REVIEWS

Augmented Reality for Balance Rehabilitation in Older Persons: A Scoping Review

Afeef Vehra, HBSc[1,2], Patricia Hewston, MSc, PhD[2,3,6], Manuela Kunz, PhD[5], George Ioannidis, MSc, PhD[2,3,4], Sophia Matarazzo, HBSc[1,2], Teshan Dias Desinghe, MSc[2], Noorain Mamdani, HBSc[2,4], Alexandra Papaioannou, MSc, MD[2,3,4]

[1]Faculty of Science, McMaster University, Hamilton; [2]St Peter's Hospital, Geras Centre for Aging Research, Hamilton; [3]Faculty of Health Science, Medicine, McMaster University, Hamilton; [4]Department of Health Research Methods, Evidence, and Impact, McMaster University, Hamilton; [5]School of Computing, Queen's University, Kingston; [6]School of Rehabilitation Sciences, McMaster University, Hamilton, ON, Canada

https://doi.org/10.5770/cgj.29.892

ABSTRACT

Background

Falls are a leading cause of injury and loss of independence in older adults. Impaired balance is a modifiable risk factor yet traditional rehabilitation approaches may not fully address balance control. Augmented reality (AR) provides an interactive method to support balance training and fall prevention. This scoping review summarizes key characteristics of AR interventions for balance rehabilitation in older adults, as well as associated outcome measures.

Methods

Literature searches were performed across CENTRAL, CINAHL, EMBASE, Medline, PubMed, ScienceDirect, SCOPUS, and Web of Science from inception to July 2024. Using Arksey and O'Malley's framework, we included studies meeting the following criteria: (i) older adults (65+), (ii) AR-based balance rehabilitation, (iii) randomized control trials (RCTs) or observational studies, and (iv) outcomes related to balance, balance confidence, or fear of falling, categorized using the Balance Evaluation Systems Test (BESTest) framework. Two reviewers independently screened and extracted data.

Results

Ten studies (six RCTs, four observational) involving 235 participants (ages 64.70-75.8 yrs) met inclusion. AR interventions were delivered 1–5 times/week over 4 to 12 weeks (4–36 total hr), with adherence rates of 83.3% to 100%. The most frequently assessed balance systems were stability in gait (100%) and anticipatory postural adjustments (90%), which improved with AR. Only one study evaluated all balance systems. RCTs showed statistically significant improvements in balance, while observational studies mainly reported associations and trends.

Conclusions

This review highlights AR as a complementary tool for fall prevention, supporting tailored interventions across balance domains. Clinicians may find AR useful for engaging older adults in targeted, functional rehabilitation.

Key words: augmented reality, older adults, balance, rehabilitation, balance confidence, fear of falling

INTRODUCTION

Canada's aging population is projected to experience a 68% increase in adults aged 65 and older over the next two decades, with falls affecting approximately one in three older adults annually.(1,2) Falls are the primary cause of injury-related hospitalization and death among seniors in Canada, highlighting the importance of prevention as a public health and clinical care priority.(3) Impaired balance is one of the most common risk factors for falls,(4) often leading to chronic pain, loss of independence, reduced quality of life, and, in extreme cases, death.(5,6) The World Health Organization (WHO) and the Canadian 24-Hour Movement Guidelines recommend that older adults participate in balance-challenging activities at least twice weekly.(7,8) Research suggests that participating in strength and balance training can reduce the risk of falls by 34%.(9) However, adherence to such exercises is low due to a lack of social support and enjoyment, fear of falling or injury, and difficulty accessing exercise programs. These barriers can often prevent health-care providers from implementing and delivering effective fall-prevention strategies.(10) Unaddressed balance problems can strain Canadian health-care systems due to an increase in morbidities and mortalities in the elderly population.(11) Additionally, these balance problems can increase both nursing home admissions and hospitalizations, resulting in higher medical expenditures.(12)

Therefore, early identification and targeted rehabilitation for balance deficits are critical to clinical practice in geriatric care. This is especially important for geriatricians and allied health professionals who routinely assess mobility, prescribe rehabilitation, and monitor frailty. As falls are multifactorial and strongly linked to modifiable risk factors, targeted balance training represents a high-yield intervention within geriatric care models.(13,14) Incorporating novel approaches, such as augmented reality (AR), into routine assessment and intervention may support interdisciplinary care planning and enhance adherence to evidence-based fall prevention strategies.(15)

Balance control is a complex process that involves multiple underlying systems.(16,17) While previous models function hierarchically, the Balance Evaluation Systems Test (BESTest) was developed on the general idea that postural control arises from systems interacting with one another. The BESTest identifies affected underlying balance control systems and directs rehabilitation efforts in six domains: (i) Biomechanical Constraints: postural alignment, joint and hip strengths, and the ability to rise from the ground; (ii) Stability Limits/Verticality determines how far the body can move from its base of support without losing balance; (iii) Anticipatory Postural Adjustments: moving the body's weight to maintain stability during movements such as standing or walking; (iv) Postural Responses: the ability to adjust balance in response to an external disturbance, such as being pushed; (v) Sensory Orientation: the ability to sense and maintain spatial awareness to maintain balance; (vi) Stability in Gait: maintaining balance while walking. The BESTest provides a conceptual framework for evaluating and treating patients with various balance issues.(17)

AR is an emerging technology used to help older adults with rehabilitation and balance exercises.(15) It incorporates virtual communication cues into physical surroundings and enhances the real-world environment.(18) Balance exercises incorporating AR provide real-time guidance and feedback, which may improve balance, elevate confidence, and reduce the fear of falling.(15,19,20) Other forms of technology used in rehabilitation include virtual reality (VR) and mixed reality (MR). Virtual reality creates an entirely digital environment, whereas MR combines real and virtual worlds for a more immersive experience. AR overlays virtual objects with physical surroundings, allowing the interaction and manipulation of both virtual and physical settings. In AR systems, users can interact with digital elements in ways that feel natural to them, and seamlessly integrate them into their physical surroundings.(21) For clinicians, AR offers an innovative tool to further engage patients in exercise, potentially increasing adherence and functional outcomes.(22) However, to effectively design and evaluate the impact of this technology on balance, one must know which underlying balance systems to target and how to assess them.

As a result, this scoping review aims to explore the application of AR for balance rehabilitation in older adults. Through its summary of existing evidence, this review provides a comprehensive resource for health-care professionals interested in AgeTech. For clinicians, this review offers practical insights into how AR can be applied in clinical practice to target specific domains of balance control, inform program development, and support fall prevention efforts. Additionally, understanding the current landscapes of AR interventions will offer guidance for future research, development, and assessment of AR technologies in improving balance outcomes among older adults.

METHODS

Arksey and O'Malley's(23) Methodologic Framework was used, which followed a five-step process: 1) identifying the research question; 2) identifying relevant studies; 3) selecting the studies; 4) charting the data; and 5) collating, summarizing, and reporting the results. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) was used to ensure that all items outlined in the reporting guidelines were included.(24)

Research Questions

The research questions were developed with input from the research team comprising geriatricians, occupational therapists, and engineers. Key questions included:

1. What are the key characteristics of AR balance rehabilitation interventions?
2. Which outcomes are used to assess the effectiveness of AR interventions targeting balance?

Identifying Relevant Studies

A preliminary search yielded few results. With the assistance of a Cochrane-trained librarian, a broader search strategy was developed and involved a primary search of multiple databases: CENTRAL, CINHAL, EMBASE, Ovid Medline, PubMed, Science Direct, SCOPUS, and Web of Science. Search terms included: ("augmented reality") AND (balance OR accidental falls OR falls OR stability OR "fear of falling" or "falls-efficacy") AND (aged OR elderly OR adults OR older adults). Searches spanned from the inception of the database and were restricted to English. The final search strategy was completed in July 2024.

Study Selection

The inclusion criteria were older adults aged 65 years or older, augmented reality interventions, outcomes related to balance, balance confidence, or fear of falling, and articles published in English. Exclusion criteria were adults younger than 65, individuals diagnosed with conditions such as stroke, multiple sclerosis, or Parkinson's disease, interventions using virtual or mixed reality, outcomes unrelated to balance, balance confidence, or fear of falling, and studies with no full-text access available.

We included studies that examined healthy individuals to determine whether AR interventions could be considered as preventative measures for future health implications among this demographic. Two independent reviewers screened studies, and full texts were assessed if the abstracts met the inclusion criteria. A secondary search of the reference lists and citations of the included studies was also completed.

Charting the Data

Data was charted into four tables. Table 1 summarizes an overview of augmented reality systems. Key outcome measures of AR interventions are extracted in Table 2. Epidemiological metrics of all studies are included in Table 3. We also classified each assessment tool within its corresponding underlying balance systems using the BESTest framework (Table 4).

Collating, Summarizing, & Reporting the Results

A PRISMA flow diagram documented the study selection. The charted data findings were collated with descriptive statistics (percentages, standard deviation, and ranges). Findings are presented in a narrative format intended to serve as an extensive resource for physicians, allied health-care professionals, and health policymakers interested in AgeTech.

RESULTS

Figure 1 shows a PRISMA flow diagram of the scoping review. The search strategy across multiple databases yielded a total of 1631 citations (CENTRAL, n=49; CINHAL, n=22; EMBASE, n=56; Ovid Medline, n=41; PubMed, n=64; Science Direct, n=1156; SCOPUS, n=30, and Web of Science, n=213). Of these 1631 citations, 45 abstracts met the inclusion criteria for full-text review. 221 studies were identified as duplicates and removed after cross-referencing among databases. A secondary search of reference lists and citations added one additional study.(25) Ultimately, ten studies were included in this scoping review.

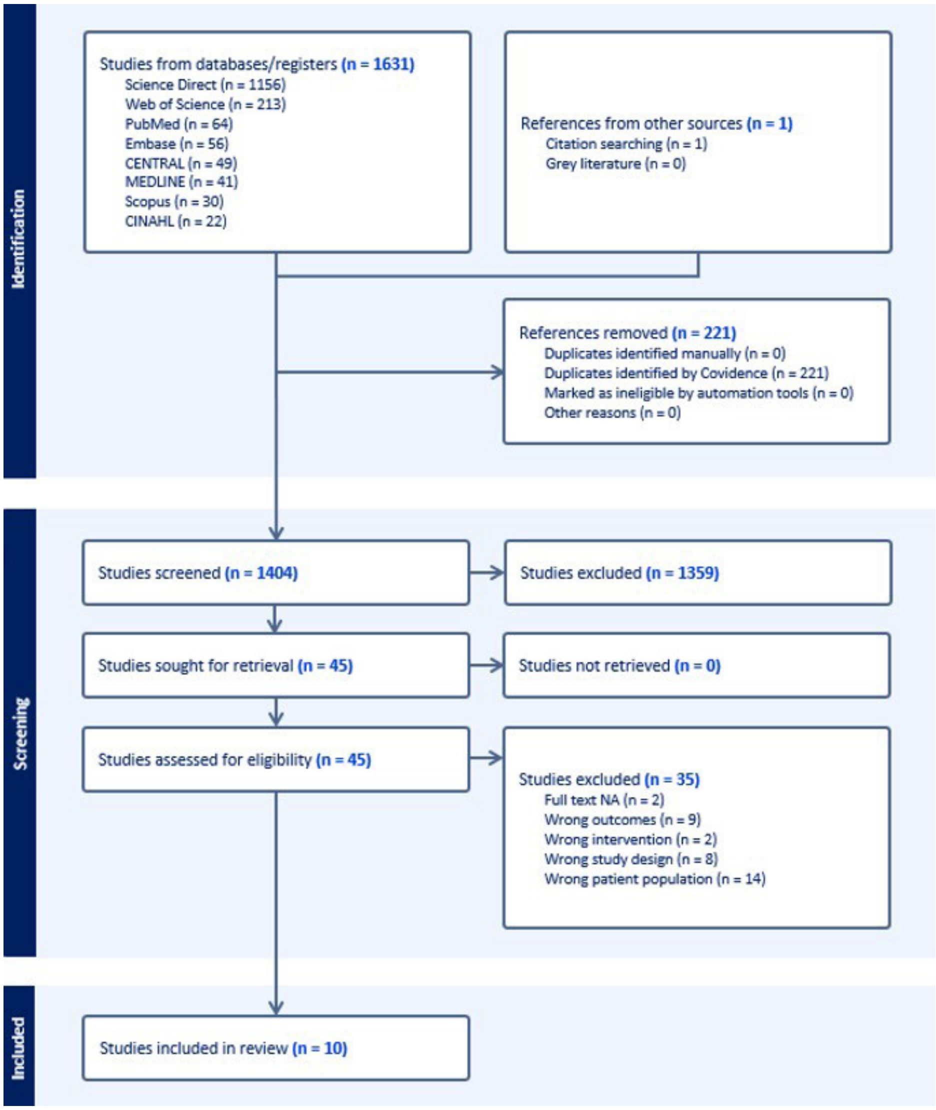

FIGURE 1. PRISMA flow diagram, illustrating the screening process used to include studies from our search strategy; it records the number of records identified, screened, and included

Figure 2 shows the percentage of studies reporting balance outcomes of the BESTest. The most frequently assessed underlying balance systems were Stability in Gait at 100%,(15,25–33) Anticipatory Postural Adjustments at 90%,(15,25,26,28–33) and Stability Limits/Verticality at 80%.(15,26,28–33) Biomechanical constraints and sensory orientation were the least targeted underlying balance systems, with only 20% of studies focusing on these domains.(26,29)

Six randomized controlled trials(26,28,29,31–33) and four observational studies(15,25,27,30) were included in this scoping review. Among the ten studies, seven(25,26,28,30–33) originated from East Asia, two(27,29) from North America, and one(15) from Europe. Two studies(15,27) used Microsoft HoloLens glasses as their AR intervention, while three studies(26,30,32) used the Microsoft Kinect, the most commonly used AR system. Nearly all studies reported that AR intervention improved balance and physical activity in older adults. However, according to one study,(15) there were no improvements in the balance of older adults after AR training.

Table 1 provides an overview of augmented reality systems. Several studies(26,28,30,32,33) had participants perform exercises in front of a sensor or camera to track body movement. The most used virtual information included virtual exercise guidance systems(28,31–33) and AR-based games.(15,25,26,30) Microsoft Kinect sensors(26,30,32) were the most-used tracking technology, and screens(26,30,32) and TV/monitor(28,29) were commonly used as display technologies. User interaction varied across studies. Participants engaged in balance and mobility games,(15,26,30) interacted with virtual holograms of park redesign elements,(27) and performed guided exercises while receiving real-time feedback.(28,31–33) In one study,(25) users stepped on projected stimuli as per instructions, and in another study,(29) maintained trunk stability while walking on a treadmill.

Table 2 summarizes the key characteristics of augmented reality interventions. There were ten studies with a total sample size of 235 older adults (mean age range: 64.7 (30)-75.8(29)). Participant sample sizes varied from 7(15) to 40(29) across the studies. The frequency of augmented reality interventions ranged from one(27) to five times(28) per week, with Vieira *et al*.(27) completing the study in one session, and Im *et al*.(30) having ten sessions. Moreover, only one study(33) reported that the AR interventions were of moderate intensity for the first week, performed by participants five times. In contrast, another study(29) had participants walking at comfortable speeds. Park and Shin(25) reported a low-intensity intervention, and Jeon and Kim(28) used a perceived exertion (RPE) rate ranging from 7–13 to describe the different intensities. Only one study(32) reported progressive AR-based exercises, gradually increasing in difficulty.

Furthermore, the duration of the AR interventions across studies ranged from four to 12 weeks,(26,28,31,33) for a total duration of 4–36 hours,(15,31,33) with each session lasting from 20 to 60 minutes.(15,31,33) Adherence rates varied across the studies from 83.3–100%.(29,30,32) One study(26) reported a 94% adherence rate, while two studies(30,32) reported an adherence rate of 100% as all participants completed the exercise program. Another study(29) reported an adherence rate of 83.3%, as at least 10 of the 12 scheduled training sessions were completed by all participants. Two studies reported adherence rates of 85.7%(15) and 90%(28) due to participants dropping out because of health issues.

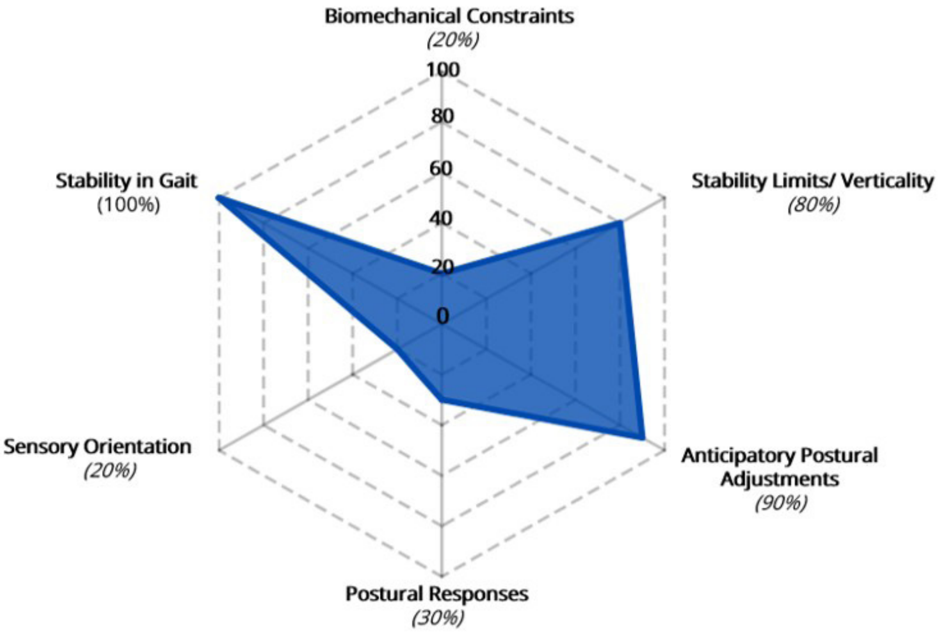

FIGURE 2. Percentage of studies reporting outcomes in the six domains of the BESTest; the radar chart illustrates the distribution of BESTest outcome measures reported across studies

TABLE 1.
Overview of augmented reality systems technology[a]

First Author & Year	*Real-world Information*	*Virtual Information*	*Tracking/Registration Technology*	*Display Technology*	*User Interaction*
Ku *et al.*(26)	Users performed exercises in a controlled environment in front of a Kinect sensor	3D-ARS training system featuring balance and mobility exercises in virtual games such as balloon, cave, and rhythm game	Microsoft Kinect sensor	Large screen	Users interacted with virtual objects in an in-game environment while viewing themselves on the screen
Vieira *et al.*(27)	Outdoor Park	Microsoft HoloLens AR glasses display virtual design features such as walls, lane separators, and benches	GAITRite® system (an instrumented mat for gait analysis)	Microsoft HoloLens display	While walking on an instrumented mat, users interacted with virtual holograms of park redesign elements
Bolmqvist *et al.*(15)	Space in a health center that allowed users to walk along a straight corridor.	AR-based training games focusing on balance were displayed via Microsoft HoloLens	Microsoft HoloLens	Microsoft HoloLens holographic display	While wearing HoloLens, users played two games: users caught a ball using a ring and tracked a moving ball with a laser pointer
Jeon & Kim(28)	Spaces in elderly welfare centers with enough space to accommodate an AR system with a range of 1.2-4.5m	UIN-HEALTH rehabilitation exercise system involving aerobic, resistance, and flexibility exercises on screen	3D motion analysis sensor with red, green, blue light (RGB) and infrared camera	40” monitor	Users exercised while watching and following content displayed on the monitor
Anson *et al.*(29)	Treadmill	Trunk motion (translation and angular vertical deviation)	Two webcams tracked the 3D position of three markers attached to the trunk	27” TV screen	While walking on a treadmill, users tried to keep trunk movement in the target area
Im *et al.*(30)	Users performed games at a 1.2-3.5m distance from the Kinect sensors	3D-ARS training system featuring balance and mobility exercises in virtual games such as balloon, cave, and rhythm game	Microsoft Kinect sensor	Screen display	Users interacted with virtual objects (games) while viewing themselves on the screen
Lee *et al.*(31)	Controlled environment with enough space for exercises	Virtual cues to guide exercises (specific cues not mentioned)	Force plate to measure static and dynamic load distribution	(-)	Users performed AR-guided exercises while receiving real-time feedback
Chen *et al.*(32)	Users performed exercises in a controlled environment in front of the Kinect sensor	Virtual Tai-Chi coach displayed on screen	Microsoft Kinetic sensor	Screen display	Users followed the movement of the virtual coach and received real-time feedback on their accuracy
Yoo *et al.*(33)	Users performed exercises in a controlled environment in front of a computer with a web camera	Virtual exercises displayed on the computer	Web camera with SVGA resolution (800 × 600)	Head mounted display (i-visor FX601, Dae-Yang E&C Co, Korea, 2008)	Users followed the movement displayed on the computer and received real-time feedback on accuracy and speed.
Park & Shin(25)	Dedicated 4.5 m × 2.5 m plane space	Game components, such as tap steps, balloons, pathfinding, catching bugs, speed cards, shape stepping, and random squares	3D sensor (LiDAR)	Projection on the dedicated floor space	Users moved their feet per instruction or stepped on the projected stimulus.

[a] Real-world information, virtual information, tracking or registration technologies, display systems, and user interaction methods used by AR interventions are presented for each study.
3D-ARS = Augmented Reality Systems; (-) = information not available; SVGA = Super Video Graphics Array; LiDAR = Light Detection and Ranging.

TABLE 2.
Key characteristics of augmented reality interventions[a]

First Author & Year	*Sample (N)*	*Mean Age (yrs) (SD)*	*Study Population*	*Frequency (per wk)*	*Intensity*	*Time (wks)*	*Duration (min)*	*Total Dose (hrs)*	*Adherence (%)*
Ku *et al.*(26)	36	56-76 (range)	Healthy older adults	3	-	4	30	6	94%
Vieira *et al.*(27)	10	65 (±5)	Healthy older adults	One time	-	-	-	-	-
Bolmqvist *et al.*(15)	7	74 (-)	Older adults with impaired balance	2	-	6	20	4	85.7%
Jeon & Kim(28)	30	72.74 (±3.64)	Elderly Korean women	5	RPE (7-13)	12	30	30	90%
Anson *et al.*(29)	40	Control: 75.8 (6.5) Experimental: 75.7 (5.3)	Older adults with self-reported balance issues	3	Participants walked at comfortable speeds	4	30	6	83.3%
Im *et al.*(30)	18	64.70 (±7.27)	Healthy older adults	Ten total sessions	-	4	30	5	100%
Lee *et al.*(31)	30	72.60 (±2.67)	Healthy elderly women	3	-	12	60	36	-
Chen *et al.*(32)	28	72.2 (±2.8)	Healthy older adults	3	Progressive	8	30	12	100%
Yoo *et al.*(33)	21	72.90 (3.41)	Healthy elderly women	3	Moderate for the first week	12	60	36	-
Park & Shin(25)	15	70.47 (3.54)	Healthy older adult females	3	Low intensity	6	30	9	-
Range	7-40	64.70-75.8	-	1-5	-	4-12	20-60	4-36	83.3-100%

[a] The study sample, population, intervention frequency, intensity, duration, and adherence are presented across each study; ranges for each characteristic are recorded at the bottom.
(-) = information not available; RPE = Rate of Perceived Exertion.

Table 3 presents the epidemiological characteristics of the included studies. A total of six RCTs(26,28,29,31–33) and four observational studies(15,25,27,30) were included. Most studies(15,25,28,29,31–33) reported a higher proportion of female participants; however, Ku *et al.*(26) and Im *et al.*(30) reported equal representation of men and women, while Vieira *et al.*(27) did not report sex-specific characteristics. Across all studies, participant ages ranged from 56(26,30) to 92(29) years. Ku *et al.*(26) was conducted across both clinical hospital settings and surrounding community environments. Overall, six studies(25,27,28,31-33) were conducted in community settings and three(15,29,30) in clinical settings. Eight studies(25,26,28,29,30,31-33) reported statistically significant improvements in balance outcomes, while two studies(15,27) reported no significant effects. Interaction effects were reported in four studies(26,28,29,31). Improvements in balance were observed in all studies, with the exception of Bolmqvist *et al.*(15) which reported no improvements. Only Anson *et al.*(29) reported that the overall mean change did not exceed the minimum clinically important difference; however, a specific minimal detectable change value was not defined. No other studies reported outcomes related to minimal clinically important differences.

Biomechanical Constraints

Two studies(26,29) assessed biomechanical constraints, including postural alignment, joint strength (specifically in the ankles and hips), and the ability to rise from the ground. The Fugl-Meyer Assessment (FMA-LE) and BESTest were used to evaluate the biomechanical limitations of the lower extremities, the range of motion of joints, and the ability to carry out functional movements such as standing up from a seated position.

Stability Limits/Verticality

Eight studies(15,26,28–33) evaluated how far the body can move from its base of support without losing balance. The most commonly used tools were the Berg Balance Scale (BBS), Functional Reach Test (FRT), and BESTest. These tests evaluate many movements, including reaching forward, sitting upright, and leaning laterally, to determine stability limits.

Anticipatory Postural Adjustments (APA)

APA was evaluated in nine studies.(15,25,26,28–33) It entails moving the body's weight to maintain stability during movements such as standing or walking. Some of the tests included the Five Times Sit-to-Stand Test (5TSTS), BBS, Timed Up and Go test (TUG), and BESTest. These tests evaluate participants' ability to anticipate and change their posture during transitions, such as sitting-to-standing, standing on one leg, rise to toes, and standing arm raise.

Postural Responses

Three studies(15,26,29) evaluated postural responses, which involved responding to external disturbances to adjust for balance. The BESTest and Tetrax posturography frequently

TABLE 3 (part 1 of 2).
Epidemiological characteristics and outcome summary of included studies

First Author & Year	*Study Design*	*Sample Size*	*Sex (M/F)*	*Age Ranges (yrs)*	*Setting*	*Primary Balance Outcomes*	*Significant Change Reported*	*Adjusted/ Interaction Effect Reported*	*Direction of Change*	*MCID*
Ku & Kim(26)	RCT	36	17 (47.2%) 17 (47.2%)	56-76	Clinical and community- based	BBS TUG FAC MBI FMA-LE FMA-C FMA-B Tetrax posturography	BBS: $p=.042$ TUG: $p<.001$ Textrax (fall risk index): $p=.033$	Yes (group × time) interaction	↑ Improvements	-
Vieira *et al.*(27)	Observational	10	-	≥60	Community-based outdoor public park	Gait parameters (velocity, cadence, step length, and step width)	Not statistically significant	-	↑ Slight improvements (postural sway increased 25%)	-
Bolmqvist *et al.*(15)	Observational	7	2 (28.6%) 5 (71.4%)	66-68	Clinical (physio-therapy-supervised training; rehabilitation setting	BBS SPPB-S FES-S Center of pressure (force platform)	Not statistically significant	-	No improvements	
Jeon & Kim(28)	RCT	30	0 (0%) 30 (100%)	≥65	Community-based indoor setting (welfare centers)	TUG 6m Walk Chair Stands (30s) 2MST F8W Sit and Reach	TUG: $p=.032$ 6m Walk: $p=.013$ Chair Stands: $p=.033$ 2MST: $p=.020$	Group × time interaction	↑ Improvements	-
Anson *et al.*(29)	RCT	40	11 (27.5%) 29 (72.5%)	66-92	Clinical (rehabilitation setting)	BESTest mBESTest BBS TUG ABC 6MWT	BESTest: $p=.031$ mBESTest: $p=.019$	Group × time interaction	↑ Improvements	MCID not defined Below MDC overall; mean change did not exceed MDC for BESTest or mBESTest
Im *et al.*(30)	Observational	18	9 (50%) 9 (50%)	56-76	Clinical (hospital-based rehabilitation setting)	BBS TUG	BBS: $p<.001$ TUG: $p<.001$	No (paired *t*-tests for clinical outcomes linear regression analysis	↑ Small improvements	-
Lee *et al.*(31)	RCT	30	0 (0%) 30 (100%)	-	Community-based setting (senior centers)	OLS TUG SPPB BBS 6MWT	$p<.05$	Yes (between groups)	↑ Improvements	-

TABLE 3 (part 2 of 2).
Epidemiological characteristics and outcome summary of included studies

First Author & Year	*Study Design*	*Sample Size*	*Sex (M/F)*	*Age Ranges (yrs)*	*Setting*	*Primary Balance Outcomes*	*Significant Change Reported*	*Adjusted/ Interaction Effect Reported*	*Direction of Change*	*MCID*
Chen *et al.*(32)	RCT	28	3 (10.7%) 25 (89.3%)	≥65	Community-based setting	BBS TUG FRT	In group; BBS: $p<.001$ TUG: $p=.001$ FRT: $p<.001$ Between group; BBS $p=.044$ TUG ($p=.015$ FRT ($p<.001$	No (independent *t*-test for the between-group test)	↑ Improvements	-
Yoo *et al.*(33)	RCT	21	0 (0%) 21 (100%)	-	Community-based	BBS Gait (velocity, cadence, step length, and stride length) FES-I	BBS: $p<.001$ Gait velocity: $p=.001$ Cadence: $p=.000$ Left side stride length: $p=.041$ Right side step length: $p=.011$ Right side stride length: $p=.019$ FES-I: $p=.019$	No (Independent *t*-tests used for between-group comparisons)	↑ Improvements	-
Park & Shin(25)	Observational	15	0 (0%) 15 (100%)	≥65	Community-based setting (indoor exercise space)	TUG 5TSTS 1MSTS	TUG: $p=.001$	No (paired *t*-test)	↑ Improvements	-

BESTest = Balance Evaluation Systems Test; mBESTest = Modified Balance Evaluation Systems Test; (-) = information not available; MCID = minimal clinically important difference; BBS = Berg Balance Scale; TUG = Timed Up and Go; FAC = functional ambulation category; MBI =Modified Barthel Index; FMA-LE/ C/ B = Fugl-Meyer Motor Assessment Balance section (lower extremity/coordination/balance); SPPB/SPPB-S = Short Physical Performance Battery/Short Physical Performance Battery (Swedish Version); FES-S/FES-I =Falls Efficacy Scale (Swedish Version)/Falls Efficacy Scale (International Version); 2MST = 2-Minute Walk Test; F8W = Figure-of-8 Walk Test; ABC = Activities-Specific Balance Confidence Scale; 6MWT = 6-Minute Walk Test; MDC = minimum detectable change; OLS = One Leg Standing Test; FRT = Functional Reach Test; 1MSTS/5TSTS = 1-Minute Sit-to-Stand/5-Times Sit-to-Stand; Tetrax = Tetrax Posturography system; p = p value.

assessed participants' ability to recover from changes in balance, such as being able to step forward, backward, or laterally after being pushed.

Sensory Orientation

Two studies(26,29) assessed sensory orientation, which evaluates the body's ability to use sensory inputs like vision and proprioception to maintain balance, especially on unstable surfaces. The BESTest and Tetrax posturography were used to evaluate participants' balance with eyes closed or while standing on uneven surfaces.

Stability in Gait

Stability in gait, which assesses balance while walking, was examined in all ten studies.(15,25–33) The BBS, TUG test, and Short Physical Performance Battery (SPPB) were the most frequently used tests to assess this underlying balance system. The aim was to evaluate participants' ability to maintain balance while walking and during functional ambulation. The effect of gait stability on daily activities was measured using assessment tools such as the Modified Barthel Index (MBI) and the Functional Ambulation Category (FAC), which assessed whether participants effectively carried out daily tasks that depended on walking.

Fear of Falling

Three studies(15,29,33) measured participants' fear of falling using the Falls Efficacy Scale (FES) and the Activities-Specific Balance Confidence (ABC) Scale. These tools measure the confidence level in carrying out daily activities without losing balance, becoming unsteady, or falling, allowing us to identify participants at high risk of balance impairments (see Table 4).

DISCUSSION

This scoping review highlights that AR technologies are novel, complementary tools that can be integrated into multidisciplinary fall-prevention programs. For clinicians, our findings underscore the importance of tailoring interventions to the full spectrum of balance systems and using validated functional measures, such as the Berg Balance Scale and the Timed Up and Go (TUG) test, to guide care and track progress. These AR-based approaches may be beneficial for older adults with mild-to-moderate mobility impairments, offering an engaging, tech-enabled way to reinforce rehabilitation goals and promote adherence.

Assessing all balance systems is essential to fully understand how well someone can balance and where they may have difficulties.(17) This review found that most AR interventions targeted gait stability and anticipatory postural adjustments, but overlooked balance domains such as sensory orientation and postural responses, which are critical for older adults who experience falls due to environmental challenges or external perturbations.(16) Clinicians should be aware that AR interventions may not fully address all key areas of balance and may require supplemental interventions. Moving forward, AR should be designed to incorporate programs that target the underrepresented systems, such as unexpected balance perturbations or multisensory conflict tasks, in order to provide comprehensive rehabilitation for fall prevention and prevent hospitalizations due to balance impairments.

Most included studies enrolled a higher proportion of female participants, and participant ages ranged widely across studies, which may have further influenced balance outcomes due to sex-based physiological differences, such as differences in strength. Although several studies reported statistically significant improvements in balance, outcomes were neither stratified nor adjusted by sex or age, limiting the interpretation of these effects on balance. Additionally, a few studies reported interaction effects, but they were examined within intervention and control subgroups rather than across epidemiological characteristics. Future studies should incorporate sex- and age-specific analyses, as well as subgroup interaction analyses, to better highlight how balance improvement varies across characteristics and to improve clinical relevance.

AR has several advantages over traditional balance training methods, such as conventional fitness programs, as it provides users with interactive and immersive experiences that increase engagement and improve physical outcomes.(22,34) AR interventions increase motivation and involvement by providing real-time visual feedback and guidance with virtual elements, giving health-care professionals a better understanding of movement among older adults.(35,36) Additionally, several emerging AR-based interfaces, such as sensors, wearables, and mobile devices, enable increased accessibility that caters to individual needs.(37–39) Different AR interventions will implement personalized approaches, making users more likely to participate in exercise programs, thereby boosting overall engagement and improving rehabilitation outcomes.(22)

Many AR programs incorporate challenges that stimulate daily activities, allowing older adults to practice functional movements in settings that stimulate real-world environments.(15,18) Having this preliminary experience can facilitate a smoother transition to daily tasks, promoting safe mobility at home and in the community. AR technology also enhances accessibility and supports aging in place, as it can be implemented in a wide range of environments, including senior centers, clinics, and homes.(40) Moreover, AR interventions tend to be more cost-effective compared to usual care, as they minimize clinician time, in-person clinic visits, and transportation costs.(41) This may result in fewer emergency department visits, hospitalizations, and lower long-term care service utilization. Furthermore, early evidence suggests that AR interventions may lead to greater improvements in balance measures, such as the Berg Balance Scale and the Timed Up and Go test, compared to standard exercise programs.(42) These advantages establish AR as a promising tool in geriatric care for preventing falls and enhancing mobility. In contrast to VR, which fully immerses users in digital environments, AR overlays virtual elements

TABLE 4 (part 1 of 2).
Fear of falling and underlying balance outcome measures categorized using the BESTest framework[a]

First Author & Year	*Biomechanical Constraints*	*Stability Limits/ Verticality*	*Anticipatory Postural Adjustments*	*Postural Responses*	*Sensory Orientation*	*Stability in Gait*	*Fear of Falling*
Ku *et al.*(26)	Lower-extremity subscale of the Fugl-Meyer Assessment (FMA-LE)	Berg Balance Scale (BBS) Fugl-Meyer Motor Assessment Balance section (FMA-B) Tetrax posturography	Berg Balance Scale (BBS) Timed-Up-and-Go (TUG) test Fugl-Meyer Motor Assessment Co-ordination section (FMA-C)	Automatic balance score using Tetrax posturography Fugl-Meyer Motor Assessment Balance section (FMA-B)	Automatic balance score using Tetrax posturography Berg Balance Scale (BBS)	Timed-Up-and-Go (TUG) test Functional Ambulation Category (FAC) Modified Barthel Index (MBI)	-
Vieira *et al.*27)	-	-	-	-	-	Gait parameters (velocity, cadence, step length, and step width)	-
Bolmqvist *et al.*(15)	-	Berg's Balance Scale (BBS) Force Platform (Ergopower Technology)	Berg's Balance Scale (BBS) Short Physical Performance Battery - Swedish version (SPPB-S)	Force Platform (Ergopower Technology) - sway measurement	-	Short Physical Performance Battery - Swedish version (SPPB-S)	Falls Efficacy Scale - Swedish version (FES-S)
Jeon & Kim(28)	-	Sit-and-Reach Test (cm)	Chair Stand for 30 s Timed Up-and-Go test (TUG)	-	-	Timed Up-and-Go test (TUG) Figure-of-Eight Walk Test (F8W) 2-Minute Step Test (2MST)	-
Anson *et al.*(29)	BESTest	BESTest Berg Balance Scale (BBS)	BESTest mBESTest Berg Balance Scale (BBS) Timed Up-and-Go test (TUG)	BESTest mBESTest	BESTest mBESTest	BESTest mBESTest Timed Up-and-Go test (TUG) 6-min Walk Test (6MWT)	Activities-specific Balance Confidence (ABC) Scale
Im *et al.*(30)	-	Berg Balance Scale (BBS)	Berg Balance Scale (BBS) Timed Up-and-Go test (TUG)	-	-	Timed Up-and-Go test (TUG)	-
Lee *et al.*(31)	-	Berg Balance Scale (BBS)	Short Physical Performance Battery (SPPB) Berg Balance Scale (BBS) One Leg Standing test (OLS)		-	6-Minute Walk Test (6MWT) Short Physical Performance Battery (SPPB)	-

[a] Percentages at the bottom summarize the proportion of studies that evaluated each domain.
(-) = information not available; BESTest = Balance Evaluation Systems Test; mBESTest = Modified Balance Evaluation Systems Test.

TABLE 4 (part 2 of 2).
Fear of falling and underlying balance outcome measures categorized using the BESTest framework[a]

First Author & Year	*Biomechanical Constraints*	*Stability Limits/ Verticality*	*Anticipatory Postural Adjustments*	*Postural Responses*	*Sensory Orientation*	*Stability in Gait*	*Fear of Falling*
Chen *et al.*[32]	-	Berg Balance Scale (BBS), Functional Reach Test (FRT)	Berg Balance Scale (BBS), Timed Up- and-Go test (TUG)	-	-	Timed Up- and-Go test (TUG)	-
Yoo *et al.*[33]	-	Berg Balance Scale (BBS)	Berg Balance Scale (BBS)	-	-	Gait parameters (velocity, cadence, step length, and stride length)	Falls Efficacy Scale-International (FES-I)
Park & Shin[25]	-	-	Timed Up-and-Go test (TUG) Five Times Sit-to-Stand Test (5TSTS) 1-Minute Sit-to-Stand Test (1MSTS)	-	-	Timed Up-and-Go test (TUG)	-
Summary (%)	20%	80%	90%	30%	20%	100%	30%

[a] Percentages at the bottom summarize the proportion of studies that evaluated each domain.
(-) = information not available; BESTest = Balance Evaluation Systems Test; mBESTest = Modified Balance Evaluation Systems Test.

onto the physical world,(21) helping older adults maintain spatial orientation and reducing sensory disorientation. AR systems are also typically less complex than VR, making them more feasible for use in community and home settings.(40) These characteristics support AR's suitability as an accessible, age-appropriate tool for balance rehabilitation in older adults.

Although the findings from this review provide valuable insights into the role of AR in fall prevention and improving mobility among older adults, several limitations should be noted. Most studies were conducted in East Asia, which may limit the applicability of the findings to other health-care systems or cultural contexts. This limitation may have introduced regional bias in the intervention design, delivery, and participant characteristics. Moreover, we used a rigorous search and screening process where we considered balance and fear of falling as a secondary outcome in the literature, and these terms were not always included in the titles or abstracts of screened papers. This may have excluded relevant studies that met the inclusion criteria during the title and abstract screening level, but may not have explicitly mentioned these terms.

CONCLUSION

AR is a promising fall-prevention strategy for older adults, particularly for improving gait stability and anticipatory postural control. For geriatricians and health-care professionals, AR can enhance engagement and support individualized care when paired with validated tools such as the TUG and Berg Balance Scale. Home-based AR may also promote adherence and aging in place.

ACKNOWLEDGEMENTS

We are grateful to all authors for their valuable contributions to this scoping review.

CONFLICT OF INTEREST DISCLOSURES

We have read and understood the *Canadian Geriatrics Journal*'s policy on disclosing conflicts of interest and declare that we have none.

FUNDING

This project was supported by the CIHR-Funded CAN-TAP-TALENT Summer Student Research Award (AV) and the National Research Council of Canada's Aging in Place Challenge program (AP).

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Correspondence to: Alexandra Papaioannou, MSc, MD, Geras Centre for Aging Research, St. Peter's Hospital, 88 Maplewood Ave., Hamilton, ON L8M 1W9
E-mail: PAPAIOANNOU@HHSC.CA