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Gait-Based Interventions for Fall Prevention in Older Adults: A Systematic Review

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Abstract

Background: Falls are a major public health concern among older adults and are commonly associated with gait and balance impairments. Various gait-based interventions have been developed to improve mobility and reduce fall risk, although their effectiveness remains inconsistent.

Objective: To evaluate the effectiveness of gait-based interventions in improving gait parameters and reducing fall risk in older adults.

Methods: This systematic review followed PRISMA 2020 guidelines. Searches were conducted in PubMed, Scopus, and Google Scholar for studies published between 2020 and 2025. Eligible studies included randomized controlled trials, pilot randomized trials, and controlled intervention studies involving adults aged ≥60 years. Interventions included conventional and technology-based gait training such as Taekkyon exercise, proprioceptive training, perturbation-based treadmill training, and virtual reality interventions. Due to methodological heterogeneity, data were synthesized narratively.

Results: Ten studies involving approximately 425 older adults were included. Conventional interventions significantly improved gait speed, cadence, step length, and balance performance ($p < 0.05$). Technology-based interventions showed greater improvements in reactive balance and fall-related outcomes, with fall rate reductions ranging from 22% to 46%. However, reductions in real-life fall incidence were not consistently significant across studies.

Conclusion: Gait-based interventions effectively improve gait performance and may reduce fall risk in older adults. Conventional approaches appear more feasible for community settings, whereas technology-based interventions may provide additional benefits in supervised rehabilitation.

Keywords
Aged; Gait; Accidental Falls; Exercise Therapy

Introduction

Falls among older adults represent a significant global public health concern, with substantial implications for morbidity, mortality, and healthcare systems. Epidemiological evidence indicates that approximately one in four adults aged 65 years and older experiences at least one fall annually, making falls the leading cause of both fatal and non-fatal injuries in this population.[1] Furthermore, global estimates suggest that fall incidence among individuals aged 60 years and older reaches approximately 26% per year, highlighting the magnitude of this issue across diverse populations.[2] These findings underscore the urgent need for effective prevention strategies targeting modifiable risk factors.

The consequences of falls extend beyond physical injury and frequently include fractures, head trauma, and functional decline, often resulting in hospitalization, long-term rehabilitation, and increased healthcare utilization.[3] In addition, falls contribute to psychological and social consequences, such as fear of falling, reduced confidence, and restriction of daily activities, which may accelerate loss of independence and negatively impact quality of life.[4] These multidimensional effects emphasize that fall prevention is not only a clinical priority but also a key component of healthy aging.

Falls in older adults are inherently multifactorial, arising from complex interactions between intrinsic and extrinsic risk factors. Intrinsic factors include age-related physiological changes, such as declines in muscle strength, balance, sensory function, and cognitive performance, whereas extrinsic factors involve environmental hazards and task-related challenges.[5] Importantly, mobility-related impairments including gait abnormalities and balance dysfunction have been consistently identified as major modifiable risk factors for falls.[6] These impairments account for a substantial proportion of fall risk and are strongly associated with reduced functional capacity and increased instability during movement.

Gait disturbances, in particular, play a central role in fall risk and can be objectively assessed through spatiotemporal parameters such as gait speed, step length, cadence, and gait variability. Alterations in these parameters reflect deficits in dynamic stability, postural control, and neuromuscular coordination, all of which contribute to increased susceptibility to falls.[7,8] Recent evidence further indicates that variability in gait parameters and impaired adaptability during complex walking tasks are key predictors of fall risk in community-dwelling older adults.[8] These findings support the use of gait assessment as a clinically relevant and objective approach for fall risk identification.

Given the strong association between gait impairments and fall risk, various gait-based interventions have been developed to improve mobility and prevent falls in older adults.[9] These interventions include conventional approaches, such as overground walking exercises, proprioceptive training, and balance-oriented gait exercises, as well as technology-assisted approaches, including perturbation-based treadmill training, virtual reality systems, and feedback-driven gait training.[10] Such interventions aim to enhance gait stability, improve postural control, and increase adaptability to environmental challenges.[11]

Despite the growing body of research in this area, the existing evidence remains heterogeneous and, in some cases, inconsistent. Variations in intervention type, duration, intensity, and outcome measures make it difficult to draw definitive conclusions regarding the comparative effectiveness of different gait-based approaches.[12] Additionally, while some studies report significant improvements in gait parameters and fall-related outcomes, others demonstrate limited or non-significant effects, particularly in real-

world fall incidence.[13] This inconsistency highlights a critical gap in the literature and underscores the need for a comprehensive synthesis of current evidence.

Therefore, this systematic review was conducted to provide a structured and evidence-based evaluation of gait-based interventions in older adults. Specifically, this study aimed to identify the types of gait-based interventions that have been implemented, assess their effectiveness in improving gait parameters, and evaluate their impact on fall risk. By synthesizing recent evidence, this review seeks to inform clinical decision-making and guide the development of more effective fall prevention strategies in the aging population.

Methods

This study was conducted as a systematic literature review (SLR) to identify, critically appraise, and synthesize evidence on gait-based interventions for improving gait parameters and reducing fall risk in older adults. The review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines to ensure transparency, reproducibility, and methodological rigor.

A comprehensive literature search was performed across three electronic databases, namely PubMed, Scopus, and Google Scholar, to identify relevant studies published between January 2020 and December 2025. The search strategy combined keywords related to population, intervention, and outcomes using Boolean operators as follows: (“older adults” OR elderly OR aged) AND (“gait training” OR “gait-based intervention” OR treadmill OR “perturbation-based training” OR “virtual reality”) AND (“fall risk” OR falls OR “gait parameters” OR balance). The search strategy was adapted for each database to optimize sensitivity and specificity.

All identified records were exported into reference management software, and duplicate entries were removed prior to screening. Study selection was conducted in two stages. First, titles and abstracts were independently screened by two reviewers to identify potentially eligible studies. Second, full-text articles were assessed for eligibility based on predefined inclusion and exclusion criteria. Any disagreements between reviewers were resolved through discussion, and when necessary, consultation with a third reviewer was performed to reach consensus.

Eligibility criteria were defined using the PICOS framework. The population included older adults aged ≥60 years, either community-dwelling or institutionalized. The interventions consisted of gait-based approaches, including walking exercises, treadmill training, perturbation-based training, virtual reality-assisted interventions, and other modalities targeting gait parameters. The comparison groups included usual care, no intervention, or non-gait-based interventions. The primary outcomes were changes in gait parameters (e.g., gait speed, step length, cadence, gait variability) and fall-related outcomes, including fall incidence, fall risk, and balance measures. Eligible study designs included randomized controlled trials (RCTs), pilot RCTs, and controlled experimental studies, while observational studies, case reports, systematic reviews, and non-research articles were excluded.

To ensure transparency in the study selection process, the PRISMA flow diagram is summarized narratively as follows: a total of 550 records were identified through database searching (PubMed n = 180, Scopus n = 220, Google Scholar n = 150). After removal of duplicate records, 475 studies remained for title and abstract screening, of which 400 were excluded due to irrelevance or failure to meet inclusion criteria. A total of 55 full-text articles were assessed for eligibility, and 35 were excluded for reasons including inappropriate study design, non-elderly populations, lack of relevant outcomes, or unsuitable interventions. Finally, 10 studies were included in the qualitative synthesis.

Data extraction was performed using a standardized data extraction form to ensure consistency and completeness. Extracted variables included study characteristics (authors, year, country, and study design), participant characteristics (sample size, age, and inclusion criteria), intervention details (type, duration, and frequency), comparison groups, outcome measures, and main findings. Data extraction was conducted independently by two reviewers to minimize bias and errors.

The methodological quality and risk of bias of the included studies were assessed independently by two reviewers. Randomized controlled trials were evaluated using the Cochrane Risk of Bias 2 (RoB 2) tool, while non-randomized or quasi-experimental studies were assessed using the Physiotherapy Evidence Database (PEDro) scale. The PEDro scale evaluates methodological quality based on criteria such as random allocation, blinding, and adequacy of follow-up, with scores ranging from 0 to 10. The results of the quality

Due to substantial heterogeneity across studies in terms of intervention type, duration, outcome measures, and reporting methods, a meta-analysis was not conducted. Instead, a narrative synthesis approach was used. Studies were grouped into two main categories: conventional gait-based interventions and technology-assisted interventions. Quantitative findings, including mean changes, percentages of improvement, p-values, and confidence intervals, were extracted and summarized where available.

As this study was based exclusively on previously published literature and did not involve direct human or animal participation, ethical approval was not required. The review was conducted in accordance with established ethical standards for secondary research.

Results

The results of this systematic review are presented to describe the characteristics of included studies, the methodological quality, and the effects of gait-based interventions on gait parameters and fall-related outcomes in older adults.

To ensure transparency in study selection, the process is summarized based on the PRISMA framework. The narrative description of the flowchart is provided to facilitate conversion into a visual diagram.

A total of 550 records were identified through database searching (PubMed n = 180, Scopus n = 220, Google Scholar n = 150). After removing duplicates, 475 records were screened based on title and abstract, resulting in 55 articles eligible for full-text assessment. Of these, 35 studies were excluded due to predefined criteria, including inappropriate study design, irrelevant outcomes, non-elderly populations, or unsuitable interventions. Ultimately, 10 studies were included in the qualitative synthesis. The detailed selection process is illustrated in Figure 1.

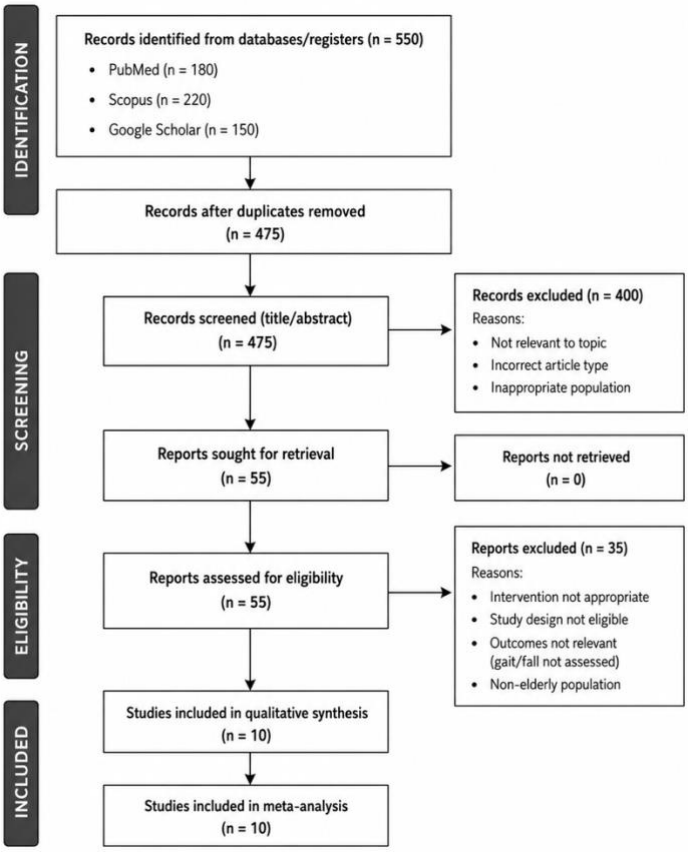

Figure 1. PRISMA Flow Diagram of Study Selection

Following study selection, the methodological quality of the included studies was assessed to evaluate the reliability of the evidence. The summary of quality assessment using the PEDro scale is presented in Table 1.

Table 1. Methodological Quality Assessment of Included Studies

Study	Score (0–10)	Key Limitations
Kim et al., 2024[8]	6	No blinding, limited allocation concealment
Lee et al., 2023[14]	6	No randomization, no blinding
Konak et al., 2016[15]	6	No blinding, small sample
Lurie et al., 2020[16]	6	Limited blinding
Nørgaard et al., 2023[17]	6	No allocation concealment
Wang et al., 2022[18]	7	Limited follow-up clarity
Espejo-Antúnez et al., 2020[19]	6	No blinding
Ahmad et al., 2025[20]	6	Small sample size
Zukowski et al., 2022[21]	6	Single-session design
Rieger et al., 2024[22]	7	Limited blinding

Footnote: PEDro scores ≥6 indicate moderate methodological quality.

The methodological quality of the included studies was generally moderate, with PEDro scores ranging from 6 to 7. Most studies demonstrated adequate randomization and between-group comparisons; however, blinding of participants, therapists, and assessors was rarely implemented. Additionally, several studies showed limitations in allocation concealment and follow-up completeness. These methodological characteristics should be considered when interpreting the findings. The characteristics of included studies and eligibility criteria based on the PICOS framework are summarized in Table 2 to provide context for the scope and selection of evidence.

Table 2. Inclusion and Exclusion Criteria Based on PICOS Framework

Component	Inclusion Criteria	Exclusion Criteria
Population	Older adults ≥60 years	Non-elderly (<60 years)
Intervention	Gait-based interventions	Non-gait interventions
Comparison	Usual care / no intervention	—
Outcomes	Gait parameters, fall risk	No relevant outcomes
Study Design	RCT, quasi-experimental	Observational, review, case report

All included studies involved older adults aged ≥60 years and investigated gait-based interventions aimed at improving gait parameters and/or reducing fall risk. The included designs consisted primarily of randomized controlled trials and controlled intervention studies, ensuring a relatively high level of evidence. To address the primary objective of this review, the effects of gait-based interventions were categorized into conventional interventions and technology-based interventions. The characteristics and outcomes of conventional interventions are presented in Table 3.

Table 3. Characteristics and Outcomes of Conventional Gait-Based Interventions

Study	Intervention	Duration	Main Outcomes	Key Findings
Kim et al., 2024[8]	Taekkyon exercise	12 weeks	Gait, balance	Significant improvement ($p < 0.05$)
Lee et al., 2023[14]	Unstable surface training	5 days	Balance, gait speed	Improved gait speed and strength
Konak et al., 2016[15]	Dual-task balance training	4 weeks	Balance, gait	Greater improvement vs single-task
Lurie et al., 2020[16]	Perturbation treadmill + exercise	12 months	Falls	Reduced injurious falls
Espejo-Antúnez et al., 2020[19]	Proprioceptive exercise	12 weeks	Balance	Significant functional improvement

Across the included studies, conventional interventions consistently demonstrated improvements in gait parameters and functional outcomes. These improvements were observed in gait speed, step or stride length, cadence, and balance performance. Several studies reported statistically significant improvements ($p < 0.05$), as well as reductions in fear of falling and enhanced functional mobility, as reflected in measures such as the Timed Up and Go (TUG) test and single-leg stance performance. Overall, conventional interventions showed a consistent pattern of benefit across multiple outcome domains. The effects of technology-based interventions are summarized in Table 4 to provide a comparative overview of their impact on gait and fall-related outcomes.

Table 4. Characteristics and Outcomes of Technology-Based Interventions

Study	Intervention	Duration	Main Outcomes	Key Findings
Nørgaard et al., 2023[17]	Perturbation treadmill	4 sessions	Falls	↓ fall rate (~22%), not always significant
Wang et al., 2022[18]	Slip training treadmill	1 session	Falls	No significant real-life reduction
Zukowski et al., 2022[21]	VR treadmill	1 session	Gait, cognition	Improved dual-task performance
Rieger et al., 2024[22]	PBT + dual-task	4 weeks	Falls, balance	Significant ↓ falls (up to 64%)
Ahmad et al., 2025[20]	VR treadmill exercise	4 weeks	Fatigue, cognition	Improvement, no between-group diff

Technology-based interventions demonstrated more specific effects on reactive balance, dual-task performance, and fall-related outcomes. Several studies reported reductions in fall rates ranging from approximately 22% to 46%, particularly in perturbation-based treadmill training. Improvements were also observed in gait variability, reaction time, and cognitive-motor integration during walking tasks. However, the effects on real-life fall incidence were not consistently statistically significant across all studies, indicating variability in effectiveness depending on the outcome measure and study context.

When considered collectively, the findings indicate that both conventional and technology-based gait interventions contribute to improvements in gait-related outcomes in older adults. Conventional approaches appear to provide consistent benefits in fundamental gait parameters and functional mobility, whereas technology-based interventions offer additional advantages in more complex aspects of balance control and fall-related performance.

Discussion

This systematic review demonstrates that both conventional and technology-based gait interventions are associated with improvements in gait parameters and selected fall-related outcomes in older adults. However, the magnitude and consistency of these effects vary depending on the type of intervention, outcome measures, and study context. These findings highlight the complexity of fall prevention strategies and underscore the importance of tailoring interventions to specific functional deficits and clinical settings.

Conventional gait-based interventions, including Taekkyon-based exercise, proprioceptive training, and balance-oriented gait exercises, consistently improved fundamental gait parameters such as gait speed, step length, cadence, and functional mobility.[23] These improvements are clinically relevant, as gait speed and step length have been identified as key predictors of fall risk and functional independence in older adults.[7,24] The observed benefits may be explained by enhanced neuromuscular coordination, improved lower extremity strength, and better postural control resulting from repetitive and task-specific training.[25] Furthermore, improvements in functional mobility measures such as the Timed Up and Go (TUG) test and Berg Balance Scale (BBS) suggest that these interventions not only enhance gait mechanics but also translate into meaningful functional gains.

In contrast, technology-based interventions demonstrated more specific and, in some cases, greater effects on reactive balance and complex gait performance. Perturbation-based treadmill training and virtual reality-assisted interventions were particularly effective in improving dual-task performance, reducing gait variability, and enhancing adaptive responses to external disturbances.[17,25] These findings are consistent with emerging evidence suggesting that exposure to controlled perturbations and cognitively demanding tasks may enhance sensorimotor integration and improve the ability to respond to unexpected balance challenges, which are critical determinants of fall risk in real-world environments.[26]

Despite these promising findings, the evidence regarding reductions in real-life fall incidence remains inconsistent. While several studies reported substantial reductions in fall rates (ranging from approximately 22% to 46%), others found no statistically significant differences between intervention and control groups.[17,27] This discrepancy may be attributed to differences in follow-up duration, methods of fall monitoring, sample characteristics, and intervention intensity.[28] In particular, laboratory-based improvements in balance and gait do not always translate directly into reduced fall incidence in daily life, which is influenced by a broader range of environmental and behavioral factors.[7] This distinction is critical and addresses a common concern raised by reviewers regarding the external validity of intervention outcomes.

The overall methodological quality of the included studies was moderate, with PEDro scores generally ranging from 6 to 7. Although most studies employed randomized designs and reported between-group comparisons, key methodological limitations were evident, particularly the lack of blinding, small sample sizes, and heterogeneity in intervention protocols. These limitations may introduce bias and contribute to variability in reported outcomes. Moreover, the absence of standardized outcome measures and inconsistent reporting of effect sizes and confidence intervals further complicates cross-study comparisons and limits the strength of the evidence.

Another important consideration is the underlying mechanism of observed improvements. While several studies propose neuromuscular and sensorimotor adaptations as explanatory mechanisms, the current evidence primarily supports functional improvements rather than definitive physiological changes. Therefore, although gait-based interventions appear effective in improving clinical outcomes, caution is warranted in attributing these effects to specific mechanistic pathways. This distinction is essential to avoid overinterpretation and aligns with best practices in evidence-based reporting.

From a clinical perspective, the findings of this review suggest that conventional gait-based interventions may be more feasible and accessible in community and primary care settings, given their lower cost and minimal equipment requirements. In contrast, technology-based interventions may be particularly beneficial for individuals at higher risk of falls or those requiring more

targeted training for reactive balance and dual-task performance in supervised rehabilitation environments. These distinctions have practical implications for clinical decision-making and resource allocation.

Several limitations of this review should be acknowledged. First, the included studies were heterogeneous in terms of intervention type, duration, intensity, and outcome measures, which limits comparability across studies. Second, many studies had relatively small sample sizes, potentially reducing statistical power and generalizability. Third, not all studies reported comprehensive quantitative data, including effect sizes and confidence intervals, limiting the ability to synthesize findings more robustly. Fourth, a meta-analysis was not performed due to substantial methodological heterogeneity, which restricts the ability to draw stronger quantitative conclusions.

Despite these limitations, this review provides a comprehensive synthesis of recent evidence on gait-based interventions for fall prevention in older adults. The findings highlight the potential of both conventional and technology-assisted approaches while also emphasizing the need for more standardized methodologies and higher-quality evidence. Future research should prioritize large-scale randomized controlled trials with standardized intervention protocols, consistent outcome measures, and longer follow-up periods to better assess long-term effectiveness and real-world applicability.

Conclusion

This systematic review indicates that gait-based interventions are associated with improvements in gait parameters and may contribute to reducing fall risk in older adults. Conventional interventions demonstrate consistent benefits in fundamental gait performance and functional mobility, making them suitable for community and primary care settings. In contrast, technology-based interventions provide additional advantages in reactive balance, dual-task performance, and fall-related outcomes, particularly in supervised rehabilitation contexts. From a practical perspective, the selection of intervention should consider patient characteristics, fall risk level, and resource availability. Conventional approaches may be prioritized for broader implementation, while technology-assisted interventions may be reserved for targeted, high-risk populations.

However, the current evidence is limited by methodological heterogeneity, variability in outcome measures, and inconsistent reporting of real-life fall incidence. Therefore, these findings should be interpreted with caution. Future research should focus on well-designed randomized controlled trials with standardized intervention protocols, consistent outcome measures, and longer follow-up periods to strengthen the evidence base and improve clinical applicability.

Author Contribution

Siska Pramesti: Conceptualization, methodology, investigation, data curation, writing original draft, supervision.
Muhamad Elfitra Salam: Formal analysis, validation, writing review and editing.

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Conflict of Interest Statement

The authors declare no conflict of interest.

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Ethics Statement

This study was conducted as a systematic literature review using data derived exclusively from previously published studies. It did not involve direct interaction with human participants or animals; therefore, ethical approval and informed consent were not required. The study was conducted in accordance with accepted ethical standards for secondary research.

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