N	Y	Y	N	Y	Y	8
[49] Khalil et al. (2019)	Y	Y	Y	Y	Y	N	N	N	N	Y	Y	6
[50] Ozdogar et al. (2020)	Y	N	Y	Y	N	N	N	Y	Y	Y	Y	6
[51] Selgrade et al. (2020)	Y	N	N	Y	N	Y	N	Y	N	Y	Y	6
[52] Molhemi et al. (2021)	Y	Y	N	Y	N	N	N	N	Y	Y	Y	8
[53] Shahnawaz et al. (2021)	Y	Y	Y	Y	N	N	N	Y	Y	Y	Y	8
[54] Karlon & Frid (2012)	Y	N	N	Y	N	N	N	N	N	N	Y	3
[55] Gutiérrez et al. (2013)	Y	N	N	Y	N	N	Y	Y	Y	Y	Y	6
[56] Kramer et al. (2014)	Y	N	N	Y	N	N	N	Y	Y	Y	Y	5
[57] Lozano-Quilis et al. (2014)	Y	Y	N	Y	N	N	N	Y	N	Y	Y	5
[58] Pau et al. (2015)	Y	N	N	Y	N	N	N	N	Y	N	Y	3
[59] Novotna et al. (2019)	Y	n.r	n.r	y	N	N	n.r	Y	Y	N	Y	4
[60] Yazgan et al. (2020)	Y	Y	N	Y	Y	N	N	Y	N	Y	Y	5
[61] Riem et al. (2021)	Y	N	N	Y	N	N	N	n.r	n.r	Y	Y	4
[62] Riem et al. (2022)	Y	N	N	Y	N	N	N	n.r	n.r	Y	Y	4

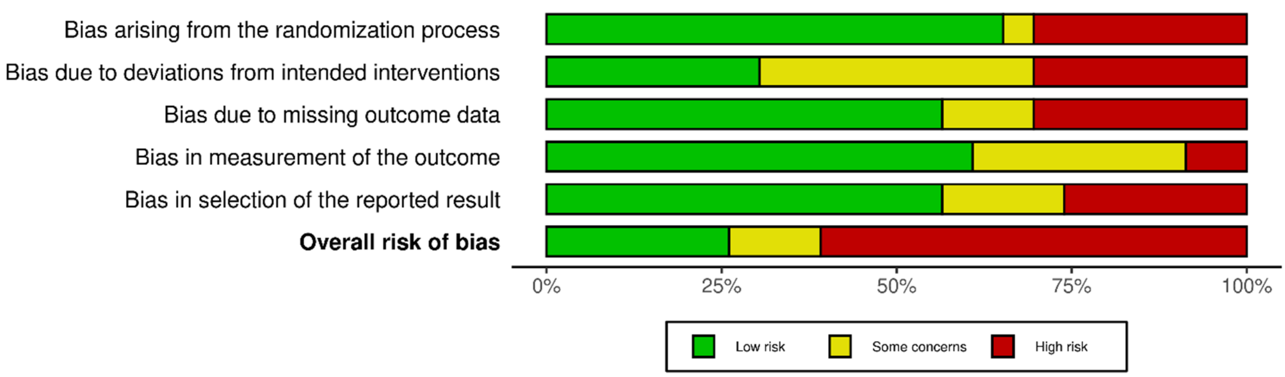

Fig. 2 Risk of bias summary [33]

that compensatory mechanisms might enable PwMS to achieve stability comparable to that of HCs under specific tasks. These mixed findings highlight the variability in postural responses across studies and suggest that VR environments engage sensory and motor systems differently in PwMS.

Overall, these findings highlight the heterogeneous nature of static and dynamic postural control mechanisms in PwMS during VR tasks. While some individuals demonstrate impairments in sensory integration, others exhibit adaptive strategies under certain conditions, emphasizing the need for further research to explore the factors influencing postural control variability in dynamic VR environments.

COP path length

The assessment of CoP path length across five studies [41, 42, 45, 47, 53] provides valuable insights into the postural stability mechanisms employed by PwMS and HCs in VR environments. While findings suggest that PwMS and HCs achieve similar levels of stability in VR conditions, the underlying strategies facilitating this stability appear to differ. For example, Kalron et al. [47] reported that PwMS demonstrated longer CoP path lengths in VR tasks than in non-VR tasks, indicating a compensatory reliance on visual input to maintain balance. This reliance suggests that VR environments uniquely engage the sensory systems of PwMS, potentially compensating for deficits in proprioceptive or vestibular functions.

Conversely, Shahnewaz et al. [53] reported no significant differences in CoP path lengths between PwMS and HCs during similar VR tasks, implying that under specific conditions, PwMS can achieve comparable stability to HCs. These mixed findings highlight the variability in postural strategies adopted by PwMS, which may be influenced by task-specific demands and individual differences in sensory integration. VR environments appear to provide PwMS with additional feedback mechanisms to maintain balance, potentially reflecting their ability to adapt to sensory and motor challenges. However, further research is needed to explore these differences in response mechanisms and to better understand how VR settings influence postural stability in PwMS.

Functional balance outcomes

Functional balance outcomes were assessed using several clinical measures, as follows: the Berg Balance Scale (BBS) [43, 44, 47–49, 51, 52, 55, 57, 59, 60], Timed Up and Go (TUG) test [40, 44, 48, 49, 52, 57, 59, 60], Functional Reach [47, 54], Six-Minute Walking Test (6MWT) [46, 52, 60], Four Step Square Test (FSST) [40, 41, 47, 48, 54], Activities-Specific Balance Confidence (ABC) scale [40, 50, 52, 53, 59], and Tinetti Balance Test [55, 57]. The majority of these studies reported significantly poorer outcomes on these clinical measures for PwMS than for HCs. These standardized assessments provide objective insights into the balance and mobility deficits characteristic of PwMS.

The BBS and TUG tests have been widely used across studies to evaluate functional balance. Yazgan et al. [60] observed significant differences in BBS scores ($p < 0.001$) and TUG performance ($p = 0.005$) between PwMS and HCs during VR tasks. Kalron et al. [47] reported higher functional reach scores in PwMS than in HCs ($p = 0.009$), indicating differential sensory feedback engagement. Contrasting findings were noted by Robinson et al. [43], who found no significant differences in BBS scores between PwMS and HCs under both VR and non-VR conditions. Similarly, Eftekharsadat et al. [44] highlighted variability in TUG performance, with outcomes influenced by task-specific demands. Yazgan et al. [60] also reported significant changes in BBS scores ($p < 0.001$) and TUG performance ($p = 0.005$) among PwMS following tasks in VR environments, suggesting distinct adaptations in balance responses. Eftekharsadat et al. [44] further reported reduced TUG completion times ($p = 0.01$) and changes in the Fall Risk Index ($p = 0.002$) among PwMS engaged in VR tasks.

Contrasting results were reported by Robinson et al. [43], who reported no differences in BBS scores between

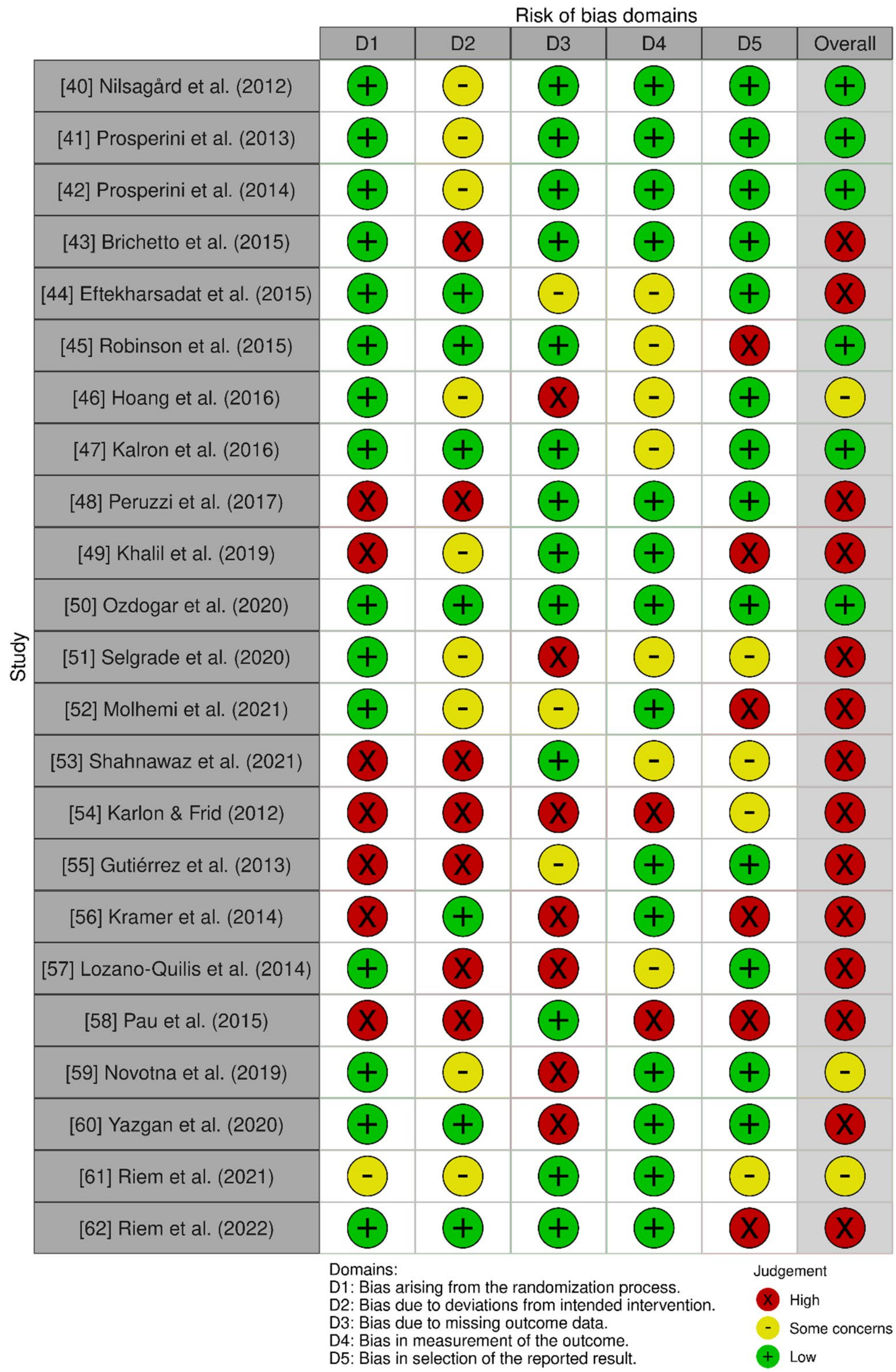

Fig. 3 Risk of bias types across all included studies [33]

tasks conducted in VR and non-VR conditions. Kalron et al. [47], using functional reach testing, noted differences in functional reach scores between PwMS and healthy controls ($p = 0.009$), suggesting that VR conditions may influence sensory feedback engagement in PwMS differently from that in controls.

Dynamic balance assessments highlighted variations in how PwMS respond under different conditions. Studies using the Tinetti test revealed differences in postural responses between VR and non-VR settings ($p = 0.003$), indicating that VR environments may elicit unique postural adjustments. The results from the TUG test also varied. Eftekharsadat et al. [44] reported altered mobility responses during VR tasks, whereas Novotna et al. [57] reported more consistent outcomes in non-VR tasks. Another study [48] described distinct balance and walking patterns in tasks involving VR conditions, showing task-specific adaptations.

Comparisons between PwMS and healthy controls revealed that both groups achieved similar balance outcomes in VR tasks, although the underlying mechanisms differed. PwMS appears to rely more on visual feedback to stabilize posture, potentially compensating for sensory deficits. The variability across these findings reflects differences in task demands, participant characteristics, and VR settings. Further research is needed to better understand the sensory and motor adjustments employed by PwMS in VR conditions.

Functional balance measures, including the BBS and the TUG test, are widely utilized to assess balance performance under VR conditions. Yazgan et al. [60] reported significant improvements in BBS scores ($p < 0.001$) and TUG performance ($p = 0.005$) following VR tasks, highlighting the ability of PwMS to adapt their functional balance responses in VR settings. Similarly, Eftekharsadat et al. [44] noted significant reductions in TUG completion times ($p = 0.01$) and improvements in the Fall Risk Index ($p = 0.002$) among PwMS.

In contrast, Robinson et al. [43] reported no significant differences in balance performance between VR and non-VR tasks, suggesting that adaptive improvements in functional balance outcomes may be task-specific or participant-dependent. Compared with control, functional reach testing also revealed significant improvements in VR tasks, with Kalron et al. [47] reporting superior functional reach scores in PwMS ($p = 0.009$).

Studies investigating dynamic balance and mobility in individuals with PwMS and HCs have revealed differences in how these groups respond under various conditions. For example, two studies using the Tinetti test highlighted significant differences between VR and non-VR settings ($P = 0.003$), with VR environments eliciting distinct responses related to dynamic balance mechanisms in both PwMS and HCs. This suggests that VR may provide a platform that uniquely engages balance strategies in PwMS, possibly owing to the additional reliance on visual feedback.

In studies using the TUG test, responses varied on the basis of the condition. One study [44] reported that VR facilitated improvements in mobility compared with no intervention, whereas another study [57] reported better performance in the control group than those receiving standard therapy. Importantly, another study [48] reported that functional balance and walking speed improved exclusively within the experimental group exposed to VR, although no differences were observed when directly comparing groups.

When comparing PwMS and HCs, the findings suggest that while both groups can achieve similar outcomes in VR environments, PwMS may employ different compensatory strategies to maintain stability, particularly in dynamic tasks. The heterogeneity across studies reflects differences in design, intervention type (i.e., VR vs. no VR), and participant characteristics, emphasizing the need for further research to understand these group-specific responses.

Role of VR in postural control

Postural control and balance outcomes were frequently explored across studies using VR systems [see Additional File 2]. Pau et al. [58] highlighted changes in postural sway and control with a non-immersive VR system, whereas Robinson et al. [45] reported that postural sway outcomes in VR settings were comparable to those observed during traditional balance training. Other studies [41, 42, 47, 49, 61, 62] have documented differences in postural sway measures when VR environments are utilized.

Variability in VR protocols and levels of immersion was noted, with distinct trends in postural control measures over time [40, 43, 47, 55, 60]. Non-immersive VR systems frequently produced postural control outcomes aligned with control settings or standard balance training environments [40, 56]. Yazgan et al. [60] documented shifts in balance metrics during VR tasks, whereas Selgrade et al. [51] noted distinct patterns in treadmill-based VR scenarios compared to supervised walking on treadmills.

Eftekharsadat et al. [44] reported significant improvements (< 0.05) in postural control with VR interventions using the BIODEX balance system over 12 weeks, although functional balance did not change. Novotna et al. [59] reported better postural control outcomes with semi-immersive console-based interventions than with no balance training. Shahnewaz et al. [53] reported differences in imbalance counts on a balance board, with VR and traditional training showing variations ($p = 0.045$). Robinson et al. [45] reported significant changes in postural sway measures (anterior-posterior, medial-lateral, and CoP velocities) using a semi-immersive Nintendo Wii Fit™ system, with outcomes comparable to those of traditional training methods. These findings collectively highlight trends in postural control outcomes across different VR approaches.

Role of VR in functional outcomes

Functional outcomes, including gait, mobility, and specific functional reach measures, displayed variability across studies. Functional reach testing demonstrated measurable changes following VR-based interventions. Kalron et al. [47] reported higher functional reach scores ($p = 0.009$) and lower fear of falling scores ($p = 0.021$) in VR training groups than in balance-trained controls. Similarly, Kalron and Frid [54] reported a 9.1% improvement ($p = 0.03$) in functional reach test results following a single session (30 min) of non-immersive VR intervention.

Gait-related outcomes and mobility measures have been explored in several studies, with mixed results. Novotna et al. [59] reported variations in gait performance between semi-immersive VR training and no intervention over four weeks. Eftekharsadat et al. [44] noted changes in mobility, muscle movement, and fall risk measures when non-immersive VR training was used compared with no balance intervention ($p < 0.05$). Ozdogar et al. [50] identified differences in gait performance across multiple measures between VR training and traditional balance training. Yazgan et al. [60] reported changes in gait outcomes with VR training compared with no intervention but reported comparable results compared with balance-trained groups.

Some studies have reported no differences between VR and other interventions. Robinson et al. [45] and Nilsagård et al. [40] reported no differences in gait or mobility scores between VR and traditional balance training or control groups, whereas Peruzzi et al. [52] reported measurable changes in walking test scores ($p < 0.001$) and obstacle negotiations ($p = 0.028$) for both VR and non-VR groups, with no differences noted between groups after six sessions over 18 weeks. Similarly, Kramer et al. [56] reported no differences in gait outcomes between non-immersive VR and traditional balance training over three weeks.

Sensory integration strategies

Sensory integration has emerged as a key mechanism influencing balance control in PwMS in VR environments. Kalron et al. [47] reported increased reliance on visual feedback, as evidenced by longer CoP path lengths during visually controlled VR tasks. This finding suggests that PwMS prioritize visual input to compensate for impairments in the proprioceptive and vestibular systems. Conversely, Riem et al. [62] reported that visually dynamic perturbations, such as oscillating stimuli, exacerbated postural instability in PwMS ($p < 0.05$), indicating difficulties in integrating visual feedback during rapid postural adjustments. These findings highlight that PwMS exhibit sensory reweighting strategies in VR environments, where visual feedback serves as a compensatory mechanism to stabilize balance.

Gait and mobility outcomes

Studies assessing gait performance under VR conditions have yielded mixed results. Peruzzi et al. [48] reported significant improvements in TUG times ($p = 0.042$) and FSST scores ($p = 0.028$) following VR-based treadmill tasks, suggesting improvements in dynamic stability and functional mobility. In contrast, Kramer et al. [56] reported no significant differences in gait performance between VR and conventional balance training, reflecting variability in gait adaptations under VR settings.

Patient experience, safety, and adverse events in VR environments for PwMS

PwMS in VR environments consistently reported positive experiences, demonstrating engagement, confidence, and adaptability in performing balance tasks. Studies using tools such as the Simulator Sickness Questionnaire (SSQ) and the Suitability Evaluation Questionnaire (SEQ) indicated that participants maintained spatial orientation and physical comfort, with minimal symptoms of cybersickness such as nausea or dizziness [53, 57]. These findings suggest that PwMS adapt well to immersive visual stimuli, retaining balance and stability throughout VR tasks.

Adverse effects during VR sessions were minimal and transient across studies. Mild symptoms of cybersickness, such as nausea or dizziness, were occasionally reported but did not interfere with task completion. For example, Shahnewaz et al. [53] and Riem et al. [62] reported no significant discomfort, even during challenging VR conditions such as treadmill-based tasks. Lozano-Quilis et al. [57] noted that participants maintained physical comfort and orientation without disorientation, whereas Ozdogar et al. [50] reported no negative impacts on depression or fatigue, further supporting the physical and psychological tolerability of VR.

However, variability in assessment methods highlights the need for standardized evaluation protocols to capture subtle responses and adverse effects. Tools such as the SSQ and SEQ provided structured assessments but were not consistently applied across studies, which may have led to underreporting of minor symptoms. The adoption of comprehensive tools such as the Virtual Reality Sickness Questionnaire could offer deeper insights into patient safety and tolerability in future research. PwMS has demonstrated confidence, stability, and adaptability in VR environments, reinforcing its potential for exploring balance control mechanisms. The consistent use of comprehensive evaluation tools is necessary to better understand sensory and motor adaptations and ensure patient safety in VR settings.

Discussion

The present systematic literature review aimed to identify and quantify the role of VREs in the postural control of PwMS. The methodological quality of the 23 included studies varied. The key findings of this study suggest that PwMS display considerable deficits in postural control compared with their healthy counterparts, irrespective of their sensory state or task complexity. Despite the relative homogeneity between studies in terms of apparatus, conditions, and protocols, the included studies demonstrated diversity in the reported measurement variables. Although a meta-analysis was not conducted for similar outcome measures, it was impossible to reach a definite conclusion owing to heterogeneity between the studies.

The COP path length comparisons between PwMS and healthy controls during VR tasks revealed no significant differences [41, 42, 45, 47, 53]. This finding suggests that while PwMS can achieve similar stability levels in VR environments, the mechanisms facilitating this stability may differ. For example, PwMS may rely more heavily on visual feedback in VREs, a hypothesis requiring further exploration through experimental studies. Clinical measures such as the BBS, Tinetti test, and TUG test are variably responsive to VR-based training. Notably, the Tinetti test demonstrated significant benefits favor of VR, indicating the utility of VR in dynamic balance contexts.

The BBS and TUG tests demonstrated mixed results [40, 43, 44, 46–49, 51–53, 55, 57, 59, 60], with considerable heterogeneity across studies due to variability in program design and participant characteristics. Limited comparisons between VREs and non-VREs are available, making it challenging to determine differences in balance control mechanisms. In studies comparing PwMS and healthy controls, healthy controls generally exhibited superior balance stability, but no significant differences were observed in certain VR tasks.

The differences among the variables used to assess the balance response, equipment, and aperture were ascertained. Some of the included studies were conducted via force plates and posturography [63, 64]. Notably, advances in posturography have been valuable for enabling reliable and objective assessments of balance control in different VR settings. Other included quantifiable measures that align with the clinical outcome measures include the BBS, TUG, and the Tinetti test. However, these advancements have led to significant additional difficulties, as they evidently provide an infinite number of measurement variables at the researcher's disposal with little agreement on the key outcomes for extraction. Thus, the optimal approach for assessing the balance response in a holistic manner (when a VR setting is used) remains unclear.

The VR system varied across studies, with some using Nintendo Wii as a head-mounted display. However, no superiority could be demonstrated, and the optimum device could not be identified as various outcome measures were used across the studies. The overlapping findings observed in this review highlight the lack of an optimal approach for assessing balance response (although posturography is the gold standard for assessing the COP). This review highlights the need for developing a core measurement set for postural control. This would considerably facilitate the identification of the elements of postural control that may reliably identify fallers and potential areas of focus for rehabilitation [65].

The reviewed studies revealed methodological challenges that complicate data interpretation. Despite advances in VR technology, inconsistencies in immersion levels, training intensity, session frequency, and intervention duration remain significant barriers to establishing optimal protocols. For example, immersive systems, such as head-mounted displays, are hypothesized to provide superior engagement by integrating visual, vestibular, and proprioceptive stimuli. However, this review reveald no consistent evidence of their superiority over semi-immersive systems, such as the Nintendo Wii Fit™. These findings align with prior research suggesting that engagement and adherence may play a more critical role than immersion level in determining outcomes.

The findings showed that the use of VR training for improving postural control and functional outcomes in PwMS is feasible and is associated with numerous positive effects on key outcomes. However, there was marked heterogeneity across studies in terms of the outcomes achieved for posture, balance, and function, particularly compared with active control groups (i.e., including balance training in a non-VRE).

Previous studies have suggested that VR training may be valuable in PwMS who have motor and cognitive deficits; they have suggested an association between VR training and improved balance performance and outcomes [65–68]. However, although these reviews have suggested that VR training may yield positive motor and cognitive outcomes, they included a limited number of studies and did not adequately evaluate outcomes related to balance and functional measures (such as gait). In addition, issues have been noted in relation to the low quality of available studies, lack of long-term outcomes, heterogeneity in the VR methods used, and outcomes assessed [17, 66–68]; these issues largely persist in the data set used for the present review.

Compared with previous reviews, the present systematic review provides further insights into the data related to VREs as a training tool for posture and balance improvement in MS (on the basis of the comprehensive and contemporary nature of the dataset and the depth of analysis provided). VR rehabilitation was largely found to be equally or more effective than non-VR methods in improving balance and functional outcomes (e.g., gait performance), regardless of the level of immersion achieved. Although immersion levels vary across studies, there is no clear evidence to suggest that fully immersive approaches are superior. However, there are limited instances of fully immersive VR protocols in the literature. Another key observation of this review was the association between VR rehabilitation and improvements in numerous functional outcomes in PwMS. Although heterogeneity in outcome measures is a challenge in systematic reviews [17, 19] the consistency of the reported findings across studies suggests that the convergence of these measures may have wide-ranging effects on balance and gait in this population [69].

From a practical perspective, the efficacy data presented in this review suggest that VR training may have advantages over traditional balance training in some patients. However, the clear superiority of VR over traditional methods cannot be confirmed. The heterogeneity of protocols used poses a challenge to generalization of the relative efficacy of these approaches [69]. Additionally, long-term data on their effectiveness are lacking; this may pose problems in supporting the use of one approach over another in chronic conditions (as seen in stroke and Parkinson recovery contexts) [69–71]. It will be necessary to develop an optimal protocol that maximises the potential benefits to patients; this will ensure the effective use of VR rehabilitation in practice. These protocols need to consider the training length, immersion level of VR, and specific intensity and frequency of training that may be expected for an individual patient. It is also necessary to ensure that the efficacy of these protocols is balanced with the safety of rehabilitation techniques; this will provide a positive benefit-risk ratio [65, 66].

Notably, none of the studies in the review reported any adverse outcomes or harmful events associated with VR training; this suggests that this approach may be safe and well-tolerated in this patient group. Nonetheless, the effectiveness of VR training in MS rehabilitation relies on the novelty of the type of VR intervention employed, its ease of implementation, and the VR features used. However, owing to the diversity of VR systems and types of sessions performed, there is no uniform approach for enhancing its clinical use. To improve the balance response in PwMS, it will be necessary to conduct high-quality research to further expand the body of evidence that supports the use of VR as a tool [72].

Balance impairments in individuals with MS result from disruptions in sensory integration, motor coordination, and central nervous system processing, which are often exacerbated by reliance on compensatory mechanisms due to disease progression [44, 48]. VR leverages this reliance by enhancing visual feedback, partially compensating for proprioceptive and vestibular deficits in PwMS. Sensory reweighting, supported by VR's multisensory feedback, facilitates motor learning, neural adaptation, and improvements in gait stability and postural sway [42, 46].

VR engages critical neural pathways, including the cerebellum, promoting microstructural integrity and plasticity in damaged tracts. These changes align with observed improvements in dynamic balance and reductions in COP path length, as assessed by functional tests such as the TUG test and BBS [41, 44, 48]. Dual-task paradigms reveal PwMS's difficulty managing cognitive and motor tasks simultaneously, a limitation addressed by VR's integration of cognitive challenges [45, 47].

Home-based biofeedback systems tailored to individual needs have demonstrated efficacy in improving static and dynamic balance in individuals with moderate to severe MS [50, 59]. Exergaming enhances attentional control and cognitive functions whereas VR environments challenge PwMS to distinguish between self-motion and object motion, a common source of instability in complex settings [50, 62]. These features not only mitigate balance deficits but also deepen our understanding of sensory, motor, and cognitive interactions in balance regulation [52, 53, 62].

While numerous studies have demonstrated VR's rehabilitative potential for improving gait stability, reducing postural sway, and enhancing neural plasticity in PwMS [42, 44, 46], few studies have explicitly investigated how VR operates as a tool to unravel the underlying mechanisms of balance control in this population. Current evidence highlights VR's ability to engage sensory reweighting, visuomotor entrainment, and cognitive-motor integration, suggesting its potential as an experimental platform [51, 53, 62]. For example, visual oscillations in VR environments have revealed errors in motion processing and balance regulation, particularly in distinguishing self-motion from object motion, which could deepen our understanding of sensory and motor adaptation in PwMS [50, 62]. Although promising, the focus remains largely on the application of VR as a rehabilitative tool rather than an investigative framework for balance mechanisms. Bridging this gap requires research specifically designed to probe how VR interacts with sensory, motor, and cognitive processes in PwMS. Such studies would provide critical insights into the dynamics of balance control and inform both therapeutic approaches and theoretical frameworks of motor adaptation in this population.

The quality of the included studies was also found to be heterogeneous and had limitations such as small sample sizes, varied outcome measures, and the use of different types of VR. These limitations may have introduced bias in the results and restricted their generalisability. Despite these limitations, the findings suggest that the use of VR for balance control offers potential benefits to PwMS, including safety and improved balance outcomes. However, the inconsistency in studied outcome measures highlights the need for a more standardized approach for assessing balance control in a VRE. Further research is needed to determine the optimal protocol for evaluating balance control using quantifiable methods in a VRE. Future studies need to address this gap in order to provide a more accurate and reliable assessment of balance performance in PwMS.

Conclusion

This systematic review explored the use of VR for balance and its associated outcomes in PwMS, which are critical in clinical practice. Analysis of the data indicated that there is evidence to support the use of VR rehabilitation for improving balance in PwMS (including functional outcomes related to gait). However, there was a considerable degree of heterogeneity in terms of the reported outcomes and evidence for the relative efficacy of VR training (versus standard balance training using non-VREs). This heterogeneity affected the comparison of the dataset and their generalizability to the MS population.

Abbreviations

6MWT	Six-minute Walking Test
ABC	Activities-specific Balance Confidence
BBS	Berg Balance Scale
CDP	Computerized Dynamic Posturography
CI	Confidence Interval
CNS	Central Nervous System
COP	Centre of Pressure
DT	Dual Task
FSST	Four-Step Square Test
HC	Healthy Control
LOS	Limits of Stability
MS	Multiple Sclerosis
PEDro	Physiotherapy Evidence Database
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PwMS	People with Multiple Sclerosis
QoL	Quality of Life
RCT	Randomized Controlled Trial
SMD	Standard Mean Difference
TUG	Time Up and Go
VR	Virtual Reality
VRE	Virtual Reality Environment

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12984-025-01612-0.

Supplementary Material 1: MEDLINE search strategy.

Supplementary Material 2: Characteristics of the included studies.

Acknowledgements
Not applicable.

Author contributions
BA, EA, DM, and SM conceived and designed the study. BA and EA conducted the data collection and analyzed and interpreted the data. BA prepared the first draft of the manuscript, and all authors reviewed the final results, revised the manuscript, and approved the final version. All authors have read and approved the final manuscript.

Funding
The research received no external funding.

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

Declarations

Ethics approval and consent to participate
The study did not require ethical approval.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Received: 5 August 2024 / Accepted: 18 March 2025
Published online: 07 April 2025

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