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Article

Game-based balance training in older adults: systematic review and meta-analysis

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Abstract

Functional decline in older adults is a major contributor to both falls and increased fall risk. Nevertheless, such decline may be mitigated through multidimensional interventions. Game-based and gamified interventions have emerged as promising alternative strategies. This study aimed to evaluate the effectiveness of these approaches in improving balance and reducing fall risk among community-dwelling adults aged 65 years and over. The research question was: Do serious games and gamification improve balance and reduce fall risk in community-dwelling older adults, compared with exercise programmes, non-gamified interventions, or control conditions?

A systematic search of randomised controlled trials was conducted in accordance with PRISMA guidelines, resulting in the inclusion of nine studies from 634 records screened. Meta-analysis demonstrated significant improvements in the Functional Reach Test and the Berg Balance Scale. However, no significant overall effects were observed for the Timed Up and Go Test or the Single-Leg Stance Test.

Although game-based interventions may improve specific dimensions of balance in community-dwelling older adults, the findings should be interpreted with caution. The limited number of studies, small sample sizes, heterogeneity of interventions, and reliance on balance-related surrogate outcomes rather than direct measures of fall incidence highlight the need for further high-quality research.

1. Introduction

1.1 Background

Global demographic changes and population aging have positioned falls as a major public health concern, with approximately 26.5% of individuals worldwide experiencing at least one fall each year [1]. Falls represent a leading cause of injury and are strongly associated with functional decline and reduced quality of life in older adults [1], [2].

Among the intrinsic determinants of fall risk, impaired postural control, compromised balance function, and muscle weakness play a central role [1]. Adequate balance capacity is essential for falls prevention as most activities of daily living require postural stability [3]. Multidisciplinary intervention programmes, incorporating physical and cognitive training as well as balance and strength exercises, have demonstrated effectiveness in improving physical and functional capacities, reducing dependency, and mitigating both fall risk and fear of falling [2], [3], [4], [5], [6]. Nevertheless, traditional exercise programs are frequently perceived as monotonous or insufficiently engaging which may compromise adherence [7].

To address the limitations of traditional exercise programmes, playful, game-based, and gamified interventions have emerged as promising alternatives. These approaches offer enjoyable, accessible, and motivating formats that provide meaningful physical challenges, enhance engagement and adherence, and support learning through continuous feedback and goal-oriented tasks [8], [9], [10], [11]. [10], [11], [12], [13], [14]. Such interventions facilitate individual adaptation, promote user interaction, and have demonstrated positive effects on multiple domains of physical performance associated with reduced fall risk [8], [14], [15], [16], [17] . Although frequently described as *serious games*, the literature often includes board games, virtual games, commercial off-the-shelf or exergame systems (e.g., Wii Fit, Kinect) repurposed for therapeutic use, rather than purpose-built serious games [18], [19], [20], [21], [22], [23], [24], [25], [26], [27], [28], [29], [30]. [11], [14], [31], [32].

Given the conceptual overlap between serious games, exergames, and gamification, these modalities are often presented in the literature as sharing similar underlying mechanisms of engagement and stimulation relevant to fall prevention[12], [16], [33], [34], [35]. The term *serious game* should be reserved for games specifically designed for therapeutic, rehabilitation, or educational purposes, where the primary objective extends beyond entertainment [36], [37], [38], [39], [40], [41], [42]. In contrast, gamification refers to the integration of game elements, or mechanics into non-game contexts [11], [14], [31], [32].

Irrespective of format (analogue or digital), factors such as game structure, configuration, content, user suitability, device characteristics and design quality are critical determinants of effectiveness [10], [11], [12], [13], [14]. The development of serious games should therefore follow user-centred principles, with a clearly defined purpose, meaningful narrative structure and content tailored to the target population. Game mechanics, dynamics and aesthetics must be aligned with the intended therapeutic objectives [12], [37], [38], [43], [44], [45], [46].

In this review, the broader term game-based and gamified interventions is adopted to encompass purpose-designed serious games and other applications incorporating game elements for rehabilitation proposes, including virtual reality-based systems.

1.2 Knowledge gap

Although the therapeutic potential of game-based strategies is increasingly recognized, a comprehensive synthesis integrating the full spectrum of these interventions in relation to balance, falls, and the fear of falling remains limited. This systematic review addresses an important gap in the literature by: (a) synthesizing evidence across a broad range of game-based modalities, including exergames, virtual reality-based interventions and gamified approached; (b) conducting a comprehensive meta-analysis of core balance outcomes, namely the Functional Reach Test (FRT), Berg Balance Scale (BBS), Timed Up and Go Test (TUG) and Single-Leg Stance Test (SLST); and (c) providing an updated and methodologically rigorous evaluation of their specific effects on balance and fall-related outcomes in community-dwelling older adults.

1.3 Objective of the study

The aim of this systematic review and meta-analysis was to evaluate the effectiveness of game-based and gamified interventions in improving balance and reducing fall risk among community-dwelling older adults, while also characterising the nature and implementation of these interventions.

2. Methods

2.1 Design

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines[47], [48] and was prospectively registered in the International Prospective Register of Systematic Reviews (PROSPERO) under the registration number CRD42024514080, ensuring transparency and reproducibility of the review process.

The review question, adhered to the pre-specified protocol, and was structured according to the PICO framework. The PICO elements were defined as follows:

- Population (P): Community-dwelling Individuals aged 65 years or older.
- Intervention (I): Interventions incorporating game elements and mechanics, playful design elements (gamification strategies), serious games and active video games (exergames).
- Comparison (C): Interventions not involving game-based or gamified components (e.g., traditional exercise or educational programs).
- Outcomes(O): Balance and fall risk, assessed using validated outcome measures, including the “Timed Up and Go” (TUG) test, "Berg Balance Scale (BBS)," “Single Leg Stance Test” or "Functional Reach Test (FRT)".

The Research question was formulated as follows: “Do serious games and gamification improve balance and reduce fall risk in community-dwelling older adults aged 65 years and over, compared with traditional exercise programmes, non-gamified interventions, or control groups?”

2.2 Search Strategy

This review was conducted between January to March 2023, using Web of Science, ScienceDirect, and PubMed databases, in accordance with a pre-defined protocol specifying this timeframe. The search strategy combined Medical Subject Headings (MESH) and relevant keywords, including "aged,” “older,” “older adults,” “gamification,” “game,” “play,” “serious games,” “balance,” and “fall.” Truncation and Booleans operators (“AND”, “OR”, “NOT”) were applied to refine the search.

The search timeframe was set from 2010-2023. The starting year (2010) was selected to capture the period during which digital and interactive game-based interventions, including exergames and serious games for health and rehabilitation, became more consistently represented in the scientific literature. The final search was conducted in 2023 at the time of review planning and PROSPERO registration. In June 2025, the search was updated and yielded no additional eligible studies.

Although publication was delayed due to manuscript revisions and peer review process, the review reflects the most recent evidence available at the time of the update. Additional details regarding the search strategy and results are provided in the ‘Supplementary Data 1’. Relevant studies were also identified through manual searches and by screening the reference lists of included articles.

The research question and PICO framework guided the definition of inclusion criteria. Prespecified inclusion and exclusion criteria were applied to refine the search strategy and structure the study selection process.

2.3 Screening process

The study screening process was conducted by two independent reviewers (A.T. and S.C.) in accordance with pre-defined inclusion and exclusion criteria. Following duplicate removal, titles were screened independently by both reviewers. Abstracts were subsequently assessed for eligibility. Any potential disagreements were resolved through discussion and, when necessary, consultation with a third reviewer (M.R.).

Full-text articles were independently evaluated for final eligibility. The selection process followed PRISMA guidelines and is illustrated in Figure 1.

2.3.1 Inclusion and exclusion criteria on screening process

Studies were included if they met the following criteria:

- Published in English-language between 2010 and 2023 and involved human participants.
- Peer-review randomized controlled trials (RCTs) evaluating the effects of games or game-based and gamified intervention on balance and/or fall risk in older adults.
- Reported at least one outcome measure related to static or dynamic balance, fall incidence, fall-related self-efficacy, or fall risk.
- Included community-dwelling participants aged 65 years or older
- Studies including participants aged 60-64 were also considered when the overall population characteristics and the clinical focus were explicitly related to fall risk, in order to enhance clinical relevance and transferability

Studies were excluded if they:

- Evaluated non-game-based interventions.
- Involved participants with specific neurological conditions (e.g., traumatic, degenerative, or vascular diseases), significant motor dysfunction, frailty or pre-frailty syndrome, vestibular disorders, diabetes, chronic pain, other musculoskeletal disorders, or infectious diseases.
- Included participants with cognitive impairment or diagnosed mental health conditions, including dementia or Alzheimer's disease.

2.4 Data extraction, analysis and outcomes

Data extraction was initially performed by the first author and independently reviewed by two additional authors. Any ambiguities regarding data interpretation or outcome measure selection were resolved through discussion among the three members of the research team.

The following variables were extracted from each included study: first author, year of publication, study design, sample size, population characteristics, participant age, outcome measures intervention protocols for both experimental and control groups, intervention dose and intensity (e.g., duration in weeks and session frequency), follow-up period, and study setting. The PRISMA checklist is provided in Supplementary Data 1 to ensure transparency and reporting completeness.

Outcome measures for this systematic review and meta-analysis were pre-specified based on their clinical relevance, validity in assessing fall risk, and frequency of use across the included studies. The assessment fall risk relied primarily on validated balance and functional mobility measures, given that few studies reported direct fall incidence.

Primary outcomes comprised four key performance-based measures included in the quantitative meta-analysis, representing critical domains of balance and functional mobility: Timed Up and Go (TUG) Test, Berg Balance Scale (BBS), Functional Reach Test (FRT) and Single Leg Stance Test (SLST).

Secondary outcomes included other objective or subjective measures of physical function, muscle strength, or fear of falling reported in the included studies (e.g., Falls Efficacy Scale-International (FES-I), Lower Limb Strength and Endurance, Centre of Pressure (COP) displacement).

Comparisons between the game-based or gamified intervention groups and control groups were conducted using pre- and post-intervention data. Intervention effects were estimated by calculating mean differences with corresponding 95% confidence intervals (CIs) based on post-intervention values. Statistical significance was set at $p<0.05$.

2.4.1 Statistical analysis

The narrative synthesis summarised the methodological quality and risk of bias of the included studies, as well as their key characteristics, including participant profiles, features of the game-based or gamified interventions, comparator interventions, intervention dose and duration, outcome measures related to balance and fall risk, and reported treatment effects. Findings were presented using descriptive text, tables and figures, and were synthesised according to the type of intervention and outcome domain.

2.4.2 Meta-analysis

A meta-analysis was conducted when at least two studies provided sufficient data (mean values, standard deviations, and sample sizes for each group). Statistical analyses were performed using Review Manager (RevMan) software, version 5.4 [48,49].

Meta-analyses were undertaken for all primary outcomes for which adequate data (means and standard deviations) were available. Studies that did not report these data were excluded from the quantitative synthesis. Treatment effects were calculated using the standardised mean difference (SMD) with corresponding 95% confidence intervals (CIs). Statistical heterogeneity was assessed, and study quality and risk of bias were evaluated as described above.

2.5 Study quality and risk of bias assessment

The risk of bias in the included studies was independently assessed by two reviewers using the Cochrane Risk of Bias tool, in accordance with the guidelines outlined in the *Cochrane Handbook for Systematic Reviews of Interventions*[49]. Disagreements between the reviewers were resolved through discussion; when consensus could not be achieved, a third reviewer (M.R.) was consulted to adjudicate.

The following domains were evaluated: random sequence generation (selection bias), allocation concealment (selection bias), blinding of participants and personnel (performance bias), blinding of outcome assessment (detection bias), selective outcome reporting (reporting bias), and other potential sources of bias (e.g., incomplete outcome data).

Overall study quality was categorised according to the number of domains rated as low risk of bias. Studies were classified as low risk of bias if six or more domains were rated as low risk; as unclear risk of bias if four or five domains were rated as low risk; and as high risk of bias if fewer than four domains were rated as low risk.

3. Results

3.1 Study selection

Data assessment began with the identification of records from of the three databases searched (PubMed = 149; Web of Science = 226; Science Direct = 122). After duplicate removal, 617 records remained and were screened based on title. Following title screening, 51 articles were assessed for eligibility through abstract review. Of these, 32 were excluded according to the pre-defined inclusion and exclusion criteria. Nineteen studies were subsequently retrieved for full-text assessment.

Of the 19 full-text articles, 10 were excluded, for the following reasons: six did not report relevant outcome measures; one was a study protocol, rather than a randomized trial, one did not include a game-based intervention; and two did not evolve community-dwelling older adults. The specific reasons for exclusion of each article are detailed in Supplementary Data 2.

As a result, nine randomized controlled trials (RCTs) were included in the systematic review for qualitative synthesis. The study selection process is illustrated in the PRISMA flowchart (Figure 1).

3.2 Study quality and risk of bias assessment

The results of the risk of bias assessment are presented in Figures 2 and 3. Overall, the included randomized controlled trials demonstrated a predominantly low risk of bias across most domains, reflecting generally sound methodological quality.

Most studies showed a low risk of selection bias, indicating appropriate implementation of random sequence generation. Similarly, a high proportion demonstrated a low risk of reporting bias, suggesting that outcomes were reported as pre-specified. Although slightly more variable, allocation concealment also showed a general trend toward low risk.

However, studies that did not adequately implement random sequence generation or allocation concealment were classified as having a high risk of bias [19], [28], [30]. In additional small sample sizes were identified as a potential source of bias in several studies, potentially limiting statistical power and reduced the capacity to detect intervention effects. These studies were likewise rated as high risk [19], [28], [30].

Owing to the nature of the interventions, blinding of participants and personnel was generally not feasible, resulting in a high risk of performance bias. The domain relating to blinding of outcome assessment (detection bias) also demonstrated a notable proportion of high-risk ratings, which may have influenced the reliability of subjective outcome measures.

The "other bias" domain revealed high-risk ratings in several studies, potentially attributable to factors such as funding sources, baseline imbalances, or deviations from study protocols.

Figure 3 provide a study-by-study overview of the risk of bias assessments. The Risk of Bias summary plot indicates a consistent pattern of low risk of selection bias domains, particularly random sequence generation and allocation concealment.

In contracts, a high risk of bias was consistently observed in blinding domains (performance bias and detection bias), reflecting a recognised methodological challenge in behavioural and exercise-based interventions, including those involving games or gamified approaches, where blinding is often impractical or impossible.

The domain of incomplete outcome data (attrition bias) demonstrated variable risk across studies, whereas selective reporting was generally assessed as low risk among the included trials.

3.3 Characteristics of included studies

The main characteristics of the included studies are summarized in Table 1, including study design, sample size, population demographics, intervention protocols, outcome measures, and duration. A comprehensive overview and synthesis of the principal findings across all included studies are presented in Table 2.

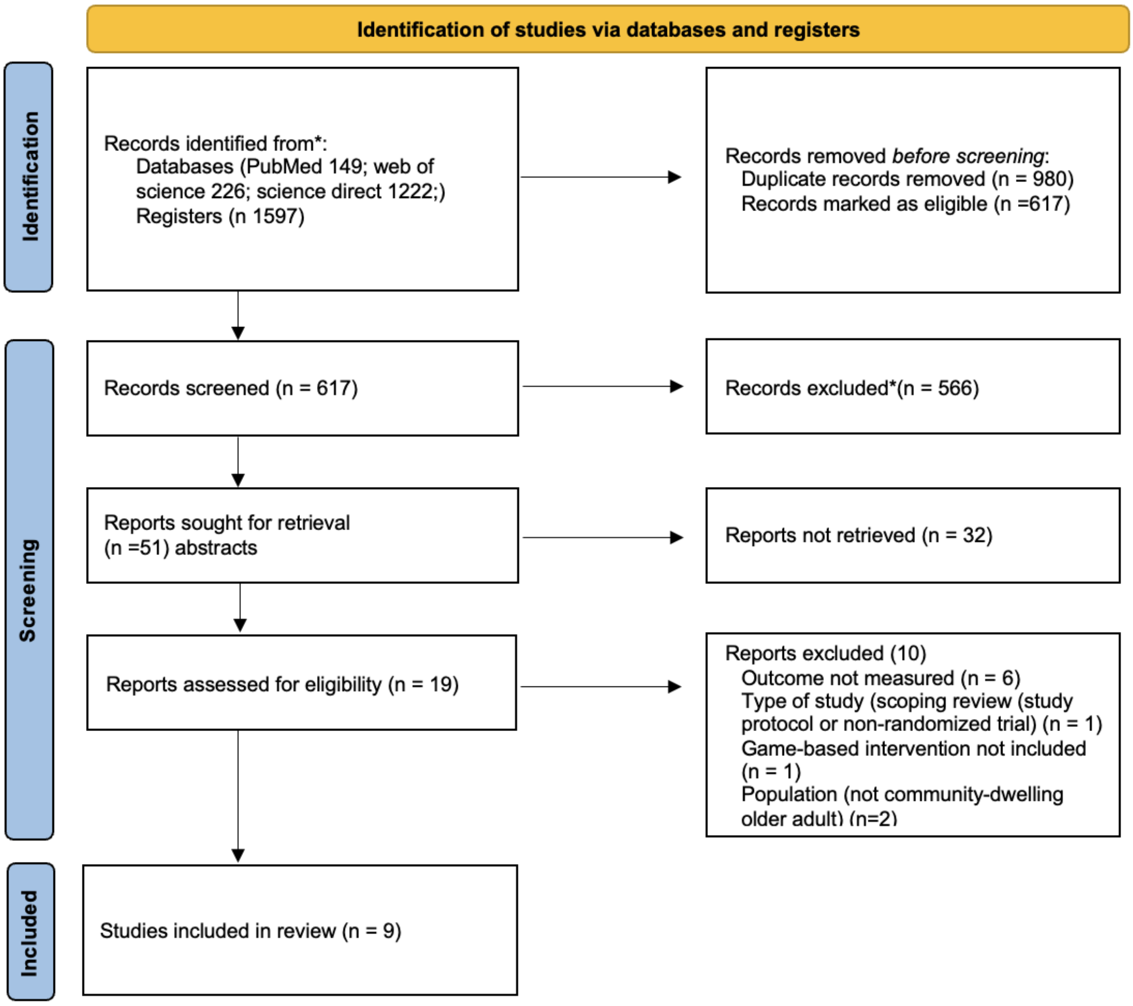

Figure 1. – PRISMA Flowchart describing the systematic review process.

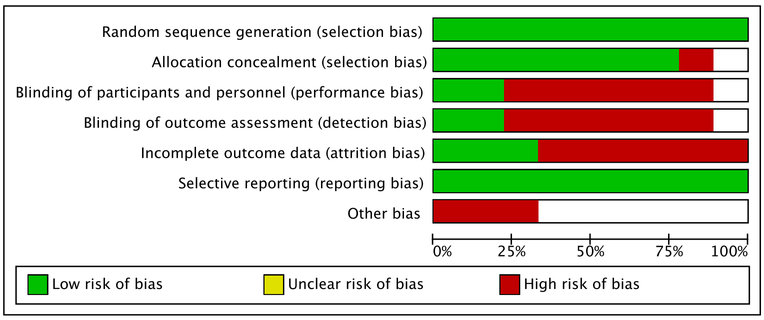

Figure 2 - Risk of bias graph: review authors' judgements about each risk of bias item presented as percentages across all included studies.

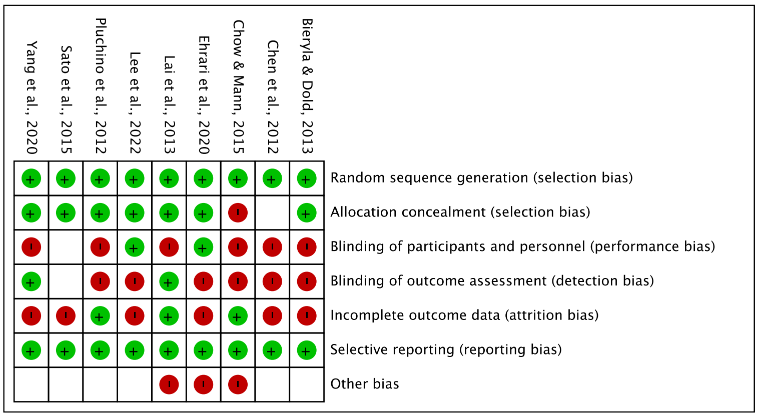

Figure 3 - Risk of bias summary: review authors' judgements about each risk of bias item for each included study

3.3.1 Participants

The qualitative synthesis included nine studies, comprising a total of 266 participants aged between 60 and 92 years. Across both intervention and control groups, the sample size per group ranged from 6 participants [19] to 22 [20]. Mean group ages varied from 68.5±5.47 years [25] to 82.5±1.6 years [23], with six studies reporting a mean age exceeding 70 years. To maximize comprehensiveness and clinical relevance, studies including mixed-age samples were eligible provided the mean participant age of 60 years or older [7], [21].

Although two studies [19], [20] did not report sex distribution, no significant differences in sex distribution between interventions and control groups were identified in the remaining studies, as summarised in Table 1.

3.3.2 Gamified Intervention

The systematic review included studies employing a diverse range of game-based, gamified and virtual reality (VR) interventions. The technologies used ranged from early Nintendo Wii Fit systems to more recent Kinect-based platforms. The specific games and platforms, and its characteristics, used in each study are detailed in Table 1 and presented on Supplementary Data 3. The interventions included:

- Wii Fit and Wii Balance Board, incorporating various balance games, yoga (e.g., Sun-Style, Tai Chi), and aerobic activities) [19]
- Wii Balance Board [29];
- Lower Limb Power Rehabilitation (LLPR) system, using a force plate and video game or a VR interaction device)[27];
- Cyber-golfing training using Exergame “Tiger Woods PGA Tour 13”)[30];
- Playful exercise via Moto tiles[28];
- IT Convergence Gamification with Balpro 110 system [7];
- Interactive Videogame Based (IVGB) system - Xavix Measured Step System (XMSS), from SPECTRUM9000MB-500system, UIS Co., Japan[26]
- Microsoft Kinect, used in two studies with different versions [20], [21].

All participants in the experimental groups were naive to the respective games, gamified platforms, and VR devices. One study [26] included a familiarisation session prior to the commencement of the intervention.

Across all included studies, interventions were delivered in supervised clinical or laboratory settings, and no physical assistance was provided during sessions. The training protocols followed a standardized structure, with no individualized adaptations implemented during the intervention period. Participants were consistently encouraged to perform with maximal effort during each session.

3.3.3 Control Interventions

The control group interventions across the included studies demonstrated considerable variability in approach. Three studies, [19], [20], [28] employed a "usual care" condition, in which participants continued with their usual daily routines without any structured intervention.

The remaining studies implemented a range of active control conditions, including: slow-speed sit-to-stand (STS) movements combined with strengthening and balance exercises [27]; supervised regular table-based games[30], conventional exercise delivered via exercise videos [7]; a six-week no treatment control phase followed by 6 weeks of supervised IVGB training intervention phase[26]; Tai-chi (Sun-Style)[29]; a standardized balance exercise program (SBEP)[29] and a conventional exercise group program specially designed for fall prevention [21].

Across all studies, participants allocated to control groups attended sessions at designated facilities or laboratory settings for the duration of the respective intervention periods.

3.3.4 Dose

The included studies demonstrated substantial heterogeneity in their intervention protocols, particularly in terms of intervention modality, duration and the inclusion of follow-up assessments. Three studies [27], [28], [29] did not report any post-intervention follow-up.

Intervention durations varied considerably across studies. The shortest protocol lasted two weeks [30]; while one study reported a duration of three weeks [19]; another study extended for five weeks[21]. Two studies implemented six-week interventions [26], [27]. The longest intervention duration was eight weeks, which was reported in three studies [7], [20], [29] whereas one study lasted ten weeks[28].

Training frequency also differed across studies, with most interventions delivered two or three times per week. The duration of individual training sessions ranged from 30 to 60 minutes. A detailed summary of intervention frequency, session duration and total intervention exposure is provided in Table 1.

3.4 Measures on balance and risk of fall

In all included studies conducted assessments at both pre-and post-intervention time points, as detailed in Table 3. The primary outcome measures used to assess balance and fall risk were:

- The Timed Up and Go (TUG) test**,** employed in seven studies as the most frequently used measure for functional balance and fall risk [7], [19], [21], [26], [27], [29], [30].
- The Berg Balance Scale was used to assess overall balance in five studies[7], [19], [20], [26], [28].
- Functional Reach Test was a commonly utilized measure in four studies [21], [26], [29], [30].
- Single Leg Test was also a commonly applied measure in three studies [26], [29], [30].

In addition to these core measures, several other outcome tools were employed to provide a more comprehensive evaluation physical performance and fall-related concerns:

- Functional Capacity: The 6-minute walking test (6MWT) [22] and the 10-meter Walking Test (10MWT) [8].
- Aerobic Capacity and Lower Limb Strength: The Chair Sit and Reach (CSR) [8], Five Times Sit to Stand (FTSS)[27], [28], and the 30-second Chair Stand Test (CST)[20], [28].

- Risk of Falling: The Fullerton Advanced Balance Scale [23], Tinetti Performance-Oriented Mobility Assessment (POMA) [27], and Tinetti Balance (TB) [29]
- Falls Prevention Efficacy/Fear of Falling: The Modified Falls Efficacy Scale (MFES) [26], [27], the Korean version of the Falls Efficacy Scale-International (KFES-I)[7], and the Falls Risk for Older People Community Setting (FROP-Com) [26].
- Postural Stability: Sway Area (SA), Sway Velocity (SV), and Centre of Pressure (COP) [26].

All reported outcome measures are further detailed in Table 1.

3.5 Treatment effect

This systematic review consistently found that participants aged 65 years and older, perceived game-based and gamified interventions positively. Feedback across several studies described these interventions as enjoyable, comfortable, feasible for home use, fun, and more engaging than conventional exercise modalities [19], [26], [28].

However, due to substantial methodological heterogeneity and insufficient reporting across the included studies, a comprehensive quantitative meta-analysis of the overall effects of game-based and gamified interventions on balance and fall risk was not feasible.

Nevertheless, pooled analyses were conducted for several frequently reported outcome measures, including functional mobility assessed by the Timed Up and Go (TUG) test, overall balance measured by the Berg Balance Scale (BBS), dynamic balance assessed by the Functional Reach Test (FRT), and static balance evaluated using the Single Leg Stance Test (SLST). These results are summarized in Table 2 and illustrated in Figures 4, 5, 6, and 7. The absence of essential statistical data (e.g., mean differences and standard deviations) in some studies precluded the calculation of estimated effect sizes.

Meta-analysis of the standardised mean difference (SMD) in TUG scores demonstrated no statistically significant overall effect of game-based interventions compared with control conditions (SMD =−0.11, 95% CI: [−0.43, 0.21], p=0.49) as shown in Figure 4. Heterogeneity was low and not statistically significant (I2=13%), indicating relative consistency across studies.

Although the pooled effect was not statistically significant, several individual studies[21], [26], [27], [29] reported non-significant trends favouring the intervention groups, reflected by negative mean differences, (Figure 4). In addition, statistically significant within-group improvements were reported in specific studies. For example, Chen et al[27], observed a reduction in TUG time from 17.20±3.51 seconds at baseline to 12.46±2.99 seconds, post-intervention (p = 0.026). Pluchino et al[29] also reported significant within-group improvements in TUG performance (see Table 2).

While these findings, do not translate into a statistically significant pooled effect, they suggest potential improvement in functional mobility, enhanced balance and mobility among participants who received gamified interventions.

	Experimental			Control				Std. Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
Bieryla & Dold, 2013	11.2	10.6	4	10.1	9.3	5	5.6%	0.10 [−1.22, 1.42]
Chen et al., 2012	12.9	3.07	20	13.83	5.97	20	21.4%	−0.19 [−0.81, 0.43]
Chow & Mann, 2015	13.2	4.1	10	10.5	2.8	10	11.1%	0.74 [−0.18, 1.65]
Lai et al., 2013	8.53	2.88	15	11.27	6.33	15	16.4%	−0.54 [−1.27, 0.19]
Lee et al., 2022	7	0.96	20	6.85	0.89	20	21.4%	0.16 [−0.46, 0.78]
Pluchino et al., 2012	8.18	2.44	11	9.44	1.49	11	12.4%	−0.60 [−1.46, 0.26]
Yang et al., 2020	7.46	1.64	10	7.85	1.12	10	11.8%	−0.27 [−1.15, 0.62]
Total (95% CI)			90			91	100.0%	−0.11 [−0.43, 0.21]

Heterogeneity: $Tau^2 = 0.02$; $Chi^2 = 6.90$, df = 6 (P = 0.33); $I^2 = 13\%$
Test for overall effect: Z = 0.70 (P = 0.49)

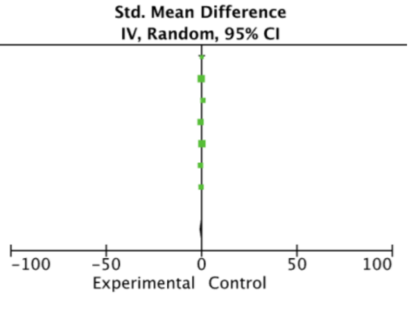

Figure 4 – Standard Mean Difference between experimental and control group in TUG results in the selected studies.

The meta-analysis indicates that the experimental intervention was associated with a statistically significant improvement in Berg Balance Scale (BBS) scores compared with control conditions, with a mean difference of approximately 6.43 points (Figure 5). This This magnitude of change may be considered clinically relevant, as improvements of ≥4–7 points on the BBS are commonly regarded as meaningful in populations at risk of falling[7], [21], [50].

This pooled effect appears to have been influenced by the study conducted by Bieryla and Dold [19], which, despite its small sample size, reported low within-group variability (i.e., small standard deviations) and an 8-point improvement in BBS scores, resulting in a comparatively precise effect estimate.

However, moderate heterogeneity was observed among the included studies ($I^2 = 58\%$) which warrants caution in the interpretation of the pooled effect. This level of heterogeneity indicates variability in effect sizes and suggests that the impact of the intervention on BBS scores may differ according to variations in participant characteristics, intervention protocols, or methodological factors.

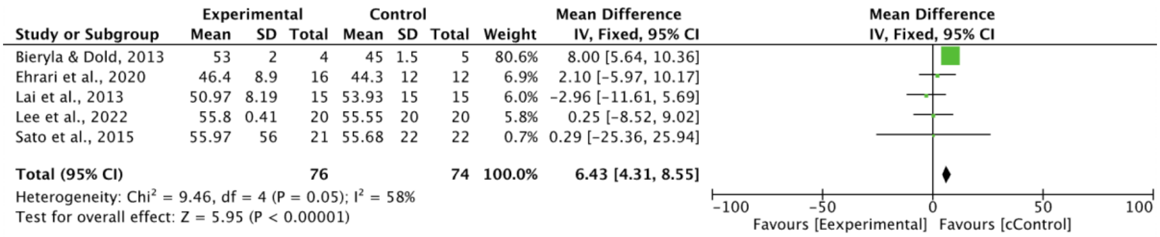

Figure 5 – Mean difference between experimental and control group in BBS results in the selected studies

The FRT was a key outcome used to assess dynamic balance, with data from five studies [19], [20], [27], [29], [30], comprising a total of 62 participants. As shown in Figure 6 meta-analysis, using a fixed-effects model, demonstrated a statistically significant improvement in FRT scores in favour of the experimental interventions compared to the control groups ($p = 0.05$).

The pooled mean difference was 2.65 cm (95% CI 1.07 to 4.24 cm). This magnitude of change may be considered clinically relevant improvements of 2.5-3.8cm (1-1.5 inches) have been suggested as representative of minimal clinically important difference for populations at risk of falling. On average, participants in the experimental group reached between 1.07 cm to 4.24 cm further than those in the control groups, with a point estimate of 2.65 cm (Figure 6).

Heterogeneity was negligible and not statistically significant ($I^2 = 0\%$) indicating high consistency across studies. This consistency supports the stability of the pooled estimate and the use of a fixed-effects model.

Overall, the findings indicate that gamified interventions were associated with improvements in dynamic balance, as measured by the Functional Reach Test, with reliable and consistent effects observed across studies.

The forest plot presented in Figure 7, summarized a meta-analysis of four studies, comprising a totalising 90 participants, using a fixed-effects model. The analysis demonstrated no statistically significant difference in Single Leg Stance Test (SLS) performance between the experimental and control groups. The pooled mean difference is 4.32 seconds, however its 95% confidence interval [-2.58, 11.23] includes zero, indicating that the observed difference may be attributable to random variation rather than a true intervention effect.

Although an improvement of 4.32 seconds in SLS performance could be considered clinically relevant in certain populations, the absence of statistical significance precludes any definitive conclusion regarding the effectiveness of the intervention in improving static balance.

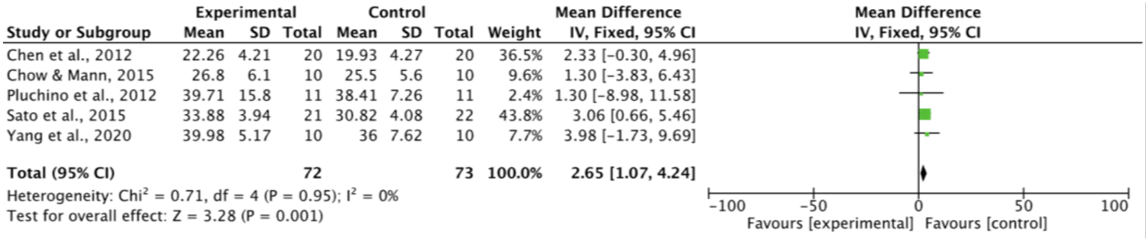

Figure 6 – Mean difference between experimental and control group in FRT results in the selected studies.

A notable strength of this meta-analysis is the absence of observed heterogeneity (I^2 = 0%), indicating high level of consistency among the included studies. This suggests that the null finding is stable across different study contexts.

In summary, although some individual studies reported positive mean differences in Single Leg Stance performance (albeit not statistically significant), the overall pooled evidence does not support the conclusion that the experimental intervention leads to a significant improvement in static balance as measured by the SLS test.

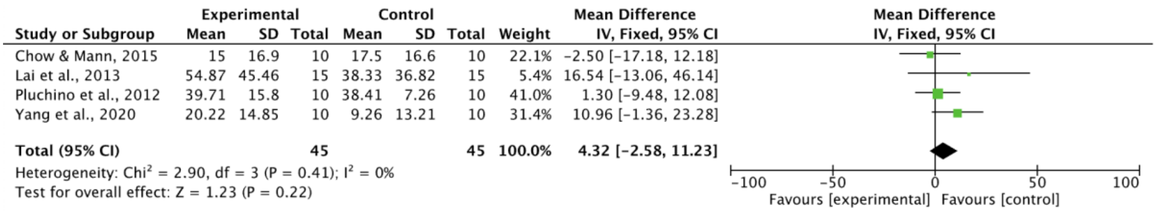

Figure 7 – Mean difference between experimental and control group in SLST results in the selected studies

4. Discussion

4.1 Main Results

This systematic review critically examined the characteristics and effectiveness of game-based and gamified interventions aimed at improving balance and reducing fall risk among community-dwelling older adults. Overall, the methodological quality of the included studies was considered good.

Although the predefined inclusion criterion specified participants aged ≥65 years, studies including mixed samples with community-dwelling adults aged≥60 years were also considered eligible when population characteristics and the clinical focus of the research addressed fall risk. This decision was made to maximize clinical relevance and transferability of the findings [7], [21]. It also aligns with the WHO definition of older adults (≥60 years) and with evidence often begin from approximately 60 years of age [51], [52], [53], [54], [55], [56]. Including participants aged 60–64 therefore avoided the unnecessary exclusion of relevant trials and improved the representativeness of community-dwelling populations engaged in digital or gamified balance interventions [3], [51], [52], [53], [57].

Table 1. Characteristics of the studies included

Author	Year	Study design	Sample size				Population characteristics		Mean Age (yr) Total EG CG	Protocol Treatment/ Intervention – Type and duration		Follow up	Outcome measured
			CG	EG	M	F			EG	CG	Duration		
[19]	2013	RCT	6	6	NA	NA	Community dwelling older adults. 70- 92 years old	81.5±5.5 82.5 ± 1.6 80.5 ± 7.8	Supervised individual training - Wii Fit and Wii Balance Board (Series of exercises and activities)	Continued their normal daily activities	3 weeks 3 times a week 30 minutes	1 month	Balance - Berg Balance Scale, Fullerton Advanced Balance scale Timed Up and Go
[27]	2012	RCT	20	20	25	15	Community older adults ≥ 65 years	Unknown 76.41±7.35 75.39(8.45)	Supervised individual Force plate of Lower limb power rehabilitation (LLPR) system (fast speed sit-to-stand movements) (videogame-based power training)	Slow speed STS movements, as well as strengthening and balance exercises	6 weeks 30 minutes 2 times a week		Modified falls efficacy scale (MFES), Tinetti Performance-Oriented Mobility Assessment (POMA), Functional reach test (FRT), Five times sit to stand (FTSS) and Timed Up and Go (TUG)
[30]	2015	RCT	10	10	7	13	Community dwelling older adults 65 -78 years	69 70.4(5.4) 68(3)	Supervised daily cyber-golfing training. (Exergame "Tiger Woods PGA Tour 13")	Supervised regular table games	2 weeks Daily 30-45 minutes/ session	1 week	Risk of fall (TUG) Static balance (single leg stance) Balance (Functional reach test)
[28]	2020	RCT	12	16	7	19	Older adults Living independently at home 65 years or above	83.54 (7.12) Unknown Unknown	Playful exercise on Moto tiles And daily physical activity - light mobility exercise training -recorded by activity trackers (SENS motion sensors)	Normal daily activities - mobility exercise - recorded by activity trackers (SENS motion sensors)	12 weeks 6 times 2 minutes spread over 1hour in 2-min session)		Balance (Berg Balance score) (primary outcome) Aerobic capacity of lower body- 30 second Chair Stand Test (CST) Aerobic capacity and endurance - 6-minute walking test (6MWT)

[7]	2021	RCT	20	20	16	24	Community dwelling participants 60 - 85 years old	unknown 69.95 |2.72) 72.45±5.16)	Information technology convergence gamification with Balpro110 (combines various game contents)	Conventional exercise (exercise videos)	8 weeks 30 minutes 3 times a week	4 weeks	Five times Sit to stand (primary) (FTSST) Berg Balance Scale (BBS) Timed Up and Go (TUG) 10-m Walking Test (10MWT) Chair Sit and Reach (CSR) Korean Falls Efficacy Scale-International (KFES-I)
[26]	2013	RCT	15	15	13	17	Community-living persons Over 65 years old	72.1±4.8 76±7.74 74.8 ±4.7	First 6 weeks - IVGB intervention phase; Subsequent 6 weeks (no exercise) (Xavix Measured Step System (XMSS), from SPECTRUM9000MB-500system, UIS Co., Japan) (supervised)	6 weeks (control phase) – no treatment, following 6 weeks- IVGB training (intervention phase) (supervised)	6 weeks 30 minutes 3 times a week	6 weeks	Berg Balance Scale (BBS) Timed Up and Go (TUG) Modified Falls Efficacy Scale (MFES) Unipedal Stance test (UST), XMSS stepping test. Sway Area (SA) and Sway Velocity (SV) of the center of pressure (COP) in a bipedal stance with eyes open and closed.
[29]	2012	RCT	11 11 (CG2)	11	25	15	Healthy community older adults	70.72±8.46 76±7.74 70.72±8.46 69.28±6.03 (CG2)	Wii Fit- balance board program (training facility)	CG1 -Tai-chi (Sun-Style) CG2 - SBEP (standardized balance exercise	8 weeks 5/8 games daily for 10 minutes each game		Timed Up and Go (TUG) Tinetti balance (TB) One leg Stance (OLS)

										program) (training facility)			Falls risk for older people community Setting (FROP-com) Functional Reach (FR) Falls Efficacy Scale (FES) Posturography
[20]	2015	RCT	22	21	NA	NA	Healthy community older individuals	69.25±5.41 70.07(5.35) 68.5±5.47	Supervised intervention game based (Kinect and Kinect SDK version 1.5 (Microsoft) and Unity version 3.4.2 (Unity Technologies SF Inc.)	Daily living as usual	8 weeks 2 to 3 times per week. 40-60 minutes		Berg Balance Scale (BBS) Functional Reach test (FRT) 30-second chair stand test (CS-30 test)
[21]	2020	RCT	10	10	2	18	Community older adults over 60 years	Unknown 68.71(64.09-74.84) 67.54(62.08-76.75)	Supervised in group exercise - Kinect (for Xbox 360) Exercise Group	Conventional exercise group (for falls prevention)	5 weeks 45' each 2 times a week		0- second Chair Stand Test (30 sec CST) Timed Up and Go Functional Reach Test (FRT) One Leg Stance Test (OLST)

Table 2 - Global description of the key findings of the studies

Author	Abstract summary / Aim	Journal	Major findings
[19]	To investigate feasibility of using Nintendo's Wii Fit for training to improve clinical measures of balance in older adults.	Clinical Interventions in Aging	Balance Berg Scale (p=0,037). High feasibility of implementing Wi Fit program at home was founded.
[27]	To compared training group exercise on a force plate to lower limb power training with slow STS, and balance exercises only.	Archives of Gerontology and geriatrics	Both low and high velocity resistance training could improve muscle strength (0,001), but only high velocity resistance training could improve muscle power (p=0,045). Exercise group showed significantly better scores on functional performance (balance, mobility, and self- confidence), p<0.05.
[30]	This study intends to evaluate if exergaming, in particular cyber-golfing, can be a feasible and inexpensive alternative to balance training. It found that cyber-golfing might be an alternative to golfing, which is capable to enhance balance ability	Hong Kong Journal of Occupational Therapy	Cyber-golfing might be an alternative capable to enhance balance ability measured with functional reach test and single leg stance, amongst community-dwelling (F=5,32, p=0,03, with the effect size of 0.24 and F=5,16, p= 0,04, with the effect size of 0.23, respectively) which may influence and decrease risk of fall. Cyber-golfing exergame may be considered a therapeutic activity for static balance training in geriatric care, and could be a feasible alternative to facilitate physical-activity participation of healthy community-dwelling older adults
[28]	To measure the effects pf a playful exercise intervention with Moto tiles on functional ability and daily physical activity and how it may empower older adults' functional and physical ability	Journal of population ageing	Playful exercise created a joyous social atmosphere among the participants, and the sessions seems to be much more fun than standard light exercise program done before. Between-group differences were not observed (mean difference on BBS and chair stand test score of both groups with a p value 0.11 and 0.70 respectively), which means that the results don't show significant, improvements on balance outcomes.
[7]	Analyse safety and efficacy of information technology convergence gamification exercise equipment (Balpro110) comparing with conventional exercise in older adults.	Journal of Post-Acute and Long-Term Care Medicine (JAMDA)	Informational technology convergence can be used safely in older adults. Exercises using the Balpro110 has similar effects to conventional exercise and is a good alternative to exercise for older adults. FTSS_30, BBS, and KFES-I showed greater functional improvement in experimental group, (p<0.15). A more interesting approach is possible by combining various contents.
[26]	To study the effects of Interactive Videogame Based (IVGB) training on the balance of older adults.	Gait & Posture	A significant improvement was observed in outcome measurement parameters in both groups ate the 12-week assessment on XMSS, MFES and BBS score (p value < 0.05 and <0.001 respectively). The Xavix Measured Step System (XMSS) was used to measure stepping and perform IVGB exercises. XMSS show moderate correlation with all outcome measures (BBS, MFES, TUG, UST) (≤0.3 r≤0.49), Video game-based intervention, compared with traditional stepping exercises, may be more feasible and attractive and provides a purposeful and challenging exercise.

Table 2 (continued)

[29]	To compare changes in balance and postural control resulting from the Wii Fit balance program (Wii), a standardized balance exercise program, and a Tai Chi program (Tai Chi)	Archives of Physical Medicine Rehabilitation	It shows that Wii system produced similar improvements in postural control and balance when compared with the other interventions in healthy, independent-living persons, except on Centre of Pressure Area with a p value of 0.00 and on overall linear displacement (Dynamic Posturography Measurements score), with a p value 0.036. Wii balance program has the advantage that can be used at home, with few costs. The small sample size may justify the lack of differences among training interventions across the training period (low statistical power).
[20]	To analyse the effects of using an exergame that uses a Kinect® sensor on muscle strength and balance in healthy older adults' individuals and found its effectiveness in improving walking, muscular strength, and balance in older adult's people.	Games for Health Journal	Even without a specific walking element, the exergame caused an improvement in everyday walking movements and appears to be highly effective in maintaining and improving motor function with significant improvements on BBS, FRT and CS scores in the intervention group, with $p<0.001$. Exergame seems to facilitate effective exercise without the need of an instructor.
[21]	To compare the feasibility, safety, and effectiveness of Kinect exercise against conventional exercise over balance training among the community older adults. Virtual reality creates an interactive simulated environment capable of immersing users in a virtual setting	Medicine	Both treatments were helpful in improving the participants' balance performance with a p value <0.005 on different outcome measures (30-sec CST, TUG, FRT, OLST). Kinect exercise was more effective in terms of overall balance ability and was particularly beneficial to functional reach enhancement in comparison with traditional exercise. Kinect exercise could be a feasible, safe, and effective alternative for dynamic balance training among older adults.

CST(Chair Stand Test), TUG (Timed Up and go), FRT (Functional Reach Test), OLST (One Leg and Stance Test)

Table 3 – Pre- and post-intervention results of the studies included in the quantitative analysis.

Author	Intervention type		Outcome measure	Results				*P* value
	EG	CG		EG pre int	EG PI	CG pre int	CG PI	
[19]	Wii Fit and Wii Balance Board	Daily normal activity	TUG BBS	12.8 (12.2–14.9) 50 (47.5–51.5)	11.2 (10.6–14.3) 53 (52–54)*	10.8 (9.2–19.2) 51 (44–54)	10.1 (9.3–17.1) 54 (43–54.5)	0.174 0.037
[27]	Force plate of Lower limb power rehabilitation (LLPR) system	Slow speed exercise	TUG	17.15 ±4.4	12.90 ± 3.07	15.98 ± 6.52	13.83 ± 5.97	0.026
[30]	Cyber-golfing - Exergame "Tiger Woods PGA Tour 13"	Regular table game	TUG	13.2 ±4.1	NA	10.7±2.8	NA	0.53
[28]	Playful exercise on Moto tiles	Normal daily activity	BBS	41.32±11.27	46.4±8.9	42.3±7.56	44.3±9.56	0.11
[7]	Information technology convergence gamification with Balpro110	Exercise videogame	BBS TUG	54.65 ±1.04 7.73± 0.97	55.8±0.41 7.00 ± (0.96)	54.70 ±1.34 7.57 ±1.25	55.55±0.69 6.85±0.89	0.63 0.34
[26]	IVGB (Xavix Measured Step System (XMSS), from SPECTRUM9000M255B-500system, UIS Co., Japan)	IVGB	BBS TUG	50.53±4.75 9.54±3.52	53.93±3.45 8.53±2.88	46.47±9.98 14.07±8.35	50.67±8.19 11.27±6.33	<0.001 0.002
[29]	Wii Fit- balance board program	Balance exercise	TUG	7.71±2.34	8.18±2.44	9.38±1.86	9.44±1.49	NA
[20]	Kinect and Kinect SDK version 1.5 (Microsoft) and Unity version 3.4.2 (Unity Technologies SF Inc.)	Normal daily activity	BBS	55.31 (56)*	55.97 (56)*	55.68 (56)*	55.64 (56)*	<0.01
[21]	Kinect (for Xbox 360) Exercise Group	Conventional exercise	TUG		7.46 (6.77–8.41)**		7.85 (7.41–8.53) **	0.47

NA (not available); EG (experimental group); CG (control group); PI (post intervention); Data presented as median (IQR); ** Data presented as median(Q1-Q3); TUG (Timed up and Go test); BBS (Berg Balance Scale)

All included interventions incorporated structured exercise components, reinforcing existing evidence that gamified approaches represent a promising and engaging modality for promoting physical activity among older adults. These findings are consistent with previous systematic reviews reporting that game-based exercise can increase participation and adherence to physical activity programmes in older populations [25], [58], [59]. Considering that regular physical activity is a key protector factor against of falls and fall, such interventions may represent a valuable strategy for fall prevention [3], [60], [61], [62], [63].

The meta-analysis yielded mixed results across the primary outcome measures. Significant improvements were observed in the FRT (dynamic balance, and stability), reflecting enhanced dynamic balance and stability. Improvements were also reported in some studies for the BBS and on SLST [7], [26], [28]. However no statistically significant pooled effect was identified on the TUG test (p=0.49). These findings suggest that the effects of game-based interventions may vary depending on the specific balance assessed, with stronger effects observed for dynamic balance tasks.

The significant pooled effect observed for the BBS should nevertheless be interpreted cautiously, given the moderate heterogeneity identified across studies (I2=58%) and the potential influence of smaller sample sizes on the pooled estimate. Variations in intervention characteristics and participant profiles may also have contributes to this variability [20], [27], [29].

The substantial methodological heterogeneity across the included trials represents a key factor limiting the comparability and interpretation of the findings. Differences were observed in technological platforms (e.g., repurposed commercial off-the-shelf systems such as Wii versus purpose-built virtual reality systems), intervention protocols (e.g., duration, frequency, and level of supervision), and participant characteristics.

4.1.1 Game design features and engagement mechanisms

Beyond the exercise components themselves, several game design features embedded in exergame systems may contribute to increased engagement and adherence. Elements such as real-time visual feedback, goal-oriented tasks, progressive difficulty levels, and interactive environments can enhance motivation by providing immediate information about performance and reinforcing task accomplishment. These features may transform repetitive balance exercises into more stimulating and meaningful activities for older adults.

In addition, the challenge-based and interactive nature of many exergames may stimulate attentional and cognitive processes that are relevant for postural control and motor learning. Such mechanisms may partly explain why several studies reported improvements in dynamic balance outcomes, particularly in tasks that require continuous postural adjustments and movement coordination.

Although several included studies suggest that game-based interventions may be implemented using relatively low-cost technologies and potentially unsupervised formats [19], [20], [29], the present review did not formally assess the cost-effectiveness or long-term adherence outside supervised settings.

Importantly, the conclusions of this review are primarily based on functionality and balance outcomes uses as proxies for fall risk. Only two included studies reported actual fall incidence. Consequently, the available evidence remains insufficient to determine whether game-based interventions directly reduce long-term fall incidence.

Overall, the findings of this review suggest that game-based and gamified interventions may provide clinically meaningful benefits in specific domains of balance, particularly functional reach capacity, while also promoting motivation and adherence to physical activity programs through interactive and feedback driven exercise formats among older aldults.

4.2 Limitations

A key limitation of this review is the relatively small sample sizes of the included studies, which typically range from 12 to 43 participants per trial. This restricts the generalizability of the findings to the broader population of older adults and limits the statistical power to detect significant differences, particularly in subgroup analyses.

Another methodological limitation relates to the blinding procedures reported in the included trails, blinding of participants and therapists is inherently challenging in intervention-based studies, particularly those involving physical activity or game-based training. Consequently, performance bias may have been present in several studies.

An additional methodological consideration concerns the age distribution of the included samples. Although the predefined inclusion criteria targeted participants aged ≥65 years, some studies included slightly younger adults. These studies were retained because individuals aged 60–64 share comparable functional characteristics, trajectories of balance decline and fall-risk profiles with populations aged 65years and over. This approach is consistent with several established fall-prevention reviews and allowed the inclusion of relevant evidence without compromising the representativeness of community-dwelling older adults.

Furthermore, the limited number of studies and outcome measures, together with substantial methodological heterogeneity (e.g., differences in intervention protocols, outcome instruments and types of digital game-based technologies), restricted direct comparisons across studies and may explain the modest effect sizes observed.

Another important limitation of this review is the reliance on balance and mobility outcomes as proxies for fall risk, since only two included studies report actual fall incidence. Given the multifactorial nature of falls, improvements in a single proxy measure do not necessarily translate into a reduction in fall events. In addition, methodological issues such as the lack of long-term follow-up, potential performance and detection bias and he absence of studies examining non-digital game interventions, may affect the certainty of the available evidence.

A further limitation relates to the predefined search timeframe. The review followed a protocol established prior to data extraction, and the search timeframe reflected the state of the literature fat that time. Technology-orientated databases (e.g. IEEEXplore, ACM Digital Library and SCOPUS), was not included, as these sources primarily index computer science and engineering publications and typically yield limited clinical trial evidence on fall-prevention interventions in older adults. The selected databases (Web of Science, ScienceDirect, and PubMed), were considered more appropriate for capturing health and clinical research in this field.

For studies excluded from the meta-analysis due to missing statistical data (e.g. mean values and standard mean deviations), were not followed up by us contacting the corresponding authors to obtain the required information. This represents a limitation on the present review.

4.3 Related Work

This review builds upon prior literature by providing a comprehensive and up-to-date synthesis of game-based interventions. While earlier systematic reviews often focused exclusively on specific technological modalities (e.g., exergames), the present review integrates evidence across a broader spectrum of playful and game-based interventions including exergames, virtual reality, and different gamified interventions. In addition, it offers a comparative analysis across several core balance outcomes (FRT, BBS, TUG, SLST).

Within this broader methodological framework, our findings are consistent with those reported by Fang [64] who demonstrated that exergames can improve balance and increase participants' confidence. However, these findings should be interpreted cautiously due to the methodological heterogeneity observed across studies, particularly regarding the types of exergames, technological devices employed, and intervention protocols.

The results of the present review also reinforce previous evidence suggesting that older adults tend to prefer gamified exercise over traditional exercise programmes, echoing findings reported in earlier studies [25], [58], [59], [64], [65]. This preference may contribute to overcoming common barriers to physical activity, including cost, time constraints, transportation difficulties, limited feedback, and reduced body awareness [6], [65], [66].

5. Conclusions

This study aimed to investigate whether serious games and gamified interventions enhance balance and reduce fall risk in community-dwelling older adults aged 65 years and over, compared with conventional exercise programmes, non-gamified interventions, or control conditions.

The findings of this systematic review indicate that multicomponent physiotherapy programmes incorporating game-based and gamified strategies may improve specific balance outcomes in community-dwelling older adults, particularly dynamic balance and functional task performance. However, these findings are based on a limited number of studies and rely predominantly on proxy balance measures rather than direct fall incidence.

Beyond measurable clinical outcomes, gamified interventions may represent an innovative approach to physiotherapy delivery. By integrating principles of feedback, progression, challenge adaptation, and engagement into therapeutic exercise, these interventions may complement conventional physiotherapy by improving adherence and sustained participation—key factors for long-term functional improvement.

Importantly, gamified strategies should not be interpreted as a replacement for traditional physiotherapy, but rather as an extension of the therapeutic process. In this context, game-based interventions may function as structured therapeutic platforms in which motor training, cognitive stimulation, and motivational mechanisms converge.

From a broader digital health perspective, the integration of gamified interventions reflects an ongoing transition toward technology-supported, personalised, and accessible rehabilitation models. Nevertheless, given the small number of included trials, the heterogeneity of interventions, and the absence of direct fall incidence outcomes, these conclusions should be interpreted cautiously.

Future high-quality randomised controlled trials with larger sample sizes, longer follow-up periods, and more standardised intervention protocols are needed to better establish the clinical effectiveness and implementation potential of these approaches.

Finally, the findings of this review also highlight the decline in balance observed among participants receiving no intervention, reinforcing the importance of maintaining regular physical activity to counteract age-related functional deterioration.

Overall, the evidence synthesised in this review suggests that gamified interventions, particularly those based on exergaming, may contribute to improvements in dynamic balance, functional reach, and physical performance, while also promoting motivation and engagement in physical activity among older adults.

5.1 Future research

Further rigorous research is required to determine the most effective implementation strategies, mechanisms of action, optimal dosage, and dose–response relationships associated with specific game-based and gamified interventions. Future studies should also examine the population characteristics that may influence responsiveness to these interventions, as well as how different game mechanics may target distinct components of balance (e.g., static versus dynamic balance).

Research should also explore user experience and usability, as these factors may significantly influence the success and sustainability of game-based interventions. It would be valuable to investigate whether collaborative or co-design approaches with end users affect engagement, adherence, and long-term participation. Understanding how core game design elements—such as mechanics, dynamics, and aesthetics—contribute to intervention effectiveness is also essential. Additionally, future studies should examine the role of user-centred design in improving therapeutic outcomes.

Moreover, there is a clear need for more targeted research on serious games and different interaction interfaces, including analogue (non-digital) games. Investigating the effectiveness of such approaches in enhancing both physical and cognitive function is particularly important for older populations with limited access to digital technologies. Expanding the scope of research to include analogue formats may help bridge the digital divide and ensure that evidence-based interventions remain inclusive and accessible across diverse demographic and socioeconomic contexts, particularly in rural or low-resource settings.

Future studies should also prioritise the direct measurement of fall incidence as a primary outcome. This is essential to determine whether improvements observed in proxy measures of balance and mobility translate into meaningful reductions in fall events.

In addition, future research should examine the level of immersion provided by serious games compared with gamified interventions and investigate how psychological constructs such as autonomy and perceived competence within the game environment influence motivation for rehabilitation. The practical feasibility of integrating these interventions into routine physiotherapy practice should also be evaluated from an implementation perspective.

To enhance the quality and comparability of evidence, future studies should employ larger sample sizes and greater standardisation in key methodological aspects, including the type of game or platform used, intervention duration, and outcome measures. Importantly, research should also investigate which specific game elements or mechanics (e.g., feedback systems, reward structures, and interactive components) are most effective in improving balance outcomes.

Finally, there is a clear need for a greater number of high-quality randomised controlled trials (RCTs) to robustly evaluate the impact of gamification not only on physical performance, balance, and fall risk, but also on psychological outcomes such as motivation, self-efficacy, and overall physical activity levels in adults aged 65 years and older. Expanding the evidence base through well-designed RCTs will strengthen the validity and reliability of future systematic reviews and meta-analyses, ultimately supporting more evidence-informed practice in clinical and community settings.

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Conflicts of interest

All authors have disclosed any commercial associations that might create conflicts of interest in connection with the submitted manuscript. The authors have no competing financial interests to declare

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Supplementary Data 1

A literature search was conducted using the following medical terms (mesh) and keywords:

Older adults	Gamification	Balance	Children	Dementia
Aged	Game	Fall	Stroke	
Older	Play	Clinical study	Parkinson's	

The links used and query strategy on each data base was as follows

Data base	Query strategy	Results	Link to query strategy
Science direct	older adults OR older or aged) and (gamification OR game or play) and (balance OR fall) NOT (stroke OR children OR parkinson) AND clinical study AND research articles; years – custom range:2010-2023	1222 results	https://www.sciencedirect.com/search?articleTypes=FLA&lastSelectedFacet=accessTypes&qs=%28elderly+OR+older+or+aged%29+and+%28gamification+OR+game+or+play%29+and+%28balance+OR+fall%29+NOT+%28stroke+OR+children+OR+parkinson%29+AND+clinical+study&show=100&years=2023%2C2022%2C2021%2C2020%2C2019%2C2018%2C2017%2C2016%2C2015%2C2014%2C2013
Pubmed	((("aged"[MeSH Terms] OR "aged"[All Fields] OR "older adults"[All Fields] OR "elderlies"[All Fields] OR "older adults s"[All Fields] OR "older adultss"[All Fields] OR ("aged"[MeSH Terms] OR "aged"[All Fields]) OR ("older"[All Fields] OR "olders"[All Fields])) AND ("gamification"[MeSH Terms] OR "gamification"[All Fields] OR "game"[All Fields] OR (("board"[All Fields] OR "board s"[All Fields] OR "boards"[All Fields]) AND "game"[All Fields]) OR "play*"[All Fields]) AND ("balance"[All Fields] OR "balanced"[All Fields] OR "balances"[All Fields] OR "balancing"[All Fields] OR "fall"[All Fields]) AND ("clinical study"[Publication Type] OR "clinical studies as topic"[MeSH Terms] OR "clinical study"[All Fields])) NOT ("stroke"[MeSH Terms] OR "stroke"[All Fields] OR "strokes"[All Fields] OR "stroke s"[All Fields] OR ("child"[MeSH Terms] OR "child"[All Fields] OR "children"[All Fields] OR "child s"[All Fields] OR "children s"[All Fields] OR "childrens"[All Fields] OR "childs"[All Fields]) OR "park*"[All Fields])) AND (2010:2023[pdat])	149 results	https://pubmed.ncbi.nlm.nih.gov/?term=%28older+adults+OR+aged+OR+older%29+and+%28gamification+OR+game+OR+board+game+OR+play*%29+and+%28balance+OR+fall%29+AND+clinical+study+NOT+%28stroke+OR+children+OR+park*%29&filter=hum_ani.humans&filter=age.aged&filter=years.2013-2023&size=200
Web of Science	**older adults or aged or older** (Abstract) and **gamification or game or play** (Topic) and **balance or fall** (Topic) and **clinical study** (Topic) not **children** (Topic) not **stroke** (Topic) not **parkinson's** (All Fields) not **dementia** (Topic) and **2023** or **2022** or **2021**or **2020** or **2019** or **2018** or **2017** or **2016** or **2015** or **2014** or **2013** or **2012** or **2011** or **2010**(Publication Years) and **English** (Languages)	226 results	https://www.webofscience.com/wos/woscc/summary/2d7da62c-2952-494a-839a-462bcb56c0a1-fd267c01/relevance/1

Supplementary Data 2 – Excluded articles after abstracts screening and data extraction, and reason for exclusion

Article Reference	Reason for exclusion
Bakker, L. Donath, and R. Rein, “Balance training monitoring and individual response during unstable vs. stable balance Exergaming in elderly adults: Findings from a randomized controlled trial,” *Exp. Gerontol.*, vol. 139, Oct. 2020, doi: 10.1016/J.EXGER.2020.111037.	Outcome fall and balance not measured /included on the study.
Willaert, A. Willem De Vries, J. Tavernier, J. H. Van Dieen, I. Jonkers, and S. Verschueren, “Does a novel exergame challenge balance and activate muscles more than existing off-the-shelf exergames?”, doi: 10.1186/s12984-019-0628-3.	Outcome fall and balance not measured /included on the study
S. S. Studenski S. Perera, E. Hile, V. Keller, J. Spadola-Bogard, and J. Garcia, “INTERACTIVE VIDEO DANCE GAMES FOR HEALTHY OLDER ADULTS”.	Institutionalized participants – not community-dwelling and evaluated outcomes participants different from the inclusion criteria/research question
D. Schoene, S. R. Lord, K. Delbaere, C. Severino, T. A. Davies, and S. T. Smith, “A Randomized Controlled Pilot Study of Home-Based Step Training in Older People Using Videogame Technology”, doi: 10.1371/journal.pone.0057734.	It’s not a game or a game-based intervention; it’s a dance platform and the goal of the study is it’s validation
M. Sápi, A. Fehér-Kiss, K. Csernák, A. Domján, and S. Pintér, “The Effects of Exergaming on Sensory Reweighting and Mediolateral Stability of Women Aged Over 60: Usability Study,” *JMIR Serious Games*, vol. 9, no. 3, Jul. 2021, doi: 10.2196/27884.	Outcome fall and balance not measured /included on the study.
J. Ku, Y. J. Kim, S. Cho, T. Lim, H. S. Lee, and Y. J. Kang, “Three-dimensional augmented reality system for balance and mobility rehabilitation in the elderly: A randomized controlled trial,” *Cyberpsychol. Behav. Soc. Netw.*, vol. 22, no. 2, pp. 132–141, Feb. 2019, doi: 10.1089/cyber.2018.0261.	In-hospital participants
R. Khanmohammadi, G. Olyaei, S. Talebian, M. R. Hadian, B. Hossein, and S. Aliabadi, “The effect of video game-based training on postural control during gait initiation in community-dwelling older adults: a randomized controlled trial,” *Disabil. Rehabil.*, vol. 44, no. 18, pp. 5109–5116, 2022, doi: 10.1080/09638288.2021.1925360	Outcome fall and balance not measured /included on the study. Measures lower limb strength
J. Due Jessen and H. Hautop Lund, “Study protocol: effect of playful training on functional abilities of older adults-a randomized controlled trial”, doi: 10.1186/s12877-017-0416-5.	Is a RCT study protocol, not a RCT
H. Y. Hou and H. J. Li, “Effects of exergame and video game training on cognitive and physical function in older adults: A randomized controlled trial,” *Appl. Ergon.*, vol. 101, May 2022, doi: 10.1016/J.APERGO.2022.103690	Outcome fall and balance not measured /included on the study. Measures lower limb strength.
L. Herminia Gallo, E. Valevein Rodrigues, J. Melo Filho, J. Barbosa da Silva, M. O. Harris-Love, and A. Raquel Silveira Gomes, “Effects of virtual dance exercise on skeletal muscle architecture and function of community dwelling older women”, Accessed: Mar. 03, 2023. [Online]. Available: http://www.ismni.org	Outcome fall and balance not measured /included on the study.

Supplementary Data 3

Extraction table describing the game elements known form the include studies, such as feedback, progression, rewards, narrative, social features, difficulty adaptation, or platform.

Author	Game or game-based intervention	Game elements	
		Narrative/game dynamics	**Feedback**
[19]	Wii Balance Board with Wii Fit	a series of exercises and activities chosen from the yoga (half-moon, chair, warrior), aerobic (torso twists), and balance games (soccer heading, ski jump) modes	consistent challenge was observed with the participants score during the balance games as training progressed.
[27]	Forceplate of LLPR system uni-xial force plate and a computer system with a video game-based power training exercise	The trainee completes a squat movement and successfully reached the target power, set on the beginning by a physical therapist. The mouse was activated for gameplay	Video-game-based training program was set to be controlled by participants' lower limb power during STS movements. Video game was controlled by single clicks of the left mouse button. Progression - program would be switched on once the threshold of lower limb muscle power was reached
[30]	Xbox 360 Kinect (Microsoft Corporation, Hong Kong) exergame called "Tiger Woods PGA Tour 13	A 10-hole cyber golf gaming mode was selected.	All participants were required to finish the whole game
[28]	Gabe based and playful training using a Moto tiles tool, connected with a tablet via Bluetooth	Variety of different interactive games that challenge the players in different abilities, such as dynamic and static balance, agility, endurance and reaction.	Each tile contains a microprocessor, a battery, interface for communication, sensor, and 8 coloured LEDs in a circle which will shine in different coloured patterns to give visual feedback to participants
[26]	Xavix Measured Step System (XMSS), from SPECTRUM9000MB-500system, UIS Co., Japan	Interactive videogame based (IVGB) to stepping exercise	Results were shown on the screen, providing instant feedback to participants. Time spent standing, time spent exercising and total virtual distance travelled can be recorded during the exercise.
[7]	Information Technology convergence gamification exercise with, Balpro110 Model No. SBT 110, Men&Tel, Kore	Technology with game contents to improve strengthening, balance and cognitive training exercises programs including and uses an augmented reality (AR) e-based training system that links those various	Game content involved matching pictures (training to pair the same picture cards after showing the card arrangement for a certain period time, balance training of the lower extremities using scaffolds), solving quizzes (lower extremity training to hold the suggested position for a certain period of time after solving the quiz), obstacle running (lower extremity training to avoid running obstacles), and fruit picking (exercise that detects upper extremity movements by taking specified fruits and putting them in the box below) in consideration of the exercise program of the conventional exercise group.
[29]	Wii Fit Balance Program (balance game portion)	Participants were instructed to step on the Wii Fit balance-board and follow the instructions for the different games available. Games used for the balance program were soccer heading, ski slalom, ski jump, table tilt, tightrope walk, river bubble, penguin slide, snowboard slalom and lotus focus. The games were based on the control of an on-screen avatar using body movements that are detected by the balance board.	Personal profile of the participant was entered into the system so his or her progress could be tracked and difficulty levels could be adjusted to each person's training program according to his or her progress: daily progress, goals, and chart activities was set and registers An on-screen trainer is used to lead the user through each exercise and demonstrate proper form. System allowed the participants to perform the activities without a trainer/instructor, as well as to track their progress and goals.
[20]	Kinect and Kinect SDK	Four games were played: Apple game (targets resembling apples were distributed on a 3D coordinate system around the participants, who were instructed to use both arms to grab them). Tightrope	Each Game lasted for 90 seconds and included different levels of difficulty. The level of difficulty increased, the targets were more widely distributed

	version 1.5 (Microsoft) and Unity version 3.4.2 (Unity Technologies SF Inc., San Francisco, CA), a three-dimensional (3D) support tool/engine used with Kinect	standing game, (place feet along a straight line and stand as if they were standing on a tightrope (tandem tanding); balloon popping game, (targets resembling balloons moved in an arc over the game screen in front of participants, who were instructed to pop them when they passed through) and one-leg standing game, (participants were instructed to stand on one leg and use their knee to touch a ball that appeared in front it)	
[21]	Kinect exercise group. The hardware devices used in this group were a Microsoft Kinect for Xbox 360, projector, and stopwatch; the game software was Your Shape: Fitness Evolved II (Chinese version).	Exergame Zen Mode of Your Shape: Fitness Evolved I and II (was selected). Zen Energy (a slow and gentle fitness game; composed by some movements like tai chi and yoga); Yoga game (relaxation and coordination game that emphasizes stretching, stability, coordination, and control); Destination Bollywood uses brisk rhythms and dance moves, rhythmic dancing involving all limbs, and abdomen and hip exercises); Cardio Boxing is based on boxing moves combined with squatting, left–right weight shifting, and kicking in coordination with slow to fast beats; and Humana Vatality and Cardio share similar contents, focusing on lower-limb muscle endurance and weight shifting.	Games provide a variety of dynamic balance activities and focus on highly repetitive limb movements