

*Running title: Effect of Technology based Rehabilitation for Balance*  
**Effectiveness of Technology-based Rehabilitation for Balance Issues  
in Elderly Population: A Systematic Review**

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**ABSTRACT**

**Introduction**

Falls are a leading cause of injury and reduced quality of life among the elderly. Over 30% of individuals aged 65+ fall each year, and recurrence rates are high. Age-related conditions like sarcopenia, osteoporosis, obesity, and cognitive impairments increase fall risk. Exercise therapy has proven effective in improving balance and reducing falls, and innovative technologies like Virtual Reality, Augmented Reality, Wii-Fit, and exergaming offer engaging, interactive alternatives to conventional therapy.

**Method**

This systematic review followed PRISMA guidelines and included 19 primary studies (18 RCTs, 1 Pre-Post Analysis) involving 1088 participants aged 65+, assessing outcomes using the Berg Balance Scale, Timed Up and Go Test, and Fall Efficacy Scale.

**Results**

The review of 19 studies (18 RCTs, 1 Pre-Post Analysis) involving 1088 participants revealed that technological interventions significantly improved balance and mobility, as evidenced by changes in BBS and TUG scores. Enhanced user engagement and cognitive function were also indicated in some studies. Technologies such as Virtual Reality, Augmented Reality, force plate systems, biofeedback, sensory visual feedback, and kinetic exergaming proved beneficial.

**Conclusion**

Technology-based balance training offers a promising method for fall prevention in older adults, with potential for user-friendliness and cost-effectiveness, while yielding measurable improvements in physical outcomes, and in some instances, cognitive engagement. This review consolidates recent evidence, demonstrating the specific contexts and technologies where this approach offers a robust alternative or complement to traditional physiotherapy, particularly by synthesizing outcomes across specific validated scales.

**Keywords:** Virtual Reality, Augmented Reality, Balance, Elderly, Technology.

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**INTRODUCTION:**

Falls are a common cause of injury in the elderly, often leading to significant disabilities and a decline in quality of life. Statistics show that over 30% of individuals aged 65 and above experience at least one fall each year, and nearly half of these individuals

suffer from recurrent falls. With increasing age, the risk of falling also rises, affecting approximately 40% of individuals aged 85 years and older. Around 10% of these falls result in serious injuries to the musculoskeletal or neurological systems, such as fractures, soft tissue injuries, traumatic brain injuries, or hematomas<sup>(1,2)</sup>.

Several factors contribute to the increased risk of falls in the elderly. Sarcopenia (loss of muscle mass) and osteoporosis (loss of bone density) significantly compromise the musculoskeletal system. Other contributing factors include obesity, cognitive impairment, and reduced motor control, all of which can severely impact an individual's ability to perform daily activities and lead to decreased independence. They also lead to prolonged hospital stays and increased financial burden on families<sup>(1)</sup>.

**Exercise therapy is an effective intervention for improving balance and reducing fall risk<sup>(1,2)</sup>.** It positively changes physiology, increasing muscle mass, bone density, motor control, and proprioception, all contributing to **improved physical performance<sup>(1,2)</sup>**. Various exercise programs—including the Otago Exercise Programme, conventional physical therapy, vestibular rehabilitation, Tai Chi, and technology-based interventions like virtual reality (VR), augmented reality (AR), and biofeedback systems—are utilized to improve balance and reduce fall risk. These approaches create interactive and engaging rehabilitation sessions, which improve lower limb strength and postural control, thereby enhancing overall balance<sup>(2)</sup>.

With the evolution of modern technology, healthcare systems are also advancing. Technology has made therapy sessions more interactive, user-friendly, and cost-effective. Tools such as VR, AR, Wii-Fit, exergaming, Kinect Xbox 360°, biofeedback machines, and force platforms are now being incorporated into physical therapy. These tools enhance balance and coordination and are used in various domains of rehabilitation, including neurological, musculoskeletal, and sports therapy<sup>(3-7)</sup>.

Technology-based rehabilitation offers an alternative to conventional balance training by simulating real-world environments that promote motor learning and transfer of skills<sup>(8-10)</sup>. Furthermore, these tools have been shown to improve mobility, reduce fear of falling, and increase the enjoyment and motivation of older adults undergoing therapy. They also support functional improvements by enhancing the musculoskeletal system and the somatosensory, visual, and vestibular systems<sup>(11-15)</sup>.

Despite the growing use and promise of these digital tools, the evidence regarding their effectiveness in improving balance among older adults remains varied, often due to disparate methodologies, diverse technological applications, and inconsistent outcome measures across studies. Therefore, a systematic review is necessary to critically evaluate and

synthesize existing research, aiming to identify consistent patterns of efficacy, explore the impact of different technologies, and clarify the conditions under which these interventions are most effective. This systematic review aims to evaluate the efficacy of technology-based balance training interventions (including VR, AR, exergaming, and biofeedback) on balance, mobility, and fall risk in elderly individuals (aged 65+) with balance issues, as measured by standardized outcome scales, thereby providing a focused synthesis of recent evidence (2014-2024) specific to these key technologies and outcomes.

## **MATERIAL AND METHODS:**

### **Study Design and Registration:**

This systematic review was conducted under the guidelines of Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA). The study protocol was prospectively registered with the National Institute of Health and Care Research (PROSPERO) under the registration ID: CRD42024613240.

### **Eligibility criteria (PICO):**

Studies were selected based on the following criteria:

**Population:** Participants aged above 65 years and older of all genders experiencing balance issues or a high risk of falls.

**Intervention:** Technology-based balance training, including Virtual Reality (VR), Augmented Reality (AR), Wii-Fit, Microsoft kinetic Xbox, Force Plates, Biofeedback, and Kinetic based Exergaming.

**Comparator:** Conventional physiotherapy, standard care, or no-treatment protocols.

**Outcomes:** Quantitative assessment using the Berg Balance Scale (BBS), Timed Up and Go (TUG) test, or the Fall Efficacy Scale (FES).

### **Information Sources and Search Strategy:**

We collected data from electronic databases including Scopus, Science Direct, PEDro (Physiotherapy Evidence Database), PubMed, and EBSCO. The search was restricted to full-text articles published from 2014 to 2024 to ensure the inclusion of contemporary technology-based interventions and reflect the most recent advancements in the field, and available in English. The search strategy utilized Boolean operators (AND, OR, NOT) with keywords

such as “Virtual Reality,” Augmented Reality,” “Wii fit,” “Microsoft Kinetic Xbox,” “Force Plates,” “Biofeedback,” and “Kinetic based Exergaming”.

#### **Study selection:**

Both authors initially screened articles by title and abstract. After removing duplicates and irrelevant records, they retrieved and independently reviewed full-text versions. Disagreements regarding study inclusion were resolved through consensus and discussion.

**The screening process is detailed in the PRISMA flow diagram, showing the progression from the initial 1145 identified records to the final 19 included studies (Figure 1).**

#### **Quality assessment (Risk of Bias):**

The methodological quality and risk of bias for each included study were evaluated using the Joanna Briggs Institute (JBI) Critical Appraisal Tools. RCTs were assessed across 13 domains, including randomization, allocation concealment, and blinding. Systematic reviews were assessed for search strategy adequacy and appraisal methods. Scores were assigned as 1 for “Yes” and 0 for “No/Unclear”. Studies were subsequently categorized as High Quality (Low risk), Medium Quality (Medium risk), or Low Quality (High risk) based on their total scores, with specific thresholds defined as [e.g., 10-13 'Yes' for High Quality, 6-9 for Medium Quality, and below 6 for Low Quality].

#### **RESULT:**

##### **Study Selection and Characteristics:**

The initial database search yielded 1145 articles. After removing 450 duplicates and 277 irrelevant studies, we screened 56 records by title and abstract. Ultimately, 19 studies met the full inclusion criteria, comprising 18 Randomized Controlled Trials (RCTs), 1 Pre-Post Analysis. The total sample size across all included studies was 1105 participants, with individual study sizes ranging from 12 to 195 individuals.

##### **Quality assessment and Risk of Bias:**

**The JBI Critical Appraisal results showed that among RCTs and Pre-Post Analysis, 12 studies were classified as high quality/low risk of bias, 6 as medium quality, and 1 as high risk. This indicated a high overall standard of evidence.**

Methodological Trends: High-quality RCTs typically RCTs typically utilized true randomization and allocation concealment, though many lacked participant and therapist blinding due to the nature of exercise interventions.

##### **Efficacy by Outcome Measure**

The review focused on three primary validated scales to measure balance and fall risk: the Berg Balance Scale (BBS), the Timed Up and Go (TUG) Test, and the Fall Efficacy Scale (FES).

- **Berg Balance Scale (BBS)**

Eleven studies utilized the BBS to assess functional balance. Significant improvements in BBS scores were observed across various technologies, including Virtual Reality (VR), Augmented Reality (AR), Wii-Fit, Force Platform, Trunk motion visual feedback, and home-based Exergaming. Notably, visual feedback-based force platform training combined with functional electric stimulation showed a significant positive impact on BBS scores compared to control groups. Notably, visual feedback-based force platform training combined with functional electric stimulation showed a significant positive result on BBS scores compared to conventional therapy group.

- **Timed Up and Go (TUG) Test**

Ten studies employed the TUG test to measure dynamic balance and mobility. Of the ten studies employing the TUG test, seven reported statistically significant reductions in TUG times for individuals over age 65. Virtual Reality interventions showed particularly promising results in reducing TUG times, indicating improved gait and lower fall risk.

- **Fall Efficacy Scale (FES)**

Studies using the FES, such as those involving Kinetic-based exergaming, reported reduced fear of falling and improved balance performance<sup>(15)</sup>. These effects were found to be at least as beneficial as combined conventional exercise programs.

#### **DISCUSSION:**

This systematic review explores how modern technology integrates into balance rehabilitation for elderly individuals with fall risk or balance impairments. The findings strongly support the use of advanced technological equipment in hospitals and clinical settings, demonstrating its effectiveness as an

alternative treatment approach. Additionally, two studies conducted in nursing home environments highlighted that such interventions can be simple, effective, and efficient, even in home-based settings. These results point toward the broader applicability and safety of technology-assisted rehabilitation methods. The review encompassed a variety of study designs, including Randomized Controlled Trials (RCTs), pre-post analyses. Chief among these was the heterogeneity in study designs, intervention durations, and exercise protocols, which made direct comparisons between studies challenging. Each study underwent a risk of bias assessment using the Joanna Briggs Institute (JBI) criteria, which categorized them as low, medium, or high risk (Table 1). Specifically, RCTs were assessed using JBI criteria (Tables 2 & 3), while systematic reviews were assessed separately (Table 4).

The majority of the included studies were RCTs, with 11 categorized as low risk, indicating high-quality research. Six studies were rated as medium risk, typically due to minor methodological shortcomings such as lack of participant or assessor blinding, or incomplete reporting of outcome measures. Only one RCT was rated as high risk, primarily due to significant methodological flaws, including inadequate randomization, lack of blinding, absence of outcome follow-up, and poor allocation concealment—ultimately indicating low study quality. (Table 1,2,3,4). One pre-post analysis study was included, which was also rated as low risk and high quality. Despite minor issues such as variability in baseline participant characteristics across the three groups, the study showed promising results, particularly in the use of virtual reality for balance training.

This review demonstrates evidence supporting technology-based rehabilitation as an effective and engaging alternative, with high-quality RCTs showing particular promise for VR, exergaming, and visual feedback systems in improving balance and reducing fall-related fear in older adults

High-quality RCTs consistently showed that Virtual Reality effectively improves dynamic balance and gait, often evidenced by statistically significant reductions in TUG times<sup>(26,28-29)</sup>; Exergaming enhances motivation, reduces fall risk, and improves cognitive engagement<sup>(23,33,35)</sup>; Visual-feedback force platforms significantly improve balance scores on Berg Balance Scale<sup>(24,30)</sup>; Augmented Reality enhances lower-limb strength and stability<sup>(25,31,32)</sup>; Vibrotactile systems show promise as home-based or tele-rehabilitation tools<sup>(4)</sup>. Consistent with findings

across the TUG test, a majority of the included interventions demonstrated statistically significant improvements in balance or mobility. VR, exergaming, AR, and force-platform training showed the strongest and most consistent effects.

Furthermore, the review underscores the promising impact of various technologies such as virtual reality, kinetic exergaming, and visual feedback-based force platform training. These interventions were found to be particularly effective for balance training in the elderly population, supported by the use of reliable and meaningful outcome measures. (Table 5)

Several limitations were identified in the review. Chief among these was the heterogeneity in study designs, intervention durations, and exercise protocols, which made direct comparisons between studies challenging. This heterogeneity limits the generalizability of specific intervention effects and necessitates cautious interpretation of the overall efficacy, suggesting that optimal protocols may vary significantly. Reflecting the medium to high risk of bias identified in several included RCTs (6 medium, 1 high), some studies suffered from small sample sizes and lacked adequate control groups or blinding. These methodological weaknesses may introduce bias, potentially overestimating intervention effects and reducing the certainty of the evidence. Moreover, the review was restricted to only three outcome measures, which significantly limited the number of eligible studies. Future reviews would benefit from including a broader range of outcome measures, such as objective gait analysis parameters, patient-reported fear of falling scales, and measures of cognitive-motor interference, to provide a more comprehensive analysis of intervention effectiveness and real-world impact.

While a meta-analysis would provide statistically robust insights, it was not performed in this review due to substantial heterogeneity across studies in terms of intervention protocols, duration, and specific outcome measures, which precluded meaningful quantitative pooling of data. However, this represents a crucial future direction to provide statistically robust insights and determine the most effective intervention strategies. Researchers are also encouraged to explore the integration of artificial intelligence in treatment protocols. AI has the potential to enhance the interactivity of rehabilitation sessions, reduce human error, and offer more precise and personalized treatment plans—thereby expanding the scope and effectiveness of rehabilitation interventions.

## CONCLUSION:

This systematic review provides promising evidence supporting technology-based rehabilitation as an effective treatment approach for older adults experiencing balance issues. It highlights the potential of emerging technologies such as virtual reality, exergaming, and visual feedback systems in enhancing balance training and potentially reducing the perception of fall risk in the elderly population, as measured by validated scales. Overall, the findings suggest that such interventions offer a simple and effective method for delivering balance training, with significant implications for improving the quality of life among older adults.

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Fig. 1: The Prisma 2020 flow diagram showing the identification, screening, and inclusion of studies in the review.

Identification

Screening

Included

Table 1: Description of Articles according to Risk of Bias

STUDY TYPE	HIGH QUALITY /LOW RISK OF BIAS	MEDIUM QUALITY/M EDIUM RISK OF BIAS	LOW RISK/H IGH RISK OF BIAS
RCT	11	6	1
PRE – POST ANALYSIS	1		

Table 2: Risk Of Bias Assessment for RCT's Using Joanna Briggs criteria

	Y i n g - Y i L i	H a - n a Y o	Ko cha ph an Phi rom	M ic ha el Sc h w en k	Sa ee deh S. D.	K al pa na Pa da la	Yv es J. Gs ch wi nd	Ky eo ngj in Le e	C h i Y a n g

	a								
True randomization used	1	1	0	1	1	1	1	1	1
All ocat ion concealed	1	1	0	1	0	1	1	1	1
Treatm ent groups similar at baseline	0	0	1	0	1	1	0	0	1
Blin din g of participant	1	0	0	1	0	0	0	0	0
Blin din g of person delivering treatment	0	0	0	0	0	0	0	0	0

Time									
Treatment groups treated identically	0	0	0	1	1	1	1	1	1
Blinding of outcome assessor	1	0	0	0	0	0	0	0	0
Outcome measured in same way	0	0	0	0	1	1	1	1	0
Outcome measured in reliable way	1	1	1	1	1	1	1	1	1
Follow up	1	1	1	1	1	1	1	1	1
Participants anal	1	1	1	1	1	1	1	1	1

Randomized group									
Appropriate statistical analysis used	1	1	1	1	1	1	1	1	1
Appropriate trial design used	1	1	0	1	1	1	0	1	1
Total	9	7	5	9	9	10	8	9	9

Table 3: Risk Of Bias Assessment for RCT's Using Joanna Briggs criteria

Eric Ansón	Po- Jun- Chen	W N T S a n g	S e v g i S . Y .	S a e e d Y . B .	J e o n g h u n K u	Pa bl o C a m p o - P r i e t o	N o o l l a Z.	T i a n B a o	Z h e n L i
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True randomization used	1	1	1	1	1	1	1	1	1	1
Allocation concealed	1	1	1	1	1	1	1	1	1	1
Treatment groups similar at baseline	0	1	0	0	1	1	0	1	1	1
Blinding of participant	0	0	0	0	0	0	0	0	1	0
Blinding of person delivering treatment	0	0	0	0	0	0	0	0	1	0
Treatment group	1	1	1	1	1	1	1	1	1	1

ups treated identically										
Blinding of outcome assessor	0	0	0	0	0	0	0	0	0	0
Outcome measured in same way	1	0	0	1	0	0	1	0	1	0
Outcome measured in reliable way	1	1	1	1	1	1	1	1	0	1
Follow up	1	1	1	1	1	1	1	1	0	1
Participants analyzed in randomized group	1	1	1	1	1	1	1	1	1	1

Appropriate statistical analysis used	1	1	1	1	1	1	1	1	1	1
Appropriate trail design used	1	1	1	1	1	1	1	1	1	1
Total	10	9	8	7	7	7	7	7	8	7

											exerted effects that were at least as beneficial as those of combined exercise in improving frailty status and the frailty phenotype.
2	Kochaphan Phrom	RCT	Microsoft XBOX 360 Kinetic sensor V2	3 sessions/week for 12 weeks	TUG	2020	improvement in the physiological fall risk factors including speed processing, body sway, cognitive performance & improve dual-task				

Table 4: Summary of Characteristics Included in the study

Serial No.	Author	Study Design	Intervention	Duration	Outcome Measure	Year	Conclusion
1	Ying-Yi Liao	RCT	Kinect-based exergaming	36 sessions in 12 weeks	FES	2018	Kinect-based exergaming

							performanc e.
3	Michael Schwenk	Pilot study	Integrating sensor-based visual feedback	2 session/week for 4 weeks	TU G	2014	Current findings may help to inform tailored interventions integrating wearable sensors for interactive balance training in a home environment.
4	Saeed S. D.	RCT	Neurofeedback and somatosensory exercises	3 session/week for 5 weeks	TU G	2024	Incorporating neurofeedback training into somatosensory exercises may provide

							additional benefits for older adults in improving balance and mobility
5	Kalpana P. Padala	Pilot RCT	Wii-Fit	3 session/week for 8 weeks	BB S	2017	This study confirms the safety and feasibility of a Wii-Fit exercise program for community dwelling older adults with balance problems & can be used to improve balance.
6	Yves J. Gsc	RCT	Sensor-based	16 weeks	TU G	2015	The findings suggest



9	Eric Anson	RC T	Trunk Motion Visual Feedback	3 sessions/ week for 4 weeks	BB S	2 0 1 9	Older adults with self-reported balance problems improve their dynamic balance after training using trunk motion VFB treadmill walking. Individuals with worse sensory function may benefit more from trunk motion VFB during walking than individuals with intact sensor
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							ly function
1 0	Po- Jun Chen	RC T	Augmented reality with Tai chi	3 sessions/ week for 8 weeks	BB S, TU G	2 0 2 0	The augmented reality-assisted training with selected Tai-Chi movements, designed based on objective measurements of the practitioner's capability, improved balance control and muscle strength of lower limbs at least as effectively as the compl

							ete seque nce of traditi onal Tai- Chi exerci ses.
1 1	W N Tsa ng	RC T	Virtu al Realit y	3 sessi on/w eek for 6 week s	BB S, TU G	2 0 1 6	The impro veme nt in BBS score was signifi cantly more in the Wii Fit than the conve ntiona l balan ce traini ng group (3.7 vs 0.7). This may be attrib uted to the real- time perfor manc e feedb ack and cuing stimul i in the VR

							traini ng to suppo rt error- free learni ng.
1 2	Sev gi S. Y.	RC T	Virtu al Realit y	3 sessi on/w eek for 6 week s	BB S	2 0 1 5	Simi lar impro veme nts were found in balan ce and fall risk with VR- based balan ce traini ng and conve ntiona l balan ce traini ng in older adults living in the nursin g home.
1 3	Sae ed Y. B.	RC T	virtua l realit y	3 sessi on/w eek for 9 week s	TU G, BB S	2 0 2 1	A virtua l realit y traini ng progr am can be used



16	Steven Phu	Pre-Post Analysis	Virtual reality	2 session/week for 6 weeks	TUG	2019	study highlights the potential use of virtual reality as a practical alternative to improve outcomes of balance training for reduction of falls risk in older adults
17	Noorolha Z.	RCT	Virtual reality	2 session/week for 6 weeks	TUG, BB S	2021	According to the results of the present investigation, 6 weeks of VR balance exercises could enhance balance

							ce and fear of falling among elderly people living in nursing homes
18	Tian Bao	RCT	Vibrotactile sensory augmentation	3 session/week for 8 weeks	TUG	2018	The findings of this study support the use of sensory augmentation devices by community-dwelling healthy older adults as balance rehabilitation tools, and indicate feasibility of telere

							habilitation therapy with reduce input from clinicians.
19	Zhen Li	RCT	Visual-feedback based force platform training	15 days/month for 3 months	BBS	2018	This study showed that the visual feedback based force platform training with functional electric stimulation improved balance and prevented falls in older adults

(Abbreviations: TUG: Time Up & Go Test, BBS: Berg Balance Scale, FES: Fall Efficacy Scales)