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Review article

Action simulation as an intervention to improve balance, mobility and gait in healthy older adults: A scoping review

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ABSTRACT

Falls in older adults are a significant public health concern. Action simulation interventions involving action observation and/or motor imagery have been proposed as alternative or adjunct strategies to physical exercise for reducing fall risk. These approaches may minimize barriers to physical practice and may specifically target deficits in motor planning that are linked to falls. The purpose of this scoping review is to examine how action simulation interventions have been applied and evaluated in healthy older adults. A systematic search of six databases and repositories was conducted. Studies were included if they used action simulation interventions in healthy, community-dwelling adults aged 60+ years and examined movement outcomes related to balance, gait or functional mobility. Nineteen studies with 587 older adults were included. Motor imagery was the most common action simulation intervention ($n = 11$ [58%]), and most studies were randomized controlled trials ($n = 14$ [74%]). Only one study examined long-term effects on balance and gait performance (i.e., 1-month post-intervention). Studies varied widely in the outcomes examined, including static and dynamic balance, gait, mobility, and psychological outcomes, and reported findings were heterogeneous across studies and outcome domains. Limited reporting of intervention implementability was identified across the included studies. Overall, this review highlights the heterogeneity of how action simulation interventions have been applied and evaluated to improve balance, mobility and gait outcomes in older adults. However, if action simulation techniques are to be adopted as a fall prevention strategy, more studies examining acceptability are needed.

1. Introduction

As we age, declines in physical and cognitive function increase the risk of falls (see DiPietro et al., 2019; Muir et al., 2012 for reviews). Falls are the leading cause of injury in older adults, resulting in loss of independence and reduced quality of life (Schoene et al., 2019; Gardiner et al., 2017). Fall prevention guidelines and recommendations emphasize physical exercise as a key intervention for reducing fall risk (Montero-Odasso et al., 2022; Sherrington et al., 2019). However, older adults seldom (consistently) achieve the recommended hours of physical activity (Kosteli et al., 2019), reporting anxiety regarding unsupervised exercise, post-exercise fatigue, and post-fall immobilization as the main obstacles to sufficient engagement in physical activity (Bethancourt et al., 2014; Burton et al., 2017). Traditionally, fall prevention strategies have focused on (re)building physical capacity. However, recent research has focused on integrating cognitive factors into fall prevention interventions, as these factors are increasingly recognised as important contributors to fall risk (Sturnieks et al., 2024). Whilst predictive motor control, including aspects of motor planning, may be retained during healthy ageing, the feedback-based motor control processes deteriorate with age (Matthijs et al., 2025). Such impairments may contribute to falls through reduced capacity to integrate sensory feedback, update internal models, and adapt movements in response to balance disturbances or environmental demands (Lafargue et al., 2013; Sturnieks

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et al., 2008). Action simulation strategies have been proposed as alternative or adjunct strategies to physical exercise to optimise these cognitive processes (Moran and O'Shea, 2020) and improve physical capacity (e.g., balance, Taube et al., 2014; strength, Di Rienzo et al., 2019), due to their functional equivalence with actual physical movements (Decety et al., 1989).

Action simulation is an umbrella term covering action observation (AO), motor imagery (MI), and combined action observation and motor imagery (AOMI; Moreno-Verdú et al., 2024). AO refers to the intentional and systematic observation of a movement without its physical execution (Eaves et al., 2024), while MI refers to the mental rehearsal of an action through visual and/or kinaesthetic imagery without overtly performing the movement (MacIntyre et al., 2013). AOMI refers to the observation of human movement and simultaneous imagery of the same or a different movement (Eaves et al., 2016a, 2016b). Extensive research supports the effectiveness of action simulation interventions in enhancing motor learning, control, and execution (see Buccino, 2014; Eaves et al., 2016a, 2016b, 2022 for reviews), with evidence for locomotor tasks extending across care and rehabilitation contexts in older adults following hip arthroplasty (Marusic et al., 2018), in stroke patients (Monteiro et al., 2021) and in healthy older adults (Nicholson et al., 2018).

The neural mechanisms underpinning the facilitatory effects of action simulation on movement-related outcomes have been explained by Motor Simulation Theory (Jeannerod, 2001). Motor Simulation Theory proposes that AO and MI activate motor-related regions in the brain in a similar manner to those recruited during movement execution, suggesting covert and overt action states involve the same motor planning and encoding processes. Indeed, action simulation results in increased and more widespread activation of brain regions associated with movement control and execution when compared to control/baseline conditions (Eaves et al., 2016a, 2016b). Specifically, a comprehensive meta-analysis synthesizing whole-brain fMRI data identified that AO, MI and movement execution all recruit a bilateral network of premotor, parietal, and somatosensory regions (Hardwick et al., 2018).

Three previous reviews have examined action simulation interventions for improving motor function in older adults (see Liu et al., 2023; Nicholson et al., 2019; Jie et al., 2024). Nicholson et al. (2019) reviewed 12 studies and found that MI training significantly improved mobility and balance in older adults without neurological conditions, although it was unclear whether effects were clinically relevant due to the wide variety of balance-related outcomes examined and wide 95% confidence intervals reported. Liu et al. (2023) reported that MI training led to better strength outcomes than no exercise, however, the effects of MI were inferior to those of physical exercise, and a combination of both provided no additive benefits beyond those demonstrated for physical exercise alone. Similarly, in a review of different motor learning strategies in older adults, Jie et al. (2024) reported that AO training improved learning outcomes when combined with traditional treatments such as gait training and functional activities carried out with upper limbs in 73% of the studies, with isolated MI training only enhancing learning in 42% of the studies reviewed.

While these reviews show some promising results, key limitations are that Nicholson et al. (2019) and Liu et al. (2023) focused solely on MI interventions and thus omitted evidence on AO and AOMI, while Jie et al. (2024) and Nicholson et al. (2019) included older adults living with neurological conditions and/or recovering from orthopaedic surgery. This distinction is important when evaluating interventions, as differences in cognitive function, context and underlying neurophysiological mechanisms (such as restoring motor function versus enhancing motor control and execution) influence how action simulation interventions should be applied (e.g., Kitago and Krakauer, 2013). Additionally, these previous review articles on action simulation and movement outcomes did not extensively document (heterogeneity in) the conceptualisation and intervention design of previous studies, nor did they address implementation-related outcomes of the included studies (i.e., acceptability, fidelity, feasibility) or fall-related cognitive and psychological outcomes. This is essential for a more nuanced understanding of how action simulation interventions may vary in application and effectiveness across populations and contexts, and to help standardize approaches in terminology and approaches in this field moving forward.

This scoping review will provide an overview of what is known about action simulation (i.e., AO, MI, AOMI) interventions with regards to balance, mobility and gait outcomes in older adults. This review aims to (1) explore how action simulation interventions have been defined and conceptualized in this context and population; (2) examine how these interventions have been applied and outcomes evaluated in this context and population; (3) narratively describe the outcome measures used and the heterogeneity of reported findings across balance, mobility, gait, and associated psychological and cognitive domains, including falls efficacy; and (4) map findings related to the acceptability, fidelity, and feasibility of action simulation interventions in this population.

2. Methods

2.1. Protocol development

A scoping review was chosen as the method for this review as it permits a broader focus than systematic reviews, spanning conceptual, theoretical, and methodological trends in the literature. This scoping review adhered to the reporting guidelines of Preferred Reporting Items for Systematic reviews and Meta-analyses for Scoping Reviews (PRISMA-ScR; Tricco et al., 2018; see Supplementary Materials). The proposed protocol for this review was preregistered with the Open Science Framework (OSF) on 25 March 2024: doi:10.17605/OSF.IO/F9JZT. Any deviations from the protocol, along with justifications and supplementary material, are also provided alongside the preregistered protocol. This study adopted Arksey and O'Malley's (2005) established five-stage protocol for conducting a scoping review: identifying the research question (as presented in the introduction), identifying relevant studies, study selection, charting the data, and collating, summarizing and reporting the results.

2.2. Identifying relevant studies: Eligibility criteria

Inclusion and exclusion criteria were based on the PCC mnemonic (i.e., Population, Concept, Context), as recommended (see Peters et al., 2020). Studies were included if the population consisted of healthy, community dwelling older adults with an overall mean age of at least 60 years. We therefore excluded any study where: (i) participants were recruited from assisted living, convalescent hospital, or a care home; (ii) where participants had a progressive or neurological disorder or condition or had explicitly disclosed the presence of any comorbidities (e.g., diabetes); (iii) where participants had diagnosed or clinically defined impairments in sensory or cognitive function that were not corrected (e.g., hearing aid); or (iv) where participants used assistive devices for ambulation.

Any action simulation intervention (i.e., AO, MI or AOMI) was acceptable if the design of the study allowed for either a comparison of movement outcomes (i.e., measures of balance, gait and/or functional mobility) pre- and post-intervention, or an evaluation of differences in outcomes between intervention and control groups following an intervention. Finally, studies were eligible if they reported objective movement outcomes of balance (e.g., functional reach test, Berg Balance Scale), gait (e.g., timed up-and-go, 10-m walk), and/or functional mobility related to falls (e.g., sequential footstep task, obstacle course). This excludes movement outcome measures that are not directly related to these domains (e.g., fine motor skills, upper limb strength).

2.3. Search strategy

Six databases/repositories were searched to capture both peer-reviewed and gray literature: PubMed, Web of Science, EBSCOHost (CINAHL Plus, MEDLINE, APA PsycInfo), PsyArXiv, bioRxiv and Advanced Google Scholar Search. In line with the study aims and criteria outlined above, the search strategy was broad and consisted of general terms related to key topics such as older adults, action simulation, and balance, mobility and gait outcomes rather than including keywords related to specific outcome measures or interventions. The search string was developed with the assistance of a librarian at the lead university and finalised after initial piloting of preliminary searches. The search terms were adapted for each database to meet specific search string requirements (see Supplementary Materials document on the OSF project page for the exact search strings used for each of the databases). As the field of action simulation is well-established, no restriction was placed on the earliest possible date for eligible publications, and all articles published in English before 26 March 2024 (when the primary search was conducted) were considered. The results of the searches were imported in RIS format into Covidence (i.e., a web-based software for managing systematic reviews; Babineau, 2014) on 27 March 2024. An updated search was conducted on 28 October 2025.

2.4. Study selection

All records identified through the search were combined, and duplicate entries were removed. We followed a two-stage screening process (i.e., title and abstract, followed by full-text screening) involving two independent reviewers at each stage (authors NG and AB) who reviewed the articles against the inclusion criteria. At the full-text screening stage, detailed reasons for exclusion were recorded. Any disagreements were resolved through discussion. A detailed breakdown of the search results and the study inclusion process is presented in Fig. 1.

2.5. Charting the data

Data were extracted independently by two researchers (NG, AB) by transferring key information into a template spreadsheet, allowing for further categorisation into themes (where applicable). Following comparison of notes and extracted data, agreement was reached for all included studies. Along with some metadata (i.e., authors, year of publication, country), extracted data related to (i) the definition of the action simulation intervention and theoretical background used; (ii) intervention design/content (study design, sample size and characteristics, intervention content and intensity, and outcomes assessed); and (iii) acceptability, fidelity, and feasibility of the intervention (e.g., participant adherence, author-reported acceptability or feasibility-related outcomes).

2.6. Collating, summarizing and reporting the results

Data were descriptively analysed. Numerical frequencies were calculated to quantify the prevalence of specific characteristics and outcomes of included studies. Where the variability of the evidence did not allow for a synthesis of findings using descriptive statistics, a narrative approach was adopted. This blend of approaches allowed for a comprehensive synthesis and reporting of the results.

3. Results

3.1. Search results

The initial search returned 13,047 articles. Following the automatic removal of 2015 duplicates via Covidence and a manual removal of 1 duplicate, 11,031 articles were screened for eligibility based on their title and abstract. This resulted in a further exclusion of 10,970 articles (intercoder reliability = 99%) and full-text versions of 61 articles were sought. Despite efforts to contact authors, 4 full-texts were not accessible to the research team, leaving 57 articles to be read in-full and assessed for eligibility. Following full-text screening, a further 42 studies were

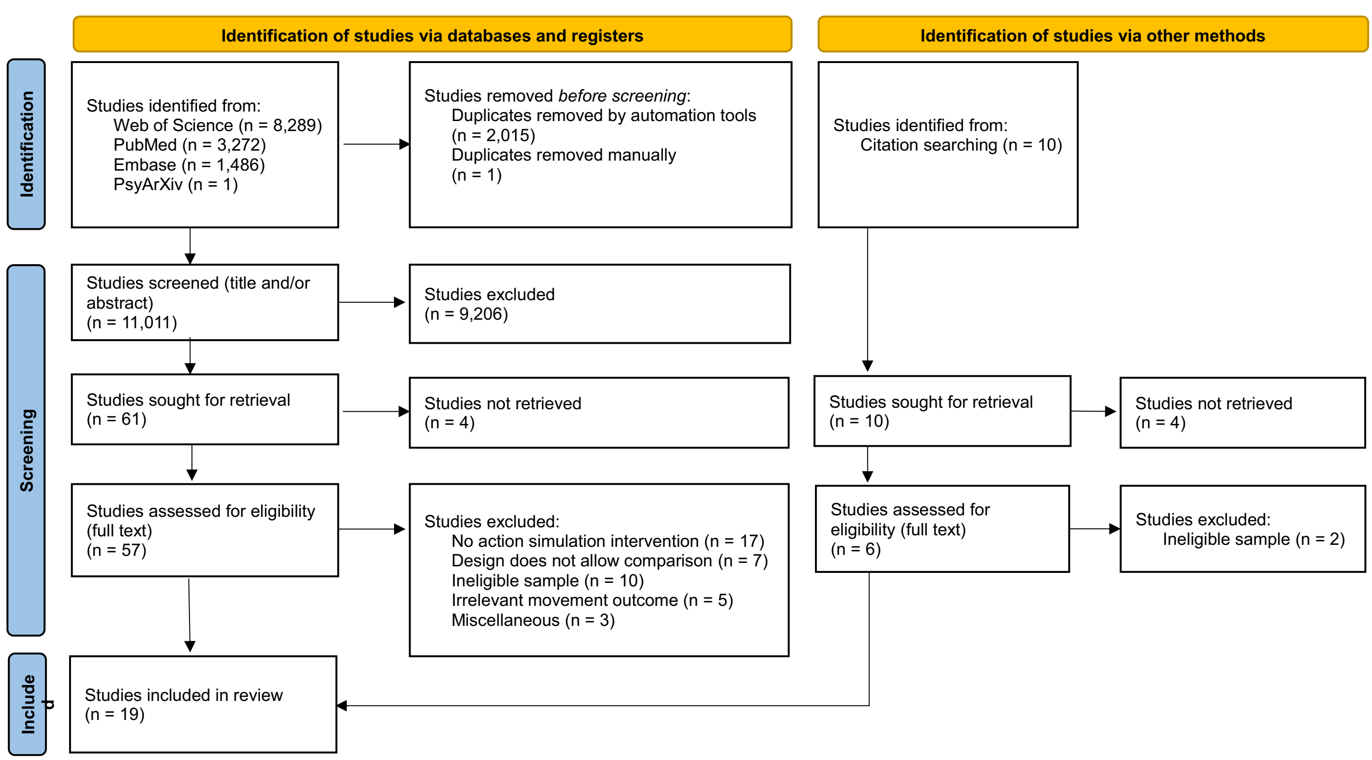

Fig. 1. PRISMA Flow Diagram of the Search Process.

excluded (intercoder reliability = 96%). Ten additional studies were identified via ascendancy and descendancy approaches (i.e., examining references cited by the included studies and studies that cited them, respectively). Following a full-text screen, 4 of these additional studies met the criteria for inclusion. This resulted in a final sample of 19 articles for inclusion in this review.

3.2. Study characteristics

An overview of the extracted data for all nineteen included studies can be found in Supplementary Materials. Seventeen studies (89.5%) were peer-reviewed papers published in scientific journals (Alsubiheen et al., 2015, 2020; Batson et al., 2007; Chiacchiero et al., 2015; Goudarzian et al., 2017; Hagedoorn et al., 2025; Hamel and Lajoie, 2005; Hilt et al., 2023; Leem et al., 2019; Linden et al., 1989; Nicholson et al., 2018, 2025; Oh and Choi, 2021; Oungphalachai and Siriphorn, 2020; Temporiti et al., 2024; Tia et al., 2010; Tunney et al., 2006), while two studies (10.5%) were considered gray literature, in the form of a Master's thesis (Post, 2005) and Doctoral thesis chapter (Srisupornkornkool, 2014). The majority of the studies included in this review were conducted in high-income countries (n = 17 [89.5%]): Seven studies (36.8%) were conducted in the USA (Alsubiheen et al., 2015, 2020; Batson et al., 2007; Chiacchiero et al., 2015; Linden et al., 1989; Post, 2005; Tunney et al., 2006), two (10.5%) each in France (Hilt et al., 2023; Tia et al., 2010), Australia (Nicholson et al., 2018, 2025) and South Korea (Leem et al., 2019; Oh and Choi, 2021), and one (5.3%) in each of Canada (Hamel and Lajoie, 2005), Italy (Temporiti et al., 2024), the Netherlands (Hagedoorn et al., 2025), and United Kingdom (Srisupornkornkool, 2014). This review also included studies conducted in Iran and Thailand (n = 1 [5.3%] each; Goudarzian et al., 2017; Oungphalachai and Siriphorn, 2020). The year of publication ranged from 1989 to 2025 (median$n$ = 2017), with most studies published since 2014 (n = 14 [73.7%]).

3.3. Definitions and conceptualizations of action simulation interventions

Eleven studies (57.9%) employed an MI intervention alone (Batson et al., 2007; Chiacchiero et al., 2015; Goudarzian et al., 2017; Hamel and Lajoie, 2005; Hilt et al., 2023; Linden et al., 1989; Nicholson et al., 2018; Oh and Choi, 2021; Post, 2005; Srisupornkornkool, 2014; Tunney et al., 2006), four studies (21.1%) employed an AO intervention alone (Hagedoorn et al., 2025; Leem et al., 2019; Oungphalachai and Siriphorn, 2020; Tia et al., 2010), and four studies (21.1%) employed both AO and MI either synchronously (i.e., at the same time; Alsubiheen et al., 2015, 2020) or asynchronously (i.e., not at the same time; Nicholson et al., 2025; Temporiti et al., 2024).

The definitions used in eighteen studies (94.7%) were broadly mapped on to those recommended for the different types of action simulation in Moreno-Verdú et al.' (2024) Guidelines for Reporting Action Simulation Studies (GRASS) (Alsubiheen et al., 2015, 2020; Batson et al., 2007; Chiacchiero et al., 2015; Goudarzian et al., 2017; Hagedoorn et al., 2025; Hamel and Lajoie, 2005; Hilt et al., 2023; Leem et al., 2019; Linden et al., 1989; Nicholson et al., 2018, 2025; Oh and Choi, 2021; Post, 2005; Srisupornkornkool, 2014; Temporiti et al., 2024; Tia et al., 2010; Tunney et al., 2006). Different terminology was used to label the action simulation interventions across the included studies. For example, MI was referred to as 'motor imagery' (n = 7 [36.8%]; Batson et al., 2007; Chiacchiero et al., 2015; Hilt et al., 2023; Nicholson et al., 2018, 2025; Oh and Choi, 2021; Srisupornkornkool, 2014), 'mental practice' (n = 2 [10.5%]; Linden et al., 1989; Tunney et al., 2006), and 'mental training' (Goudarzian et al., 2017), 'mastery imagery' (Post, 2005) and 'mental imagery' (Hamel and Lajoie, 2005). AO was predominantly referred to as 'action observation' (n = 5 [26.3%]; Hagedoorn et al., 2025; Leem et al., 2019; Nicholson et al., 2025; Temporiti et al., 2024; Tia et al., 2010) but one study used the term 'visual feedback' (n = 1 [5.3%]; Oungphalachai and Siriphorn, 2020) for this type of action simulation. Three studies (75%) employing both AO and MI only acknowledged the use of MI (despite AO occurring by observing the tai chi instructor as well as observing themselves in the mirror; Alsubiheen et al., 2015, 2020, and priming participants for MI using AO of video recordings of a model performing walking tasks; Nicholson et al., 2025).

Motor Simulation Theory (Jeannerod, 1995, Jeannerod, 2001) was the most commonly cited theoretical framework underpinning action simulation interventions in the included studies (n = 5 [26.3%]; Chiacchiero et al., 2015; Hilt et al., 2023; Nicholson et al., 2018, 2025; Tia et al., 2010) with many studies indirectly referencing the propositions of Motor Simulation Theory by highlighting the shared neural networks of action simulation with movement execution when developing a rationale for action simulation (n = 9 [47.4%] cited Grezes and Decety, 2001 as seminal work related to this theory; Batson et al., 2007; Hilt et al., 2023; Leem et al., 2019; Linden et al., 1989; Nicholson et al., 2018; Oh and Choi, 2021; Srisupornkornkool, 2014; Temporiti et al., 2024; Tia et al., 2010).

3.4. Design and content of action simulation interventions

3.4.1. Overall

3.4.1.1. Participant characteristics. In total, the nineteen studies included in this review involved 602 participants. However, reporting of participant characteristics and sample screening procedures varied across studies. The total sample size of included studies ranged from 6 to 70 (M = 31.7 ± 16.5), of which between 6 and 47 (M = 16.4 ± 9.8) participants were allocated to the action simulation intervention groups. The mean age of participants ranged from 63.6 to 86 years old. Note that this was based on sixteen studies only, as three studies only reported the age range, which ranged from 65 to 80 (Batson et al., 2007), 65–90 (Hamel and Lajoie, 2005), and 67–90 years (Linden et al., 1989). The percentage of female participants in the studies ranged from 0% to 100% (M = 44.9 ± 41.9%).

Participants' cognitive function was screened for in seven studies using (36.8%) four different measures (Mini Mental State Examination [MMSE], Korean Mini Mental State Examination [MMSE-K], MiniCog, digit span task). Participants' mean scores ranged from 26.73 to 29.17 for MMSE (Batson et al., 2007; Hilt et al., 2023; Temporiti et al., 2024; Tia et al., 2010; Tunney et al., 2006), 25.2 to 29.5 for MMSE-K (Leem et al., 2019; Oh and Choi, 2021), 4.5 to 4.6 for MiniCog (Nicholson et al., 2018, 2025), and 14.5 for the total digit span task (Srisupornkornkool, 2014). This suggests that participants had preserved cognitive function at the time of testing, as scores of 21/22 on the MMSE-K (Kim et al., 2001) and < 3 on the MiniCog (Borson et al., 2003) are typically used as cut-offs for dementia screening.

Participants' gait and balance abilities varied greatly at baseline, as indicated by the time taken to complete the Timed-Up-and-Go (TUG) and Fullerton Advanced Balance (FAB) Scale scores. Nine studies (47.4%) recorded TUG performance at baseline, with completion time ranging from 6.47 s to 16.17 s (Batson et al., 2007; Goudarzian et al., 2017; Hilt et al., 2023; Leem et al., 2019; Nicholson et al., 2018, 2025; Oh and Choi, 2021; Post, 2005; Temporiti et al., 2024). Two studies (10.5%) recorded FAB scores at baseline, with the mean score ranging from 22.3 to 32.71 (Oungphalachai and Siriphorn, 2020; Post, 2005). Where data on previous falls was gathered, three studies (15.8%) excluded participants if they had a history of falling (Alsubiheen et al., 2015, 2020; Hamel and Lajoie, 2005), and one study (5.3%) excluded participants if they had a fall in the 12 months prior to the study (Nicholson et al., 2018). By contrast, two studies (10.5%) only included participants who experienced at least one (Hagedoorn et al., 2025) or two falls (Oh and Choi, 2021) in the 12 months prior to the study, and one study (5.3%) included participants with impaired balance and/or gait, as determined by baseline measures (Post, 2005).

3.4.1.2. Design characteristics. The most commonly used design was a randomized control trial (RCT) with fourteen studies (73.7%) adopting this approach: seven studies (36.8%) were two-armed RCTs (Chiacchiero et al., 2015; Hamel and Lajoie, 2005; Hilt et al., 2023; Linden et al., 1989; Nicholson et al., 2025; Oungphalachai and Siriphorn, 2020; Tunney et al., 2006), five (26.3%) were three-armed RCTs (Hagedoorn et al., 2025; Leem et al., 2019; Nicholson et al., 2018; Oh and Choi, 2021; Temporiti et al., 2024), one study (5.3%) was a four-armed RCT (Goudarzian et al., 2017), and one study (5.3%) was a five-armed RCT (Srisupornkornkool, 2014). Thirteen RCTs (92.9%) included pre-test and post-test measures, with individual studies recording measures on a trial-by-trial basis during the intervention (Nicholson et al., 2018), at the mid-intervention point (Linden et al., 1989), and one-month after the intervention ended (Temporiti et al., 2024). One RCT assessed the outcome at post-test only (Hagedoorn et al., 2025). Aside from RCTs, variations of a pre-test-post-test design were used, with two studies (10.5%) conducting an uncontrolled and non-randomized experiment (Alsubiheen et al., 2015, 2020), two studies (10.5%) conducting an uncontrolled and randomized experiment (Batson et al., 2007; Post, 2005), and one study (5.3%) conducting a single-group pre-test-post-test experiment (Tia et al., 2010).

3.4.1.3. Intervention characteristics

3.4.1.3.1. Intervention delivery. The action simulation intervention period varied considerably across studies from 1 to 42 sessions ($M = 13.3 \pm 11.5$). The intervention was delivered across 1 day for three studies (15.8%; Hagedoorn et al., 2025; Hilt et al., 2023; Nicholson et al., 2018), 2–3 days for one study (5.3%; Tunney et al., 2006), 8 days for one study (5.3%; Linden et al., 1989), 14 days for one study (5.3%; Srisupornkornkool, 2014), 21 days for two studies (10.5%; Temporiti et al., 2024; Tia et al., 2010), 28 days for three studies (15.8%; Chiacchiero et al., 2015; Nicholson et al., 2025; Oungphalachai and Siriphorn, 2020), 42 days for three studies (15.8%; Batson et al., 2007; Hamel and Lajoie, 2005; Oh and Choi, 2021), 56 days for four studies (21.1%; Alsubiheen et al., 2015, 2020; Goudarzian et al., 2017; Post, 2005), and 84 days for one study (5.3%; Leem et al., 2019). Studies where the intervention period lasted longer than a week predominantly adopted a 3×/week schedule ($n = 7$ [36.8%]; Chiacchiero et al., 2015; Goudarzian et al., 2017; Leem et al., 2019; Oh and Choi, 2021; Oungphalachai and Siriphorn, 2020; Srisupornkornkool, 2014; Tia et al., 2010), followed by 2×/week ($n = 3$ [15.8%]; Alsubiheen et al., 2015, 2020; Post, 2005), 7×/week ($n = 2$ [10.5%]; Hamel and Lajoie, 2005; Linden et al., 1989), 1×/week ($n = 1$ [5.3%]; Batson et al., 2007), 4×/week (n = 1 [5.3%]; Temporiti et al., 2024) and 5×/week schedule (n = 1 [5.3%]; Nicholson et al., 2025).

Studies adopted different approaches to reporting the duration of engaging with action simulation tasks. Six studies (31.6%) reported the *number of blocks and trials* of the action simulation task (Hagedoorn et al., 2025; Hilt et al., 2023; Nicholson et al., 2018; Oungphalachai and Siriphorn, 2020; Srisupornkornkool, 2014; Tunney et al., 2006), with each session ranging from 4 to 75 trials ($M = 27.3 \pm 24.8$), resulting in 4 to 900 trials ($M = 177.3 \pm 355.28$ trials) in total across the intervention period for these studies. Eleven studies (57.9%) reported the *time spent engaging with* the action simulation task on a daily basis (Alsubiheen et al., 2015, 2020; Batson et al., 2007; Chiacchiero et al., 2015; Leem et al., 2019; Linden et al., 1989; Nicholson et al., 2025; Oh and Choi, 2021; Post, 2005; Temporiti et al., 2024; Tia et al., 2010), with each session involving 6 to 45 min of action simulation ($M = 22.4 \pm 14.2$ min), resulting in 48 to 720 min ($M = 345.5 \pm 263.4$ min) in total across the intervention period for these studies. Two studies (10.5%) did not adequately describe engagement information regarding the action simulation task (Goudarzian et al., 2017; Hamel and Lajoie, 2005).

The action simulation interventions were conducted in community settings ($n = 5$ [26.3%]; Alsubiheen et al., 2015, 2020; Batson et al., 2007; Goudarzian et al., 2017; Post, 2005), research laboratories (n = 5 [26.3%]; Hagedoorn et al., 2025; Hilt et al., 2023; Nicholson et al., 2018; Oungphalachai and Siriphorn, 2020; Srisupornkornkool, 2014), and home settings ($n = 3$ [15.8%]; Chiacchiero et al., 2015; Hamel and Lajoie, 2005; Tunney et al., 2006). The intervention location was unreported for six studies (31.6%; Leem et al., 2019; Linden et al., 1989; Nicholson et al., 2025; Oh and Choi, 2021; Temporiti et al., 2024; Tia et al., 2010). The action simulation tasks were carried out in a group setting (n = 5 [26.3%]; Alsubiheen et al., 2015, 2020; Batson et al., 2007; Linden et al., 1989; Post, 2005), and individual setting (n = 5 [26.3%]; Chiacchiero et al., 2015; Hagedoorn et al., 2025; Hamel and Lajoie, 2005; Hilt et al., 2023; Oungphalachai and Siriphorn, 2020). Nine studies (47.4%) did not adequately report the setting where the action simulation tasks were completed (Goudarzian et al., 2017; Leem et al., 2019; Nicholson et al., 2018, 2025; Oh and Choi, 2021; Srisupornkornkool, 2014; Temporiti et al., 2024; Tia et al., 2010; Tunney et al., 2006).

3.4.1.3.2. Intervention content. Content was deemed *target-congruent* for ten studies (52.6%) as they involved action simulation of motor task (s) that directly matched task(s) being assessed as one or more of the outcome measures in those studies (Chiacchiero et al., 2015; Goudarzian et al., 2017; Hagedoorn et al., 2025; Hamel and Lajoie, 2005; Hilt et al., 2023; Linden et al., 1989; Nicholson et al., 2018; Srisupornkornkool, 2014; Tia et al., 2010; Tunney et al., 2006). Content was deemed *target-incongruent* for nine studies (47.4%) as they involved action simulation of motor task(s) that were not assessed as outcome measures for balance, mobility, or gait (Alsubiheen et al., 2015, 2020; Batson et al., 2007; Leem et al., 2019; Nicholson et al., 2025; Oh and Choi, 2021; Oungphalachai and Siriphorn, 2020; Post, 2005; Temporiti et al., 2024).

Ten studies (52.6%) employed static action simulation where participants were instructed not to move whilst completing the action simulation tasks (Batson et al., 2007; Chiacchiero et al., 2015; Goudarzian et al., 2017; Hilt et al., 2023; Leem et al., 2019; Nicholson et al., 2018; Oh and Choi, 2021; Srisupornkornkool, 2014; Temporiti et al., 2024; Tia et al., 2010), and four studies (21.1%) employed dynamic action simulation where movement was permitted and/or instructed during the action simulation tasks (Alsubiheen et al., 2015, 2020; Hagedoorn et al., 2025; Oungphalachai and Siriphorn, 2020). Five studies (26.3%) did not specify whether movement was instructed/allowed during action simulation (Hamel and Lajoie, 2005; Linden et al., 1989; Nicholson et al., 2025; Post, 2005; Tunney et al., 2006).

Five studies (26.3%) required participants to adopt the same body position as that used in the action simulation tasks (Alsubiheen et al., 2015, 2020; Hagedoorn et al., 2025; Oungphalachai and Siriphorn, 2020; Srisupornkornkool, 2014), whereas seven studies (36.8%) involved a misalignment between participant and simulated body positions (Chiacchiero et al., 2015; Goudarzian et al., 2017; Hilt et al., 2023; Leem et al., 2019; Nicholson et al., 2018; Oh and Choi, 2021; Tia et al., 2010), and seven studies (36.8%) did not specify participants' body position during simulated tasks (Batson et al., 2007; Hamel and Lajoie, 2005; Linden et al., 1989; Nicholson et al., 2025; Post, 2005; Temporiti et al., 2024; Tunney et al., 2006).

The content of the interventions varied greatly, with the most common being action simulation of traversing a bespoke activity/obstacle course (n = 3 [15.8%]; Linden et al., 1989; Nicholson et al., 2018; Tunney et al., 2006) and Tai Chi movements (n = 2 [10.5%]; Alsubiheen et al., 2015, 2020). Other interventions included body scanning and functional movements (Batson et al., 2007), swaying and reaching exercises (Chiacchiero et al., 2015), and TUG movements (Goudarzian et al., 2017), among others not listed here (for a detailed description of interventions' content see Table 1). Nine studies (47.4%) delivered action simulation as an adjunct to physical practice component. Of these, seven (77.8%) incorporated physical exercise such as Tai Chi, leg-lifting, reactive stepping and balance training (Alsubiheen et al., 2015, 2020; Batson et al., 2007; Hagedoorn et al., 2025; Leem et al., 2019;

Table 1
Descriptive Characteristics of All Included Studies.

Sample Details	Intervention Details	Outcomes	Key Findings
Alsubiheen et al. (2015)			
N = 29 Mean age = 63.6 ± 6.5 72% female Healthy vs diabetic Scores at baseline: FRT: 11.7 ± 0.4 SLS: 44.4 ± 10.4 Excluded if history of frequent falling	Design: experimental (non-random, non-control), pre-post; MI + TC Intensity: 1 h (15 min of warm up +45 min of TC in combination with MI) 2×/week for 8 weeks Content: MI of sequence of each TC movement, coupled with PP, AO of instructor + AO of self via mirror	Movement: Balance platform tests, FRT, SLS Psychological: ABC	Intervention improved 7/10 measures of static and dynamic balance Intervention improved 1/1 measures of balance confidence
Alsubiheen et al. (2020)			
N = 29 Mean age = 63.6 ± 6.5 72% female Healthy vs diabetic Scores at baseline: FRT: 11.7 ± 1.8 SLS: 28.0 [4.3, 127.0] Excluded if history of frequent falling	Design: experimental (non-random, non-control), pre-post; MI + TC Intensity: 1 h (15 min of warm up +45 min of TC in combination with MI) 2×/week for 8 weeks Content: MI of sequence of each TC movement, coupled with PP, AO of instructor + AO of self via mirror	Movement: FRT, SLS Psychological: ABC	Intervention improved 2/2 measures static and dynamic balance Intervention improved 1/1 measures of balance confidence
Batson et al. (2007)			
N = 6 Age range = 65–80 100% female Scores at baseline: MMSE: 29.17 ± 0.75 MIQ: 57.67 ± 3.5 BBS: 48.33 ± 4.55 TUG: 15.24 ± 3.18	Design: experimental (random, non-control), pre-post; MI + PP vs MI + EDU Intensity: 6 sessions across 6 weeks (20 min of MI + 20 min of PP) Content: guided MI audiotape of bodyscanning and functional movements, two different scripts	Movement: BBS, TUG Psychological: ABC	Intervention had no impact on balance (0/1) or gait (0/1) Intervention had no impact on balance confidence (0/1)
Chiacchiero et al. (2015)			
N = 20 Mean age = 79.2 ± 6.35 85% female Inclusion criteria: MMSE 24 or above	Design: 2-armed RCT, pre-post; MI vs CTRL Intensity: 20 min of MI 3×/week for 4 weeks Content: imagined themselves performing	Movement: Balance platform tests, FRT	Intervention improved 3/15 measures of balance

Table 1 (*continued*)

Sample Details	Intervention Details	Outcomes	Key Findings
	different swaying and reaching exercises		
Goudarzian et al. (2017)			
N = 42 Mean age = 68 ± 5.78 0% female Scores at baseline (MT): TUG: 6.47 ± 0.71 5STS: 9.68 ± 2.26 Scores at baseline (MT + WBV): TUG: 6.75 ± 1.32 5STS: 10.36 ± 1.4	Design: 4-armed RCT, pre-post; MT + WBV vs MT vs WBV vs CTRL Intensity: 3×/week for 8 weeks, MT 3×/week for 8 weeks Content: imagine standing up from the chair, walking 3 m, turning around, sitting back down; each time with more skill and speed	Movement: TUG, Biodex (levels 8–12), 5STS, 6 m tandem gait, 10 m walking	Both interventions improved measures of balance (1/1), mobility (1/1) and gait (2/3 for MT; 3/3 for MT + WBV)
Hagedoorn et al. (2025)			
N = 70 Mean age = 683 ± 5.2 75% female Inclusion criteria: At least 1 fall in the 12 months prior Scores at baseline: VMIQ not reported	Design: 3-armed RCT, post; AOMS-human vs AOMS-avatar vs CTRL Intensity: 20 trials of AOMI + PP of reactive stepping Content: AO of an actor's reactive stepping movements in response to a perturbation + PP (AOMS-human), AO of a virtual humanoid avatar's reactive stepping movements in response to a perturbation + PP (AOMS-avatar)	Movement: forward lean (% BoS), weight bearing asymmetry (% BW), leg angle (deg), balance recovery with a single step for 20 trials	Both interventions improved 1/4 measures of balance
Hamel and Lajoie (2005)			
N = 20 Age range = 65–90 70% female Inclusion criteria: BBS 45 or better Absence of history of falls Scores at baseline: VMIQ not reported	Design: 2-armed RCT, pre-post; MI vs CTRL Intensity: every day for 6 weeks Content: MI with relaxation before, followed by contract-relax MI (i.e., MI of progressive muscle relaxation), followed by MI of static balance	Movement: Balance platform tests, BBS Psychological: ABC	Intervention improved 1/2 measures of static balance Intervention had no impact on balance confidence (0/1)
Hilt et al. (2023)			
N = 30 Mean age = 86 ± 2 63% female Scores at baseline (MI): MMSE: 29 ± 1 [22–30]	Design: 2-armed RCT, pre-post; MI vs CTRL Intensity: 3 blocks of 10 trials Content: MI of performing the	Movement: Sequential footstep task	Intervention improved 1/1 measures of lower-limb mobility

(*continued on next page*)

Table 1 (*continued*)

Sample Details	Intervention Details	Outcomes	Key Findings
KVIQ: 86 ± 15 TUG: 9.0 ± 1.5	footstep task as quickly as possible		
Leem et al. (2019)			
N = 30 Mean age = 79.5 ± 4.55 (MI group) 100% female Scores at baseline (AO + Otago): MMSE-K: 29.5 ± 0.71 TUG: 16.17 ± 1.99	Design: 3-armed RCT, pre-post; AO + Otago vs Otago vs CTRL Intensity: 20 min of MI + 50 min of Otago 3×/week for 12 weeks Content: MI of Otago exercises (that were practiced)	Movement: TUG, temporal gait parameters, spatial gait parameters Psychological: Short FES-I	Intervention improved 7/7 measures of gait Intervention improved 1/1 measures of falls efficacy
Linden et al. (1989)			
N = 23 Age range = 67–90 100% female	Design: 2-armed RCT, pre-mid-post; MI vs CTRL (sedentary activities) Intensity: 6 min of days 2–5 and 5–7 of the intervention Content: audio-guided MI of traversing the activity course	Movement: Bespoke motor course	Intervention had no impact on mobility (0/1)
Nicholson et al. (2018)			
N = 30 Mean age = 74 ± 5 Sex not reported Exclusion: Any falls in 12 months prior Scores at baseline (MI): MiniCog: 4.6 ± 0.8 KVIQ10: 34.8. ± 10.2 TUG: 7.86 ± 1.78	Design: 3-armed RCT, pre-post + trial-by-trial; MI vs PP vs CTRL Intensity: 20 trials Content: MI of traversing the obstacle course as quickly and accurately as possible from 1 pp	Movement: TUG, temporal gait parameters, spatial gait parameters, bespoke motor course	Intervention improved 1/6 measures of gait and had no impact on mobility (0/1)
Nicholson et al. (2025)			
N = 53 Mean age = 74.4 ± 6.3 68% female Scores at baseline (MI): MiniCog: 4.7 ± 0.5 RAPA: 5.4 ± 1.2 KVIQ-10: 32.4 ± 9.3 TMT-A: 35.8 ± 14.3 TMT—B: 84.8 ± 37.8	Design: 2-armed RCT, pre-post; AOMI vs CTRL Intensity: 15 min of AOMI 5×/week for 4 weeks Content: AO of an age-matched female model completing different walking tasks (walking on uneven ground, walking up large steps, "tightrope" walking, walking on large stepping-stones, walking on a foam balance beam), followed by MI of own	Movement: TUG, 50 cm walk, 25 cm walk, 15 cm walk, SOT Psychological: ABC	Intervention had no impact on mobility (0/1) and gait (0/4) Intervention had no impact on balance confidence (0/1)

Table 1 (*continued*)

Sample Details	Intervention Details	Outcomes	Key Findings
	performance on these tasks in 1 pp.		
Oh and Choi (2021)			
N = 34 Mean age = 79.9 ± 5.6 (MI) 68% female Inclusion: At least 2 falls in the 12 months prior Scores at baseline (MI): MMSE-K: 25.2 ± 1.61 BBS: 46.7 ± 2.4 TUG: 13.58 ± 1.67 MIQ-RS not reported	Design: 3-armed RCT, pre-post; MI vs TOT vs CTRL Intensity: 20 min of MI + 20 min of TOT 3×/week for 6 weeks Content: MI of freely imagining movements that protect their body and prevent injuries in the event of falls in diverse real-world environments	Movement: Balance platform tests, BBS, TUG, temporal gait parameters, spatial gait parameters Psychological: FES-I	Intervention improved 2/2 measures of static and dynamic balance and 6/6 measures of gait Intervention improved 1/1 measures of falls efficacy
Oungphalachai and Siriphorn (2020)			
N = 34 Mean age = 69. 65 ± 2.42 (AO group) 85% female Scores at baseline (AO): FAB: 32.71 ± 0.7 30sSTS: 13.59 ± 0.95	Design: 2-armed RCT, pre-post; AO (visual feedback) vs CTRL Intensity: 5 blocks of 15 trials of leg-lifting coupled with AO 3×/week for 4/ weeks Content: AO of own leg-lifting in real-time via mirror feedback	Movement: SLS, LOS, FAB, 30s STS Psychological: MFES	Intervention improved 3/21 measures of static/dynamic balance and had no impact on mobility (0/1) Intervention had no impact on falls efficacy (0/1)
Post (2005)			
N = 20 Mean age = 79 ± 8.78 70% female Inclusion criteria: Participants had to have impaired balance/gait as indicated by baseline scores Scores at baseline (BT + MI): FAB: 22.3 TUG: 8.54	Design: experimental (non-random, non-control), pre-post, BT + MI vs BT Intensity: 1 h of BT + 13 min of MI 2×/ week for 8 weeks Content: pre-recorded MI tape (3 min of progressive relaxation, 10 min polysensory imagery), script 1 was walk to the park and script 2 was walk to the beach, made to elicit feelings of competence in balance and mobility, imagined engaging in mobility activities	Movement: TUG, temporal gait parameters, FAB	Intervention had no impact on balance (0/2) or gait (0/4)
Srisupornkornkool (2014)			
N = 60 Mean age = 70.9 ± 4.57 50% female Scores at	Design: 5-armed RCT, pre-post; visual/external MI vs somatosensory/ internal MI vs muscular/internal	Movement: STS	Visual / external MI and somatosensory / internal MI interventions had no impact on

(continued on next page)

Table 1 (*continued*)

Sample Details	Intervention Details	Outcomes	Key Findings
baseline: MIQ-R: 20 or above for KI and VI Total digit span task: 14.5 ± 4.24	MI vs PP vs CTRL Intensity: 3 blocks of 5 trials of MI 3×/week for 2 weeks Content: MI of performing the STS focusing on: how their viewpoint has changed relative to the fixation point (visual/external MI group), how the pressure of their body feels under their feet (somatosensory/internal MI group), how the weight of their body feels in their thighs (muscular/internal MI group)		measures of mobility (0/5) The muscular / internal MI intervention improved 1/5 measures of mobility
Temporiti et al. (2024)			
N = 30 Mean age (AOMI-sleep) = 70. 4 ± 4.8 Mean age (AOMI-control) = 68.5 ± 3.8 44% female Scores at baseline (AOMI-sleep): MMSE: 28.0 ± 1.1 KVIQ (VI): 38.3 ± 12.4 KVIQ (KI): 18.9 ± 11.9 TUG: 8.3 ± 1.1 Scores at baseline (AOMI-control): MMSE: 27.3 ± 1.1 KVIQ (VI): 39.3 ± 8.2 KVIQ (KI): 21.1 ± 9.7 TUG: 8.3 ± 1.1	Design: 3-armed RCT, pre-post + retention; AOMI-sleep vs AOMI-control vs CTRL Intensity: 12 min of AOMI 4×/week for 3 weeks Content: AOMI of daily tasks performed in standing posture and requiring advanced gait and balance (at 8-10 pm for AOMI-sleep group and at 8-10 am for AOMI-control group)	Movement: TUG, 10 m walking, FSST, LQYBT Psychological: FES-I	AOMI-sleep intervention improved 6/7 measures of balance and 3/3 measures of gait. AOMI-control intervention had no impact on measures of balance (0/7) and improved 2/3 measures of gait No impact of either AOMI intervention on a measure of falls efficacy (0/1)
Tia et al. (2010)			
N = 8 Mean age = 70.5 ± 6.4 88% female Scores at baseline: MMSE: 28.25 ± 1.49 Walking speed (preferred): 1.05 ± 0.06 m/s	Design: uncontrolled trial (all in one group); AO Intensity: 10 min session 10× in 3 weeks Content: 12 walking movies and the 2 × 12 STS/BTS movies were separated into 3 blocks of 4 walking movies and 2 × 4 STS/BTS movies for the training sessions. Two of these blocks were applied 3 times and one block was applied 4 times over the 10-session training period.	Movement: Temporal gait parameters, spatial gait parameters, STS, BTS	Intervention improved 1/4 measures of mobility and 4/6 measures of gait
Tunney et al. (2006)			
N = 19 Mean age = 75.89 ± 6.33 68% female Scores at baseline: MMSE: 26.73 ± 1.14	Design: 2-armed RCT, pre-post; MP vs CTRL Intensity: 4 trials of MI in 48-72 h Content: MI of traversing the same motor course they practiced	Movement: Bespoke motor course (using a cane)	No impact of the intervention on a measure of mobility

Note. ABC: Activities-specific Balance Confidence Scale; AO: action observation; AOMI: action observation and motor imagery; AOMS: action observation and motor simulation; BBS: Berg Balance Scale; BT: balance training; BTS: back-to-sit; CTRL: control; EDU: education; FAB: Fullerton Advanced Balance Scale; FES—I: Falls Efficacy Scale – International; FRT: functional reach test; FSST: four square step task; MI: mental/motor imagery; MP: mental/motor practice; MT: mental/motor training; KI: kinesthetic imagery; KVIQ: The Kinesthetic and Visual Imagery Questionnaire; LOS: limits of stability; LQYBT: Lower Quarter Y-Balance Test; MFES: Modified Falls Efficacy Scale; MMSE: Mini-Mental State Examination; PP: physical practice; RCT: randomized controlled trial; SLS: single leg stance; STS: sit-to-stand; TC: tai chi; TOT: task-oriented training; TUG: timed up-and-go; VI: visual imagery; WBV: whole body vibration; 5STS: five time sit-to-stand.

Oungphalachai and Siriphorn, 2020; Post, 2005). One study (5.3%) incorporated the action simulation intervention alongside whole body vibration (Goudarzian et al., 2017), and one study (5.3%) delivered action simulation in addition to task-oriented training (Oh and Choi, 2021).

3.4.1.4. Outcome measures. Seventy-seven distinct fall-related movement outcomes were measured across the studies included in this scoping review. Measures of gait were mostly evaluated using the TUG test (n = 8 [42.9%]; Batson et al., 2007; Goudarzian et al., 2017; Leem et al., 2019; Nicholson et al., 2018, 2025; Oh and Choi, 2021; Post, 2005; Temporiti et al., 2024) and different temporal (n = 6 [31.6%]; Leem et al., 2019; Nicholson et al., 2018, 2025; Oh and Choi, 2021; Post, 2005; Tia et al., 2010) and spatial gait parameters (n = 4 [31.6%]; Leem et al., 2019; Nicholson et al., 2018; Oh and Choi, 2021; Tia et al., 2010). Balance was assessed using balance platform tests (n = 4 [31.6%]; Alsubiheen et al., 2015; Chiacchiero et al., 2015; Hamel and Lajoie, 2005; Oh and Choi, 2021), the Functional Reach Test (n = 3 [15.8%]; Alsubiheen et al., 2015, 2020; Chiacchiero et al., 2015), the Single Leg Stance test (n = 3 [15.8%]; Alsubiheen et al., 2015, 2020; Oungphalachai and Siriphorn, 2020), the Berg Balance Scale (n = 3 [15.8%]; Batson et al., 2007; Hamel and Lajoie, 2005; Oh and Choi, 2021) and reactive stepping performance (n = 1 [5.3%]; Hagedoorn et al., 2025). Mobility was assessed using variations of sit-to-stand tasks (n = 4 [21.1%]; Goudarzian et al., 2017; Oungphalachai and Siriphorn, 2020; Srisupornkornkool, 2014; Tia et al., 2010) and bespoke activity/obstacle course tasks (n = 3 [15.8%]; Linden et al., 1989; Nicholson et al., 2018; Tunney et al., 2006). The time between the final action simulation intervention session and post-test assessment varied across studies. Five studies (26.3%) assessed outcomes immediately following the intervention (Hilt et al., 2023; Nicholson et al., 2018, 2025; Hagedoorn et al., 2025; Srisupornkornkool, 2014), two (10.5%) reported the post-test assessments were conducted the next day following the intervention (Batson et al., 2007; Linden et al., 1989), while the majority (n = 12 [63.2%]) stated that the post-test outcomes were measured "after the intervention" without further detail (Alsubiheen et al., 2015, 2020; Chiacchiero et al., 2015; Goudarzian et al., 2017; Hamel and Lajoie, 2005; Oh and Choi, 2021; Oungphalachai and Siriphorn, 2020; Temporiti et al., 2024; Tia et al., 2010, Leem et al., 2019, Tunney et al., 2006; Post, 2005). Only one study (5.3%) examined the long-term effects of the intervention using a follow-up measurement at four weeks post-intervention (Temporiti et al., 2024). For a full list of outcome measures see Supplementary Materials on the OSF project page.

Most studies (n = 16 [84.2%]) recorded more than one movement outcome measure (Alsubiheen et al., 2015, 2020; Batson et al., 2007; Chiacchiero et al., 2015; Goudarzian et al., 2017; Hagedoorn et al., 2025; Hamel and Lajoie, 2005; Leem et al., 2019; Nicholson et al., 2018, 2025; Oh and Choi, 2021; Oungphalachai and Siriphorn, 2020; Post, 2005; Srisupornkornkool, 2014; Temporiti et al., 2024; Tia et al., 2010), with the number of movement outcome measures used in each study ranging from 1 to 22 ($M = 6.42 \pm 5.35$). Nine studies (47.4%) recorded fall-related psychological outcome measures (Alsubiheen et al., 2015, 2020; Batson et al., 2007; Hamel and Lajoie, 2005; Leem et al., 2019; Nicholson et al., 2025; Oh and Choi, 2021; Oungphalachai and Siriphorn, 2020; Temporiti et al., 2024). Specifically, seven studies (36.8%) measured balance confidence (Alsubiheen et al., 2015, 2020; Batson et al., 2007; Hamel and Lajoie, 2005; Nicholson et al., 2025; Oh and Choi, 2021; Oungphalachai and Siriphorn, 2020) and two studies (10.5%) measured falls efficacy (Leem et al., 2019; Temporiti et al., 2024).

3.4.2. Motor imagery interventions

Of the eleven studies that used MI alone as the intervention, five studies (45.5%) assessed the MI ability of the participants at pre-test (Batson et al., 2007; Hilt et al., 2023; Nicholson et al., 2018; Oh and Choi, 2021; Srisupornkornkool, 2014), and one study (9.1%) assessed the MI ability at both pre- and post-test (Hamel and Lajoie, 2005). Five different questionnaires were used to measure imagery ability across these studies, including the Movement Imagery Questionnaire – Revised second version (Hall and Martin, 1997), the Kinesthetic and Visual Imagery Questionnaire-10 (Malouin et al., 2007), Kinesthetic and Visual Imagery Questionnaire-20 (Malouin et al., 2007), Movement Imagery Questionnaire (Hall and Pongrac, 1983), and Vividness of Movement Imagery Questionnaire (Isaac et al., 1986). Five studies (45.5%) did not assess MI ability prior to delivering an MI intervention (Chiacchiero et al., 2015; Goudarzian et al., 2017; Linden et al., 1989; Post, 2005; Tunney et al., 2006). Three studies (27.3%) instructed the use of kinesthetic imagery (Chiacchiero et al., 2015; Hamel and Lajoie, 2005; Srisupornkornkool, 2014), two studies (18.2%) instructed the use of visual imagery (Goudarzian et al., 2017; Linden et al., 1989), and three studies (27.3%) instructed a combination of visual and kinesthetic imagery (Batson et al., 2007; Hilt et al., 2023; Post, 2005). Three studies (27.3%) did not report what kind of imagery participants were instructed to use (Nicholson et al., 2018; Oh and Choi, 2021; Tunney et al., 2006). In the six studies using visual imagery (alone or in combination with kinesthetic imagery), one study (16.7%) instructed participants to adopt a first-person perspective (Hilt et al., 2023), two studies (33.3%) instructed participants to adopt a third-person perspective (Batson et al., 2007; Temporiti et al., 2024), and three studies (50%) did not specify the perspective instructed (Goudarzian et al., 2017; Linden et al., 1989; Post, 2005).

3.4.3. Action observation interventions

Of the four studies that used AO alone as the intervention, one study (25%) involved observation of a self-model (Oungphalachai and Siriphorn, 2020), two studies (50%) included observation of an other-model (Tia et al., 2010; Leem et al., 2019), and one study (25%) involved the observation of an other-model or humanoid avatar (Hagedoorn et al., 2025). Two studies (50%) included third-person perspective AO footage (Oungphalachai and Siriphorn, 2020; Hagedoorn et al., 2025), and two studies did not report the AO perspective used (Tia et al., 2010; Leem et al., 2019). The AO stimuli were pre-recorded in three studies (Hagedoorn et al., 2025; Leem et al., 2019; Tia et al., 2010). In one of these, the playback speed was systematically manipulated to alter perceived motor task capability (i.e., faster or slower walking gait; Tia et al., 2010). In the study that did not use pre-recorded stimuli, the AO stimuli were presented as live visual feedback, with participants observing their own body movements via a bespoke visual feedback device during the experimental session (Oungphalachai and Siriphorn, 2020). The model characteristics such as sex and age were adequately described in both studies that adopted an other-model (Leem et al., 2019; Tia et al., 2010).

3.4.4. Combined action observation and motor imagery interventions

Out of four studies that used both AO and MI, two studies (50%) used synchronous delivery (i.e., AOMI; Alsubiheen et al., 2015, 2020), while two studies (50%) adopted asynchronous delivery (i.e., AO and MI occurring separately; Temporiti et al., 2024; Nicholson et al., 2025). Two studies (50%) did not assess MI ability (Alsubiheen et al., 2015, 2020), while one study (25%) assessed MI ability at pre-test (Temporiti et al., 2024), and one study (25%) assessed MI ability at both pre- and post-test (Nicholson et al., 2025). Neither of the two AOMI studies assessed AOMI ability. Two studies (50%) instructed the use of kinesthetic imagery (Alsubiheen et al., 2015, 2020), one study (25%) instructed the use of visual imagery (in 3rd person perspective; Temporiti et al., 2024), and one study (25%) did not specify the MI modality (Nicholson et al., 2025). Two studies (50%) used pre-recorded stimuli where the characteristics of models were adequately described (e.g., age, sex; Nicholson et al., 2025; Temporiti et al., 2024), while two studies (50%) used live stimuli, in which participants observed both their own movements in a mirror and the Tai Chi instructor performing in front of them (Alsubiheen et al., 2015, 2020). In all four studies participants observed an other-model, however, in two of the studies participants also observed self-model in the mirror (Alsubiheen et al., 2015, 2020).

3.5. Reported findings across fall-related movement, cognitive and psychological outcomes

3.5.1. Reported findings across balance, mobility, and gait outcomes

Of the nineteen included studies, four studies included multiple action simulation intervention groups, so findings are described across 24 intervention groups rather than by study (see Table 1). Favorable outcomes were reported for seventeen of the action simulation interventions on at least one movement outcome measure (Alsubiheen et al., 2015, 2020; Chiacchiero et al., 2015; Goudarzian et al., 2017; Hagedoorn et al., 2025; Hamel and Lajoie, 2005; Hilt et al., 2023; Leem et al., 2019; Nicholson et al., 2018; Oh and Choi, 2021; Oungphalachai and Siriphorn, 2020; Srisupornkornkool, 2014; Temporiti et al., 2024; Tia et al., 2010). However, for twelve interventions movement outcome measures showed mixed, inconsistent results (Alsubiheen et al., 2015; Chiacchiero et al., 2015; Goudarzian et al., 2017; Hagedoorn et al., 2025; Hamel and Lajoie, 2005; Nicholson et al., 2018; Oungphalachai and Siriphorn, 2020; Srisupornkornkool, 2014; Temporiti et al., 2024; Tia et al., 2010). Moreover, only one study assessed delayed retention following an action simulation intervention, reporting sustained significant improvements for measures of gait and balance one month after completion of the AOMI intervention (Temporiti et al., 2024).

3.5.2. Reported findings across fall-related psychological and cognitive outcomes

Nine studies assessed fall-related psychological and cognitive outcomes (Alsubiheen et al., 2015, 2020; Batson et al., 2007; Hamel and Lajoie, 2005; Leem et al., 2019; Nicholson et al., 2025; Oh and Choi, 2021; Oungphalachai and Siriphorn, 2020; Temporiti et al., 2024). Of the six studies that measured balance confidence/falls efficacy, two studies demonstrated increased confidence/efficacy (Alsubiheen et al., 2015, 2020), however four studies showed no changes for these outcomes (Batson et al., 2007; Hamel and Lajoie, 2005; Nicholson et al., 2025; Oungphalachai and Siriphorn, 2020). Of the three studies that measured concerns about falling, two studies found that concerns reduced (Leem et al., 2019; Oh and Choi, 2021), with one study reporting no change (Temporiti et al., 2024). A descriptive summary of the included studies and their key findings can be found in Table 1.

3.6. Mapping of findings related to implementability of included interventions

Acceptability data (as the first stage of implementation research) obtained from participants was referenced in three studies (15.8%). The barriers to participation were evident as early as the recruitment stage for one of the three studies (33.3%), where participants reported time and confidentiality as the main reasons for choosing not to participate in the MI intervention (Post, 2005). One study (33.3%) attempted to address acceptability during the intervention period by organizing a weekly meeting between participants and researchers (Hamel and Lajoie, 2005). Participants were able to discuss their adherence to the MI intervention in terms of difficulties experienced and levels of motivation, however no qualitative or quantitative data from these meetings were reported. In another study (33.3%), authors reported that participants made no positive comments about the MI intervention, but they did comment on the "slowness of the tape and mind control" highlighting the scepticism participants expressed about the MI intervention content (Linden et al., 1989).

Similarly, data related to fidelity of the intervention was reported as the dropout/adherence rate and was referenced in all nineteen studies (100%). Rather than being explicitly reported by the authors, the adherence rate had to be calculated based on the data provided (by comparing the number of participants who started the study to those who completed it). The dropout rates ranged from 0% to 27.5% (M = 6.0% ± 9.3%), with 12 studies (63.2%) achieving 100% participant completion (Batson et al., 2007; Chiacchiero et al., 2015; Hamel and Lajoie, 2005; Hilt et al., 2023; Leem et al., 2019; Linden et al., 1989; Nicholson et al., 2018; Oungphalachai and Siriphorn, 2020; Srisupornkornkool, 2014; Temporiti et al., 2024; Tia et al., 2010; Tunney et al., 2006). Two studies reported adherence data only for the action simulation groups: One showed excellent adherence, with 91.6% of sessions completed (Batson et al., 2007), while the other reported near-perfect adherence, with no participant missing more than one session over the six-week intervention (Post, 2005). However, in two studies that included condition-specific adherence data, adherence was lower in the action simulation groups compared to active controls (Linden et al., 1989: 76% vs. 93%; Post, 2005: 84.5% vs. 89.2%). In one study, engagement with the action simulation intervention was monitored via a phone call, but the results were not reported (Temporiti et al., 2024).

Feasibility (as the final stage of implementation research) was not evaluated but merely reported as an observation in four studies (21.1%). These studies noted that the group setting facilitated the delivery and compliance with the MI intervention (n = 1 [5.3%]; Batson et al., 2007) and highlighted the low costs/efficient use of healthcare resources associated with the delivery of MI interventions (n = 3 [15.8%]; Goudarzian et al., 2017; Hilt et al., 2023; Tunney et al., 2006). No systematic approaches to gathering this data were reported.

4. Discussion

This scoping review provides the first comprehensive overview of evidence on the application and evaluation of action simulation interventions for improving balance, mobility and gait in healthy older adults. Overall, findings suggest that there is high variability in the intervention design, content and delivery across the included studies, making comparison and synthesis difficult. This scoping review highlights inconsistent reporting practices, and limited and inconsistent evidence of long-term benefits or implementability of action simulation interventions in fall-related contexts, as key methodological and evidence gaps in the literature. Based on these findings, we propose new directions for research and strategies for standardizing reporting of protocols and interventions in action simulation studies targeting fall-related outcomes in older adults. These recommendations focus on improving methodological consistency, improving transparency and reproducibility of research, and address current limitations associated with intervention design and outcome selection.

Overall, studies consistently defined action simulation interventions in line with existing literature and broader human movement science (Moreno-Verdú et al., 2024). However, terminology varied considerably despite the field being well established (Eaves et al., 2016a, 2016b), likely reflecting its evolution since the earliest included study (i.e., Linden et al., 1989), as evidenced by the range of synonyms used in this and previous reviews (Nicholson et al., 2019; Liu et al., 2023; Jie et al., 2024). The greatest inconsistencies arose for AOMI interventions, where separate studies used this term for different delivery approaches (i.e., synchronous vs asynchronous AO and MI), whilst others just labeled this MI (see Alsubiheen et al., 2015, 2020) despite this being coupled with an AO intervention. These findings underline recent calls for a standardized approach in reporting action simulation studies (e.g., Chye et al., 2022; Lin et al., 2025), and clearly highlight the need for researchers to use the recently developed GRASS (Moreno-Verdú et al., 2024) and its accompanying comprehensive checklist to ensure transparency and reproducibility of this area of research. Correct and consistent use of terminology is important to ensure that the observed effects can be attributed to the intervention employed, as well as for translating the procedures employed from research into clinical settings (see Moreno-Verdú et al., 2024 for discussion related to this point).

Only five studies (26.3%) provided theoretical reasoning for the action simulation strategy selected to improve motor control and/or execution in the context of fall prevention in healthy older adults. Motor Simulation Theory (Jeannerod, 2001, 2006) was the only theoretical framework referenced in this subset of studies, and whilst this provides a coherent explanation of the neurological processes linking action simulation to execution (see Hardwick et al., 2018 for a meta-analysis of fMRI data), this theory stops short of offering any description of changes in motor control processes that result from action simulation training (O'Shea and Moran, 2017). Theoretical models that aim to explain action simulation effects on movement outcomes have drawn from a variety of disciplines, including social psychology (Bandura, 1977), psychophysiology (Jacoben, 1931), and neuroscience (Jeannerod, 2001). Recent integrative accounts such as the Perceptual–Cognitive Scaffolding Approach (see Frank et al., 2023) draw from evidence across disciplines to provide a more detailed account of neural, cognitive, and motoric adaptations that can be achieved via action simulation. Such theoretical propositions should be used alongside applied frameworks (e.g., Cumming and Williams, 2013; Ste-Marie et al., 2012, 2020; Wright et al., 2022) to inform intervention design, delivery and interpretation of outcomes for action simulation interventions across contexts such as rehabilitation in ageing populations (Muir and Munroe-Chandler, 2025).

Perhaps stemming from the abovementioned lack of structured conceptual/theoretical foundations, key methodological factors related to the design and delivery of action simulation interventions varied considerably across the studies included in this review. Specifically, the literature-base varied in terms of the perspective and content of the simulated tasks, duration and intensity of the intervention periods, and mapping of the movements being simulated to the fall-related outcomes being targeted through the interventions. Whilst heterogeneity of the application of action simulation interventions is not inherently problematic, the underreporting of key methodological details and incorrect administration of (otherwise standardized) measures hinder the ability to assess and compare the effectiveness of interventions across studies. The differences in how interventions have been applied, evaluated and reported posed a significant challenge to analytically mapping and grouping data, and subsequently drawing meaningful conclusions about the interventions. There are well established frameworks regarding the development and delivery of action simulation interventions in applied contexts (e.g., PETTLEP model; Holmes and Collins, 2001), and it is important that future action simulation studies adhere with these principles to maximize potential benefits regarding fall-related outcomes in older adults.

While all the studies included measures of balance, mobility and gait as primary outcomes for the interventions, no studies adopted a structured approach to evaluating implementability of the interventions tested. This does not adhere to recommendations that implementation be considered as a primary outcome during initial stages of intervention planning and evaluation in healthcare settings (Klaic et al., 2022). There is growing interest in examining aspects of implementability in the context of fall prevention and action simulation in older adult population (Swanson et al., 2024). However, more attention should be paid to recruitment and adherence protocols to ensure potential participants find the intervention acceptable and complete the intervention in-full.

Although evaluation of intervention effectiveness was beyond the scope of this review, several included studies reported findings suggestive of potential positive changes associated with action simulation interventions, broadly aligning with outcomes reported in the wider literature (Nicholson et al., 2019; Liu et al., 2023; Jie et al., 2024). However, findings across studies appeared inconsistent and difficult to synthesise due to variation in intervention characteristics, outcome measures, and reported findings. As such, any potential benefits of action simulation interventions may plausibly reflect engagement with action simulation leading to an increased activation in the motor regions in a similar manner to physical practice (Chye et al., 2022). These neurophysiological mechanisms have been demonstrated in a meta-analysis of fMRI studies using action simulation, noting the shared cortical and subcortical structures between AO, MI, AOMI and physical execution (Hardwick et al., 2018). These mechanisms largely extend to the older adult population using balance tasks (Mouthon et al., 2018). Improvements in motor tasks may however also be explained by the mental representations of those movements (Schack and Frank, 2021), where action simulation would act as a rehearsal strategy by providing sequential and temporal information (via AO) and sensory information (via MI; Kim et al., 2017). Whilst mental representation structure of gait was found to be preserved and hierarchically organized in older adults up to the age of 60 (Stöckel et al., 2015), it is currently unclear whether this extends to impaired or difficult-to-execute movements in this population, such as those associated with falls.

Several factors were identified that may influence the implementation and reported outcomes of action simulation interventions in this population. It is important to note that, contrary to the recommendations of the PETTLEP model (Holmes and Collins, 2001), ten studies (52.6%) included in this review involved simulated practice of incongruent actions (i.e., the observed and/or imagined movement was not the same as the performed/measured movement), and all but one intervention were not progressive in nature (i.e., updating the observed/imagined stimuli as the participants' skill progressed), possibly making it difficult for participants to create, maintain or update internal representations (Saimpont et al., 2012). While action simulation research typically assumes alignment between the mentally rehearsed motor task and the target movement, in clinical contexts the transfer of benefits to untrained or functional tasks may be of greater relevance, suggesting applied frameworks such as PETTLEP may require adapting to meet the needs of older adult populations in this context.

Whilst this scoping review provides an important extension of the literature on action simulation in older adults, it is not without limitations. First, due to large heterogeneity of interventions and outcomes and a moderate number of included studies, it is difficult to establish the 'optimal' action simulation intervention (i.e., type, content, intensity, duration) for improving balance, mobility and gait outcomes in healthy older adults. Second, this review focused on healthy community-dwelling older adults, which limits generalisability to the wider older adult community given the high prevalence of older adults living with different comorbidities. While most studies screened disclosed the prevalence of comorbidities (and, if present, those studies were excluded), some omitted this information. It would be pertinent to assess the moderating effects of different comorbidities on action simulation effectiveness in older adult populations. Additionally, the reported findings should be interpreted with caution due to design limitations and small sample sizes ($n < 10$) in several included studies. Finally, by providing a broader overview of existing literature rather than a qualitative or quantitative synthesis, determining the statistical and/or clinical significance of the effectiveness of action simulation interventions in this context and population was beyond the scope of this review and remains to be established through systematic review and meta-analytical processes. The limitations of this review underscore areas where existing research has been insufficient, thus providing a foundation for future studies to address these shortcomings.

Future action simulation research on older adults and falls should improve methodological reporting standards to enhance rigor and reproducibility and permit more accurate comparisons to be made between studies (Moreno-Verdú et al., 2024). Additionally, when using fall-related outcomes (i.e., movement and psychological factors, such as balance tests and falls efficacy), it is important to incorporate these target outcomes in the action simulation content whilst also considering potential transfer to 'real-world' contexts where a fall is likely to occur such as standing from and sitting in a chair, stair negotiation, and dynamic day-to-day scenarios. Given the accumulating neurophysiological and behavioral evidence supporting the effectiveness of AOMI compared to either MI or AO alone as a movement intervention (e.g., Chye et al., 2022; Binks et al., 2025), it is notable that few studies included in this review utilized AOMI as the action simulation intervention. Similarly, no studies incorporated modern immersive technology in the form of virtual reality (VR) to deliver the action simulation intervention. It has been proposed that delivering AOMI through VR can lead to increased movement benefits by enhancing sense of presence and embodiment of the actions being simulated (Choi et al., 2020; Frank et al., 2023; Lindsay et al., 2022). Given that VR is being utilized more in physical training of balance, mobility and gait in older adults (e.g., Lee et al., 2024), and has been successfully implemented alongside action simulation in hospitalized older adults (Kim and Cho, 2022a, 2022b), it is a logical step to examine the efficacy of VR-based AOMI interventions targeting falls in healthy community-dwelling older adults.

It is important to note that this review examined studies in healthy older adults, and as such is unable to provide recommendations related to clinical practice, and implications relate more to preventative and community-based contexts. Rather than considering action simulation as a discrete intervention delivered in isolation, it may be more effective to integrate this approach with existing practices adopted with this population, such as demonstration or guided observation (see Buccino, 2014). Many of the paradigms used in the studies in this review were developed with the participants in mind (e.g., audio-guided MI, videos to be watched at home), reflecting efforts to reduce burden and support the practical adoption of the interventions, and the research should continue in this direction to bridge the gap between research and application in community settings. Many action simulation interventions, however, are very tightly controlled and artificial in terms of ecological validity. Future studies should develop action simulation interventions with the end-users in mind and incorporate patient and public involvement engagement groups or co-design methodologies to promote acceptable and feasible approaches that may lead to real-world benefits in terms of fall-related outcomes in older adults (INVOLVE, 2015).

In conclusion, this review highlights heterogeneity in intervention characteristics and outcome measures by examining how action simulation interventions have been applied and evaluated in studies targeting balance, mobility, and gait outcomes in healthy older adults. Overall, the review maps existing evidence and emphasises key gaps to inform future research on action simulation approaches in this population. Action simulation interventions should therefore be considered a viable approach to achieving functional movement and psychological benefits related to fall risk in community-dwelling older adults. This study extends existing reviews by providing evidence for action simulation interventions beyond MI alone in this context and population and provides a detailed evaluation of the application of these interventions in the context of falls.

CRediT authorship contribution statement

Neza Grilc: Writing – review & editing, Writing – original draft, Visualization, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Adam Cocks:** Writing – review & editing, Supervision, Project administration, Conceptualization. **Elmar Kal:** Writing – review & editing, Supervision, Project administration, Conceptualization. **Toby J. Ellmers:** Writing – review & editing, Supervision, Software, Project administration, Conceptualization. **Ashika Chembila Valappil:** Writing – review & editing, Conceptualization. **Adam Bruton:** Writing – review & editing, Visualization, Validation, Supervision, Software, Project administration, Methodology, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Research Link Provided
Extracted Data (Original data) (Open Science framework)

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