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Augmented reality-based training versus standard training in improvement of balance, mobility and fall risk: a systematic review and meta-analysis

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Objective: Augmented reality (AR) technology is being used recently in healthcare, especially for rehabilitation purposes, owing to its ability for repetition, rapid feedback, and motivation for patients. This systematic review and meta-analysis aims to compare the efficacy of AR-based interventions to conventional physical interventions in improving balance, mobility, and fall risk.

Material and methods: PubMed, Google Scholar, Scopus, and the Cochrane Central Register of Controlled Trials were systematically searched from inception to January 2023. Randomized trials and observational cohort studies comparing the effects of AR-based exercises with conventional training in patients 18 years and older were included in the analysis. Studies using virtual reality, case reports and series, reviews, meta-analyses, letters, and editorials were excluded. Post-intervention data on the Berg Balance Scale (BBS) and Timed Up and Go (TUG) Test were extracted and studied. The fixed-effects inverse variance model was utilized to pool the extracted data.

Results: Out of 438 articles, seven articles (199 participants) comparing AR-based exercise with the standard training were included in the systematic review. Six articles with sufficient data on the parameters were included in the meta-analysis. AR-based exercises resulted in a significantly higher BBS score than conventional exercise (Hedge's g = 0.48, 95% CI = 0.19–0.77, $P<0.001$). The BBS value was significantly higher in AR-based training of 8 weeks or more (Hedge's g = 0.88, 95% CI = 0.46–1.31) when compared with trainings conducted for less than 8 weeks (Hedge's g = 0.11, 95% CI = −0.30 to 0.52), $P=0.01$). Likewise, the TUG Test score was found to be to be significantly lower in ARgroup than the controls (Hedge's g = −0.54, 95% CI = −0.85 to −0.23, $P<0.01$).

Conclusion: In comparison to conventional methods, AR-based exercises had higher improvements in balance, mobility, and fall risk parameters. The use of AR technology in elderly patients can promote independence while preventing falls and associated morbidity and mortality. There is a need for a larger randomized controlled trial to provide a more accurate comparison on efficacy and safety of different modalities of training.

Keywords: augmented reality, balance, elderly, stroke, review

Introduction

Falls are a major public health issue, with ~684,000 fatal falls occurring each year, making them the second leading cause of unintentional injury death. Especially, elderly people have the highest risk of death or serious injury arising from a fall, and the risk escalates with age[1]. Older age is characterized by the emergence of geriatric syndromes, which include frailty, urinary incontinence, delirium, pressure ulcers, and falls[2]. About 28–35% of people 65 years and above fall each year, causing severe acute and chronic pain, disability, loss of independence, and premature death. Falls in the geriatric population occur as a result of a complex interaction of risk factors such as the intake of multiple medications, excess alcohol use, sedentary behaviour, and environmental hazards such as narrow steps, poor socioeconomic status, and multiple comorbidities. Certain neurological comorbidities, such as stroke, Parkinson's disease, multiple sclerosis, and traumatic brain injuries, are associated

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with an increased risk of falling. Even though these conditions are more common in the geriatric population, adults can also suffer from balance deficits due to these conditions[3]. Fear of falling (FOF) with balance deficits results in limitations in physical activities, which in turn, might lead to falling. Disturbed balance has been defined as the inability to maintain balance and alterations in body consistency at the centre[4]. Therefore, a low-mobility lifestyle is adopted and the quality of life also decreases in these patients[5]. Falls also contribute to significant healthcare expenses. The average health system cost per one fall-injury episode in Finland and Australia was USD 3611[3,6].

Clinicians and researchers have used a variety of fall prevention strategies and interventions on patients with impaired balance and gait. Exercise is one of the interventions with the strongest association with a reduction in the rate of falls. Other interventions, such as environmental modification, falls risk assessment, and the use of assistive technology, have also been shown to reduce the number of falls[7]. The rapid development of information and technology, along with its integration into modern medicine, has made augmented reality (AR) technology available for multiple purposes today. AR is a technology that combines real-world physical space with 3D virtual objects and digital content with additional information into a single image to allow real-time interaction[8]. AR differs from virtual reality (VR) technology since the latter uses a completely immersive virtual setting for interaction. The use of AR technology in the rehabilitation of the elderly is a novel strategy that is being rapidly adopted by healthcare facilities around the world. AR technology has been well received by patients in rehabilitation owing to its fun nature, repetition, rapid feedback, and motivation[9]. This systematic review and meta-analysis aims to compare the efficacy of AR-based interventions to conventional physical interventions in improving balance, mobility, and falls risk.

HIGHLIGHTS

- Augmented reality (AR)-based exercises resulted in a significantly higher Berg Balance Scale score than conventional exercise.
- The Berg Balance Scale value was significantly higher in AR-based training of 8 weeks or more when compared with trainings conducted for less than 8 weeks.
- The Timed Up and Go Test score was found significantly lower in AR group than the controls.

Methods

Ethical compliance and research registration

This meta-analysis was reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, Supplemental Digital Content 1, http://links.lww.com/MS9/A164[10]. Additionally, a critical appraisal tool; Assessing the Methodological Quality of Systematic Reviews 2 (AMSTAR2), Supplemental Digital Content 2, http://links.lww.com/MS9/A165 guidelines were also used to assess our systematic review which categorized our review as of moderate quality[11]. This review was registered in PROSPERO with a registration number CRD42023423405 (https://www.crd.york.ac.uk/prospero/display_record.php?ID=CRD42023423405).

Publication search strategy

A systematic search of PubMed, the Cochrane Central Register of Controlled Trials, Google Scholar, Scopus, and Web of Science was performed using the following MeSH terms and keywords: “Augmented reality”, “Rehabilitation”, “Aging”, “Stroke”, “Parkinson’s disease”, “Postural balance”, “fall”, and “mobility”. Articles published from the inception to January 2023 in English language were searched. The last search was performed on 15 January 2023. The detailed search strategy is available in Appendix 1 of Supplementary File 1, Supplemental Digital Content 3, http://links.lww.com/MS9/A166. All relevant publications were reviewed. The articles in reference lists were also searched for potentially relevant publications. Since this is a meta-analysis, the need for ethical approval and informed consent was waived. Ethical approval for each of the studies included in this study can be obtained from the original publications. Full texts were requested from the corresponding authors via mail and ResearchGate.

Selection criteria

The inclusion criteria in this meta-analysis were as follows: (1) observational cohort studies or randomized controlled trial (RCT) that compared the efficacy of AR-based interventions with conventional interventions in patients older than 18 years. (2) reported on at least one parameter of balance, mobility, or fall risk measurement.

The exclusion criteria in the meta-analysis were: (1) studies describing AR-based training only without comparison with standard training, (2) letters, reviews, experimental studies, case reports, conference abstracts, (3) missing/insufficient data on the outcomes, and full-text irretrievable articles. (4) studies using virtual reality technology alone.

Data extraction and quality assessment

Two independent authors reviewed original articles and selected the articles using the eligibility criteria. During the selection process, any disagreements were worked out with the help of a third reviewer. A data extraction spreadsheet was created on Microsoft Excel version 2016 (Microsoft Corp.) to extract the data under different headings as follows: author, publication year, study country, study design, age, sample size, diagnosis of study population, frequency and duration of AR-training sessions, nature of training, and post-intervention data on functional balance parameters and falls risk parameters such as the Berg Balance Scale (BBS), Timed Up and Go Test (TUG) score, Functional Reach Test (FRT), Falls Efficacy Score-International (FES-I), short FES-I, Falls Risk Index (FRI), and Morse Falls Scale (MFS) were extracted and studied.

The Cochrane risk of bias tool was used to evaluate the quality of the RCTs. It includes seven items: random sequence generation, allocation concealment, blinding of participants and personnel, blinding of outcome assessment, incomplete outcome data, selective reporting, and other biases. Each item was divided into low-risk, unknown, and high-risk[12]. The risk of bias in the studies was calculated by two independent reviewers. In cases of dilemma, the final decision was made through discussion with a third reviewer.

Data synthesis and statistical analysis

All analyses were performed using STATA version 16.0 (StataCorp). The pooled mean difference in BBS, TUG, and FES-I between AR-based interventions and standard physical interventions was calculated using the standard mean difference (Hedges's *g*) with a 95% CI. The data were pooled using either a random-effects or fixed-effect model. Statistical heterogeneity across the studies was assessed using the I^2 index (0–40%: not important; 30–60%: moderate heterogeneity; 50–90%: substantial heterogeneity; 75–100%: considerable heterogeneity), which indicates the percentage of total discrepancy due to study variation[13]. When I^2 reached up to 50%, meta-analysis was performed using a fixed-effect model. When I^2 was greater than 50%, meta-analysis was performed using DerSimonian and Laird's random-effects model. To illustrate the overall weighted mean estimations with 95% CIs, forest plots with 95% CIs were generated. Subgroup analysis on the basis of study population and duration of AR-based training was performed to identify the cause of heterogeneity. Statistical significance was defined at a *P* value of less than 0.05. Moreover, a sensitivity analysis was performed by omitting each individual study sequentially to check the stability and robustness of the pooled outcomes. Additionally, publication bias was estimated using Begg's correlation test and Egger's linear regression test[14,15]. *P* greater than 0.05 along with the observation of symmetry in the funnel plot indicated the absence of significant publication bias.

Results

Study characteristics

A total of 438 studies were identified through systematic database searches. First, we removed 126 duplicate articles, and the titles and abstracts of the remaining articles were screened. The 22 remaining articles with full text after screening were assessed per the eligibility criteria. Finally, seven full-text articles (199 participants) were included in the systematic review. However, only six articles were included in the meta-analysis due to the unavailability of data on balance parameters. A flowchart demonstrating the details of study selection according to the PRISMA guidelines is presented in Figure 1.

All seven studies were RCTs[16–22]. All studies were conducted in South Korea except for one study by Chen *et al.*[16] conducted in Taiwan. The sample size of the studies ranged from 20 to 56 participants. The majority of the patients included in the analysis are elderly (103, 51.76%) and female (111, 55.78%). Two studies[20,22] exclusively studied elderly female patients. Out of 199 participants, 96 (48.24%) had a past history of stroke. The rest of the participants were elderly patients with no significant neurological comorbidities. The duration of AR-based training ranged from 4 to 12 weeks. Each training session's duration was 20–90 min. Various modalities of exercise, such as postural control training, Tai-chi exercise, Otago exercise, treadmill exercise, and motion-imitating exercises, were used in AR-based training by different studies. The different parameters of functional balance assessed by the studies were BBS, TUG, and FRT. BBS, TUG, and FRT measure the balance and functional ability of a person to perform basic activities of daily living along with the risk of falling. Six studies have reported on both the BBS and TUG scores of the participants. Dynamic balance was assessed using

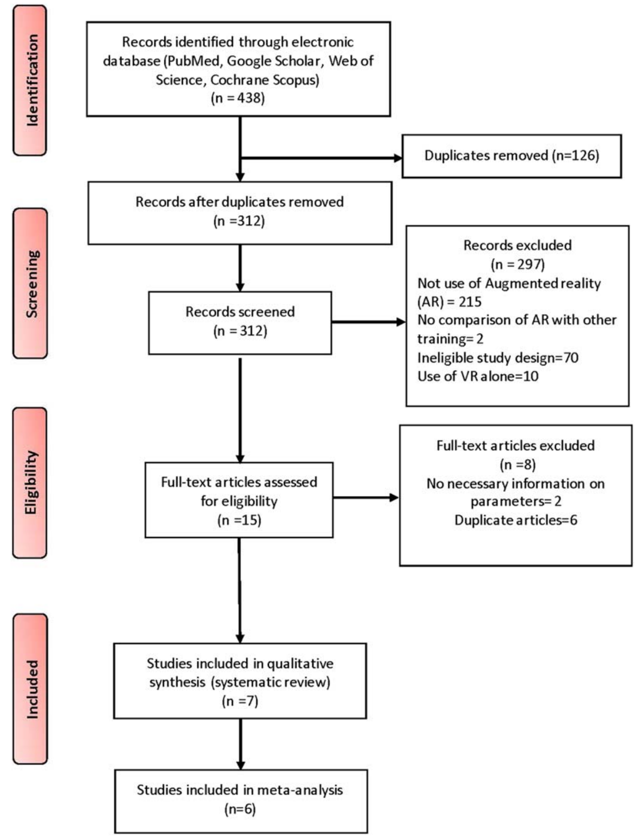

Figure 1. PRISMA flow diagram of selection of studies.

the FRT score in a single study by Chen *et al.*[16] The FOF was measured using short FES-I[22] and standard FES-I[21] by two different studies. FRI and MFS were described by one study each to quantify the likelihood or the risk of falls. The details of the studies included in the review are presented in Table 1. The risk of bias assessment of the studies is provided in Appendix 2 of the Supplementary File 1, Supplemental Digital Content 3, http://links.lww.com/MS9/A166.

Comparison of outcomes on functional balance and mobility

The BBS score was significantly higher in the AR-based training group ($n = 91$) than conventional training ($n = 87$) (Hedge's g = 0.48, 95% CI = 0.19–0.77, $P < 0.001$). The heterogeneity given by the I^2 statistic was 43.39%, which falls under moderate heterogeneity. The forest plot showing the pooled estimate of mean differences in BBS score is depicted in Figure 2. Likewise, the TUG score was found significantly lower in AR-group ($n = 80$) than the conventional training group ($n = 77$) (Hedge's g = − 0.54, 95% CI = − 0.85 to − 0.23, $P < 0.01$). The heterogeneity given by the I^2 statistic was 2.17%, which is not considered important. The forest plot showing the pooled estimate of mean differences in BBS score is depicted in Figure 3. Additionally, Chen *et al.*[16] showed that the FRT score at the follow-up was significantly higher in the AR-group than the standard group (32.5 ± 4.1 versus 24.8 ± 3.8, $P < 0.001$).

Table 1

Characteristics of included studies.

Reference	Study population	Study design	Sample size	Control group	AR-group	Study location	Female/male	Age (years)	Training in AR-group	Training in control group	Session time(min)	Duration of AR-training	Parameters tested by the study
Lee *et al.*[17]	Stroke	RCT	21	11	10	South Korea	7/14	35–65	AR-postural control training	General physical therapy	30	8	BBS, TUG
Kim & Lee[18]	Stroke	RCT	19	10	9	South Korea	8/11	35–65	AR-based functional electrical stimulation with treadmill training	Functional electrical stimulation with treadmill training	20	8	BBS, TUG
Yoo *et al.*[22]	Elderly woman	RCT	21	10	11	South Korea	21/0	> 70	AR-Otago exercise	Otago exercise	90	12	BBS, Short FES-I
Ku *et al.*[19]	Elderly people	RCT	34	16	18	South Korea	17/17	55–80	Balloon game, Cave game, Rhythm game (3D- AR system)	Conventional physical fitness program	30	4	BBS, TUG, FRI
Lee *et al.*[21]	Stroke	RCT	56	27	29	South Korea	13/43	25–83	Motion-imitating exercise	Stretching, aerobic exercise, posture balance exercise	30	4	BBS, TUG, FES-I
Chen *et al.*[16]	Elderly people	RCT	28	14	14	Taiwan	25/3	65 and above	Computer-assisted Tai-Chi	Traditional Tai-Chi	30	8	BBS, TUG, FRT
Lee *et al.*[20]	Elderly woman	RCT	20	10	10	South Korea	20/0	N/A	AR-Otago exercise (UINCARE Home®)	Self-Otago	60	12	MFS

AR, augmented reality; BBS, Berg Balance Scale; FES-I, falls efficacy score-International; FRI, falls risk index; FRT, functional reach test; MFS, Morse Falls Scale; N/A, not available; RCT, randomized controlled trial; TUG, Timed Up and Go test.

Comparison of outcomes on FOF

No meta-analysis could be performed to assess the FOF in patients due to the two different versions of the same tool used in the two studies. One study using the short FES-I reported that the AR-based Otago exercise group showed a significant difference pre-intervention and post-intervention in the short FES-I score. However, the standard Otago exercise group showed no significant differences. The second study by Lee *et al.*[21] also reported similar findings. Additionally, they also compared FES-I scores between the two groups. They discovered that the change in FES-I from baseline to post-intervention was significantly higher in the AR-based training group than in the control group.

Comparison of outcomes on degree of risk of falling

Two studies[19,20] assessed the risk of falling in participants with FRI and MFS, respectively. Ku *et al.*[19] reported an improvement in the risk of falling in an AR-based group, but the difference in FRI before and after the intervention was not statistically significant. Lee *et al.*[20] on the other hand, reported a significant decrease in MFS value in AR-based Otago exercise, whereas the self-Otago group did not.

Risk of bias and sensitivity analysis

Most RCTS has high or unknown risk of selection bias and performance bias. The studies had relatively low detection and attrition bias. However, all included studies had an unknown risk of reporting bias and other study biases. The details of the risk of bias assessment are given in Appendix 2 of Supplementary File S1, Supplemental Digital Content 3, http://links.lww.com/MS9/A166. Sensitivity analysis showed that the recalculated Hedge's g after sequentially removing each study were similar, which indicates the stability of the analysis. The details of the sensitivity analysis are given in Appendix 3 of Supplementary File S1, Supplemental Digital Content 3, http://links.lww.com/MS9/A166.

Subgroup analysis

Subgroup analysis of six studies by study population showed no significant differences in Hedge's g value between the normal elderly population and patients with a history of stroke ($P = 0.53$). The BBS value was significantly higher in AR-based training of 8 weeks or more (Hedge's $g = 0.88$, 95% CI = 0.46–1.31) when compared with trainings conducted for less than 8 weeks (Hedge's $g = 0.11$, 95% CI = −0.30 to 0.52), $P = 0.01$). However, the TUG score was not significantly different between the groups with different duration of AR trainings ($P = 0.26$). Subgroup analysis based on sex and age group could not be performed due to the unavailability of sufficient data.

Publication bias

Begg's test for small study effects showed no significant publication bias in the meta-analysis ($P = 0.06$). Additionally, Figure 4 visualizes a symmetrical funnel plot which shows no publication bias either. However, Egger's regression asymmetry test was statistically significant ($P = 0.01$).

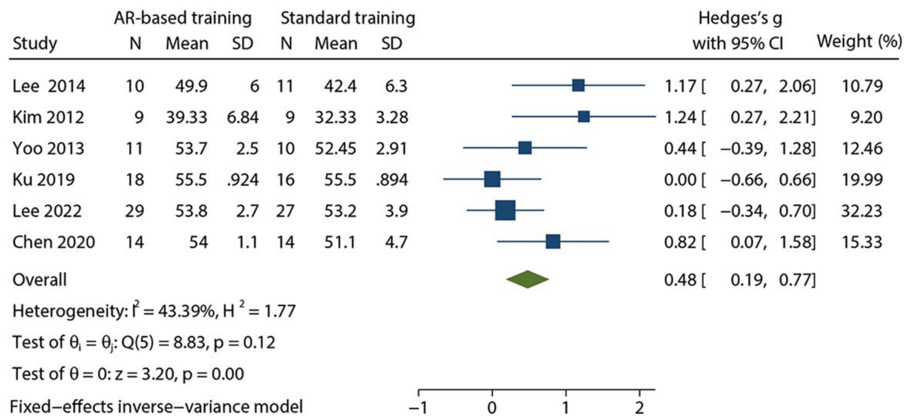

Figure 2. Forest plot of BBS score between two groups. BBS, Berg Balance Scale.

Discussion

This systematic review and meta-analysis showed significant improvements with AR-based training compared with standard training in parameters measuring balance, mobility, FOF, and likelihood of falls. The present study showed higher BBS in the AR-based group than the controls. Our analysis also revealed that the improvements in BBS were significantly higher in the participants who had AR-based training for 8 weeks or more. Two meta-analyses have identified a training period of 11–12 weeks as the most effective duration of balance therapy in healthy adults and the elderly population[23,24]. This shows that the dose-response relationship of AR-based balance training must be understood to obtain optimal results. Further studies are required to quantify this dose-response relationship in AR-based balance training. The BBS is a performance-oriented parameter that measures the balance and the risk for falls in elderly individuals. A score of 0–20 indicates a balance impairment, a score of 21–40 indicates an acceptable balance, and a score of 41–56 indicates a good balance. The BBS assesses the balance's static and dynamic components. BBS has been widely utilised for post-stroke assessment of patients as well[25,26]. A BBS score of 14 or higher among stroke survivors (sensitivity = 73%, specificity = 89%) predicted independent walking at discharge from the centre[27]. A meta-analysis reported that the BBS can be used as a screening tool to predict the risk of falls with a moderate level of accuracy in diagnostic performance[28].

The TUG was designed to assess mobility in elderly patients, which requires both static and dynamic balance. TUG has been found to have high intra- and inter-rater reliability (intraclass correlation values of 0.99 and 0.98, respectively)[29]. The TUG calculates how long it takes a participant to get out of an armchair, travel three metres, turn around, and return to the chair. A longer time indicates poor balance and mobility performance on the part of the subject[26,30]. Our meta-analysis showed a significantly lower TUG score in the patients trained with AR technology. Another meta-analysis exploring the role of AR in physiotherapy also showed significant improvements in BBS and TUG scores in the AR intervention group. However, the study did not assess the patients' fear of falling or their risk of falling[31].

The present study has also shown that the AR-based training improves the patients' FOF. The FOF has been described as one of the most important consequences of past history of falls in elderly patients by a number of studies[32,33]. The subjects who had a history of falling were 2.48 times more likely to be afraid of falling than those who had not experienced any such event[34]. The FOF creates limitations in the mobility and daily activities of these elderly people. This effect, in the long run, can lead to other

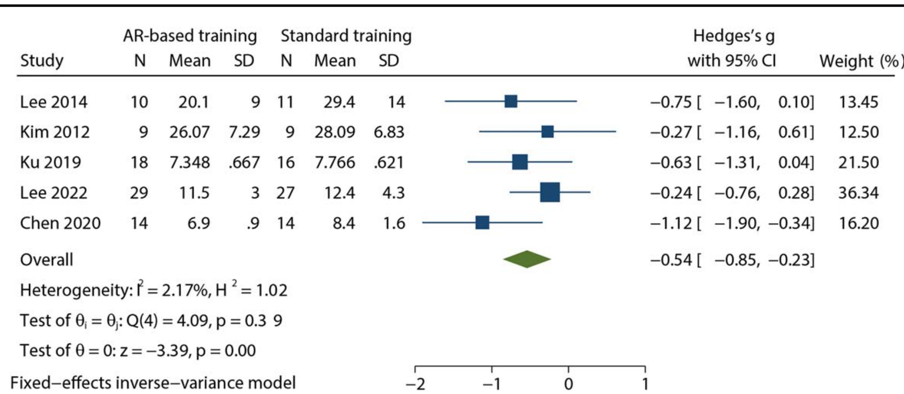

Figure 3. Forest plot of TUG score between two groups. TUG, Timed Up and Go Test.

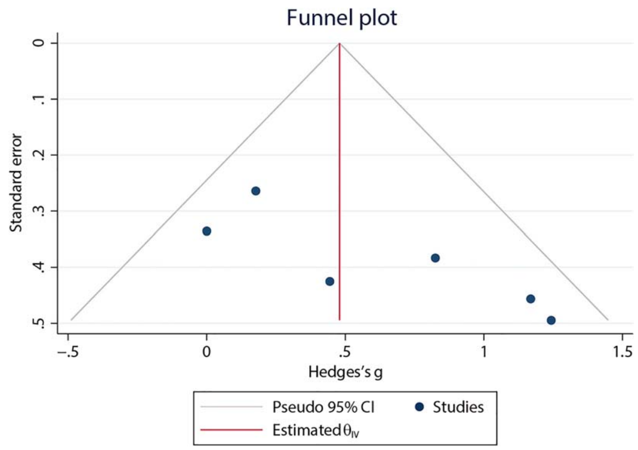

Figure 4. Funnel plot studies included in the review.

problems such as sarcopenia and poor muscle strength[35]. The fear of falling also causes a loss of independence, a reduction in social activity, depression, and a reduction in the quality of life. Since, the FOF can also lead to falls, studies have pointed out that the FOF can also be used to predict falls[34,36]. With the participation in AR-training, the balance confidence in the subject rises and the FOF decreases simultaneously.

Our study has also found a decrease in the risk of falls with AR-based exercise, although we derived this conclusion from two studies. These studies also reported no improvement in fall risk in the standard training group that did not use the AR technology. However, when compared with usual care alone, different exercises performed without the use of technology resulted in a significant decrease in subsequent falls (1.4 versus 2.1 falls per person-year)[37].

AR is a slightly different technology from VR, even though they might share some components. Both systems are capable of offering insightful and natural feedback on a subject's motion. The feedback provided by these systems improves participants' guidance and motivation to achieve the desired outcomes. VR-based rehabilitation has been used in stroke, Parkinson disease, cerebral palsy, etc., with significant improvements in balance and gait according to the literature[38–40]. Stroke patients have observed positive effects on balance, motor function, and gait with the use of VR rehabilitation[39]. Likewise, VR-based exercises enhanced balance and reduced FOF among elderly people, according to Zahedian-Nasab *et al.*[41] Unlike VR, AR allows real-world interaction for the patients with the help of additional digital objects in the same space. Since AR-based interventions can provide a better sense of reality, this promotes and induces rehabilitation with exercises in the real environment[42].

Even though AR-based exercises appear superior to conventional exercises, the devices used in AR-training cannot be operated and controlled in all processes by the participants. In reality, elderly people find it difficult to adopt advanced technology. The elderly need assistance because they believe that their advanced age prevents them from embracing technology. Hence, exercise specialists must be trained to support older people while using and controlling AR devices[30]. Furthermore, AR-training employs complex technology that necessitates sophisticated and costly hardware, software, and other accessories. Therefore, the global use of AR technology in general balance therapy and rehabilitation cannot be imagined yet. Innovation in the sector of VR/AR can improve the accessibility and affordability of such therapies in healthcare setups around the world.

Our study also has its limitations. The main limitation of the meta-analysis is the limited number of studies with a small sample size, leading to a low statistical power. Similarly, use of diverse scales in assessment of FOF and falls risk prevented the pooled analysis of these aspects in the analysis. Furthermore, although the majority of the studies (6 out of 7) were conducted in South Korea, various kinds of exercise and the AR system were utilized by each of them, which made the comparison between them difficult.

Conclusion

This meta-analysis showed that the AR-based trainings are superior to conventional or standard trainings to improve the balance, mobility, fear and the risk of falling in normal elderly as well as stroke patients. AR-training for 8 weeks or more resulted in higher improvement of balance in the patients. There is a need for a larger RCT to provide a more accurate comparison on efficacy and safety of different modalities of training used to improve balance, mobility, and fall risk in patients.

Ethical approval

Not applicable due to the nature of the review article.

Consent

Not applicable for review article.

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Author contribution

P.L.: study conception, data analysis, software, manuscript writing. S.S., B.A., S.S.: study conception, manuscript writing and editing. S.F., S.A., R.O.: manuscript writing and editing.

Conflicts of interest disclosure

None to declare.

Research registration unique identifying number (UIN)

1. Name of the registry: PROSPERO.
2. Unique Identifying number or registration ID: CRD420 23423405.
3. Hyperlink to your specific registration: https://www.crd.york.ac.uk/prospero/display_record.php?ID=CRD42023423405.

Guarantor

Dr. Pratik Lamichhane.

Availability of data and materials

All necessary data and information are presented within the article. A supplementary file containing the search strategy, risk of bias assessment, and sensitivity analysis has been provided.

Provenance and peer review

Not commissioned, externally peer-reviewed.

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