Age and Ageing 2024; **53:** 1–16
https://doi.org/10.1093/ageing/afad238

REVIEW

Digital technologies to prevent falls in people living with dementia or mild cognitive impairment: a rapid systematic overview of systematic reviews

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Abstract

Objective: Falls are a common cause of potentially preventable death, disability and loss of independence with an annual estimated cost of £4.4bn. People living with dementia (PlwD) or mild cognitive impairment (MCI) have an increased fall risk. This overview evaluates evidence for technologies aiming to reduce falls and fall risk for PlwD or MCI.
Methods: In October 2022, we searched five databases for evidence syntheses. We used standard methods to rapidly screen, extract data, assess risk of bias and overlap, and synthesise the evidence for each technology type.
Results: We included seven systematic reviews, incorporating 22 relevant primary studies with 1,412 unique participants. All reviews had critical flaws on AMSTAR-2: constituent primary studies were small, heterogeneous, mostly non-randomised and assessed as low or moderate quality. Technologies assessed were: wearable sensors, environmental sensor-based systems, exergaming, virtual reality systems. We found no evidence relating to apps. Review evidence for the direct impact on falls was available only from environmental sensors, and this was inconclusive. For wearables and virtual reality technologies there was evidence that technologies may differentiate PlwD who fell from those who did not; and for exergaming that balance may be improved.
Conclusions: The evidence for technology to reduce falls and falls risk for PlwD and MCI is methodologically weak, based on small numbers of participants and often indirect. There is a need for higher-quality RCTs to provide robust evidence for effectiveness of fall prevention technologies. Such technologies should be designed with input from users and consideration of the wider implementation context.

Keywords: aged, dementia, falls, older people, rapid review, technology

Key Points

- Limited, inconclusive evidence of technology reducing falls and falls risk for People living with dementia or mild cognitive impairment.
- Lack of clarity around which technology is more effective than alternatives at reducing falls and falls risk for People living with dementia or mild cognitive impairment.
- Reduction in falls and fall risk has potential impact on health and care service costs, and on outcomes important to People living with dementia/mild cognitive impairment.
- Appropriately designed randomised controlled trials needed to establish technology effectiveness for People living with dementia or mild cognitive impairment.
- Future technologies must be co-designed with people who will use them and a whole systems approach adopted.

Background

Falls are one of the most common causes of potentially preventable death, disability and loss of independence among older people [1]. The annual financial burden on health and care services is estimated to be an additional £4.4bn due to care needed by those injured in non-fatal falls [2].

People living with dementia (PlwD) or mild cognitive impairment (MCI) are more than twice as likely to fall (Odds Ratio (OR) = 2.24 (95% confidence intervals (CI) 1.25 to 4.03)) and nearly four times as likely to have recurrent falls (OR = 3.65 (95% CI 1.71 to 7.79)) compared to people of the same age without cognitive impairment [3]. PlwD also have higher risks of injury or fracture when they fall. Their clinical outcomes after injurious falls, compared to those without cognitive impairment, are worse, and this may be exacerbated as they are sometimes less likely to access rehabilitation [4]. Since the number of PlwD in the UK (currently approximately 900,000) is predicted to rise to 1.6 million by 2040 [5], clearly any technology which helps to reduce falls and fall risk in PlwD has potential for substantive health impacts.

Technology has known potential to contribute to fall prevention in the wider population of older adults [6, 7]. There is evidence on the effectiveness of a wide range of different technologies on falls or falls prevention measures including the use of exergames [8–11], virtual reality training [12, 13] wearables and body-worn sensors [14, 15] environmental sensor technology [16, 17], and apps [18]. Whilst current literature extensively covers technology-driven fall prevention strategies [19–21], a critical gap persists in understanding their applicability and efficacy within the context of MCI and dementia.

Many factors contribute to the heightened fall risks for PlwD or MCI [22], and in many cases technology has potential to reduce or manage risks. Issues with mobility, balance and muscle weakness can affect gait, reaction to the start of a fall and staying upright. Poorer memory and wayfinding are associated with decreased familiarity with surroundings and increased trip hazards, whilst higher prevalence of depression can hinder reactions to change [23, 24]. Difficulties with vision and visual processing may make recognising and reacting appropriately to situations harder, whilst dementia can increase risky behaviour and reduce risk perception. The side effects of high levels of medication, including drowsiness, dizziness or lowered blood pressure, can all increase fall risk further [22].

Whilst technology holds considerable promise it also presents complex challenges in the context of PlwD or MCI [25, 26] and this applies to falls prevention applications. For example, changes in visual perception and comprehension can hinder interactions with complicated interfaces; difficulties in processing auditory signals may cause confusion and anxiety if unfamiliar alarms sound and slower comprehension of verbal and written instructions can create frustration and barriers to use [27]. As cognitive decline progresses there may be a greater reliance on caregivers and professionals who will increasingly need to engage with technology to support and enhance care [28]. This underscores the importance of tailoring technology to accommodate as wide a range of user need and capacity as possible whilst also considering carer and staff involvement [28–31]. Technology in care is rapidly evolving, accelerated by the COVID-19 pandemic, but we know little about which technologies are most effective for fall prevention for PlwD.

Objectives

The aim of this overview is to evaluate evidence for any types of technologies that aim to reduce falls and fall risk for PlwD or MCI, and to identify gaps in the evidence base. An earlier version [32] was produced to inform the UK Government's proposed major conditions strategy [33]. This overview will help to provide direction for future research and generate new insights for policy decisions on adoption of technology in dementia care.

Methods

Several relevant systematic reviews have been completed, and therefore a review of reviews offered the best method of rapid evidence synthesis [34–36]. The findings are reported in line with the preferred reporting items for overviews of reviews statement [37]. The protocol was registered with the Open Science Framework [38].

Search strategy

Our search strategy used three main facets to identify relevant systematic reviews: technology, falls and older people. We drew on previous reviews by members of our wider team and on the NICE [NG97] review in identifying terms. [18, 21, 39, 40]. We did not use a filter to limit the search to systematic reviews although we included only systematic reviews in this overview. The full Medline search is provided in Supplementary material S1; strategies for other databases are available on request.

Information sources

The following databases were searched without date restrictions: MEDLINE, EMBASE, PsycINFO, Cochrane Database of Systematic Reviews (all OVID), CINAHL (EBSCO), Scopus. Initial searches were conducted in December 2021 and updated in October 2022. The search was limited to English language publications. We also checked references and used forward citing searching.

Eligibility (inclusion and exclusion) criteria

The inclusion criteria were guided by the PICOS (Population, Intervention, Comparator, Outcome, Study design) framework [41, 42], (full details in Supplementary material S2).

Population

Studies including people of any age living with dementia or MCI. Community and supported living/residential care settings were included, but hospital inpatient studies excluded.

Intervention

Any digital health technology aimed at or exploring reducing falls including: computing platforms, connectivity, software and sensors for health care and related uses, and mobile health including apps, health information technology, wearable devices, telehealth and telemedicine [43]. We use intervention in its broadest form of something provided by healthcare professionals/researchers to people within a study.

Comparator

Any comparator or no comparator.

Outcomes

- Primary: Falls as defined by the ProFaNE definition [44]. We accepted the following measures: proportion of participants with fall at specified timepoint; time to first fall; number of falls per participant in specified period
- Secondary: Fear of falling, fall risk including relevant balance measures, e.g. postural stability.

Study design

Systematic reviews, with or without meta-analysis.

Study selection, screening and data extraction

Search records were imported into Rayyan [45]. Following deduplication, two researchers independently screened both title and abstracts and full texts (Supplementary material S3 gives full text exclusions with reasons). A tailored, predefined, data extraction form was used by two reviewers and disagreements were resolved through discussion.

Quality appraisal

Two reviewers independently assessed the quality of included reviews using the AMSTAR 2 tool [46]. Disagreements were resolved through discussion or consultation with a third reviewer.

Data synthesis

This overview of reviews considered evidence at the level of the included systematic review. However, some reviews included evidence which was not relevant to this overview, as well as relevant evidence. Additionally, appraisal of the evidence in all reviews required us to consider the rigour, relevance and precision of the primary evidence represented. This means that we report review characteristics including our quality assessment of the overall review but then provide information on the primary evidence (relevant to our overview) that the review authors used to support their conclusions, together with their assessments of this evidence. Where primary study characteristics are noted it is in this context.

Due to the heterogeneity of reported interventions and outcomes we could not conduct meta-analysis. Therefore, we followed an approach adapted from the synthesis without meta-analysis guidelines [47]. Our synthesis was structured around the interventions (types of technology), aligned to the FARSEEING Taxonomy which aims ‘to classify and describe studies which use Information Communication Technology (ICT) devices to detect falls, monitor or promote movement-related function and physical activity in fall prevention’ [48]. Additionally we considered outcomes reported; study populations and settings (e.g. community/care home and country); and reporting of equity factors (employing the PROGRESS-Plus framework [49, 50]). Where multiple reviews assessed a type of technology we focused in the first instance on the highest quality and most recent review; where these differed we reported results equally from both. We supported this best evidence approach with evidence from less recent and lower quality reviews.

Overlap

To assess overlap between included systematic reviews we used the overall corrected covered area measure (CCA) [51], visually represented as a matrix [52, 53]. This enables mapping of relevant primary studies in the included reviews to avoid double counting of evidence.

Results

Study selection

After screening 272 records and 15 full texts, we included seven systematic reviews [54–60] (Figure 1); two included at least one meta-analysis.

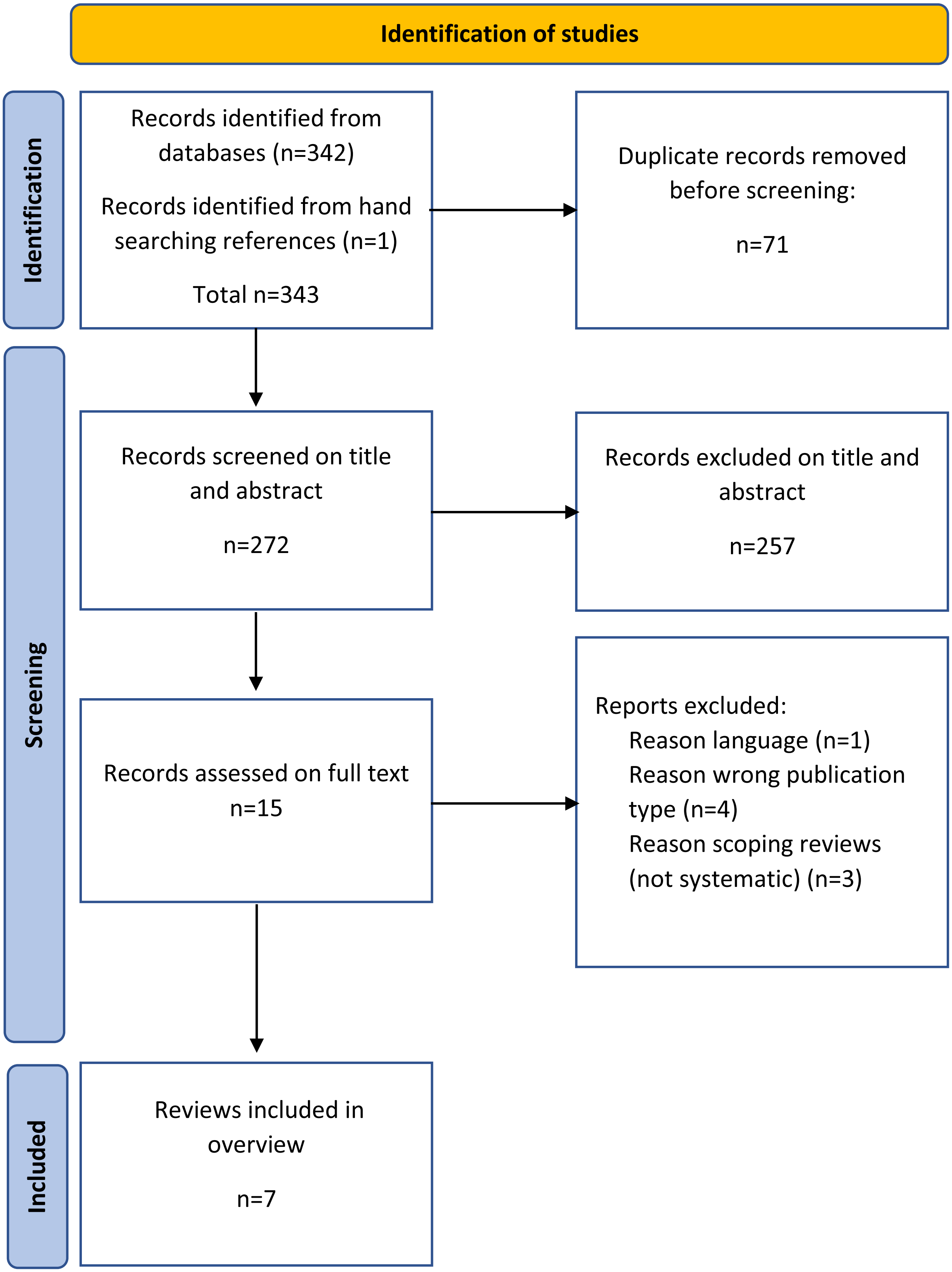

Figure 1. PRISMA flowchart outlining the study selection process.

Characteristics of included systematic reviews

The reviews were published between January 2007 and December 2021 (Table 1). Three reviews targeted fall prevention among PlwD or MCI and we considered all their primary studies [55, 59, 60]. Four reviews focused on wider populations or outcomes, and we considered only relevant primary studies [54, 56–58]. A total of 22 relevant primary studies (seven unique RCTs including two pilot RCTS) were included in the reviews. All seven reviews reported quality or risk of bias assessments, with most using standard tools, e.g. Downs and Black checklist [61] or the Newcastle-Ottawa scale [55, 58, 62].

Review populations

Participants and settings

Reviews included 1,412 unique relevant participants; numbers in reviews ranged from 39 to 685. Mean ages of participants ranged from 64 to 88 years and proportions of female participants from 40% to 91%, where stated for included primary studies. Settings included private homes and long-term care facilities, in high income countries in Europe or North America.

Where reported, reviews incorporated different dementia types and severity levels, from mild though severe. Assessment criteria for cognitive impairment were sometimes unclear, however the Mini-Mental State Examination (MMSE) was the most frequently recorded tool, used in 11 of the 22 primary studies (see Table 1 for further information). No review reported details on user involvement in developing the technologies or consideration of context in which the technology was being used.

PROGRESS-Plus equity factors were poorly reported (Figure 2; Supplementary material S4). Gender and age were the most frequently reported factors. Others such as Place of residence and Plus factors which can lead to inequity (e.g. disability, mental health and falls) were included in fewer reviews. Only two reviews used equity factors as a lens to interpret outcome data.

Overlap in primary studies included in reviews

Three primary studies were included in more than one review and the calculated CCA was 2.27%, indicating a limited overlap among the seven reviews (Figure 3).

There is high overlap (CCA = 10%) between the Weizman *et al*. [60] and Bezold *et al*. [54] reviews and very high overlap (CCA = 50%) between van Santen *et al*. [59] and Prosperini *et al*. [58], although there are only three relevant studies in each review. No other overlap was identified. The full evidence matrix is in Supplementary material S5.

Quality appraisal of included systematic reviews

Overall quality was low in three reviews (flaw in one critical domain) and critically low in four reviews (flaws in more than one critical domain). Critical domains 7 (complete list of excluded study justifications) and 13 (discussion of the impact of risk of bias in interpretation of results) had the largest effect on overall ratings affecting seven and five reviews respectively (for full details see Supplementary materials S6 and S7).

Interventions: technologies used

Using the FARSEEING taxonomy [25] all included technologies were classified as Systems although they differed in Locations (i.e. they were all Systems technologies which were either body worn/fixed; environmental or portable) (Table 2). Technologies were used for prediction (e.g. fall risk assessment), detection (e.g. alarm systems), monitoring (e.g. fall event recording research tools) or prevention (e.g. apps to improve strength and balance, or detectors to identify person out of bed and alert carer).

Effectiveness of interventions

Body worn or body fixed

Wearable technology/sensors

Two reviews, both rated critically low, assessed wearable sensor-based devices for falls risk in PlwD or MCI [54, 60]. They included seven primary studies (one cross-sectional (83 participants); six cohort (762 participants)). There was high overlap between reviews (10%); we use the most recent review here [54]. Sensors were primarily worn at the lower back, trunk, waist or chest. The review authors identified evidence they graded as moderate quality supporting consensus around the ability of classification models to differentiate between PlwD who experienced falls and those who did not, based upon data related to balance and stability (Table 3). This evidence is indirectly relevant to the question of the impact of falls on technology and is included because it is based upon measurement of secondary outcomes.

Virtual reality

A single review included only one relevant quasi-experimental study (39 participants) [57]. The review authors assessed this as moderate certainty evidence, however the study is very small and non-randomised suggesting a low or very low certainty assessment may be more appropriate. Findings indicated significantly worse performance on measures of postural stability and falls risk for people living with Alzheimer's disease (AD) with a history of falling, relative to both those with AD but without a fall history, and those without cognitive impairment (Table 3). This included worse postural stability (needing more power to achieve postural adjustments), longer time lag in cognitive strategies for postural correction, and delayed reaction time for changes in power. This evidence is indirectly relevant to the impact of technology on falls but is included because it is based upon measurement of secondary outcomes.

Technology located in the environment

Environmental sensor-based systems/video systems

Two reviews included environmental sensor-based systems, utilising digital care technologies (or assistive technologies

Table 1. Characteristics of included reviews

Author/year	Type of review	Study aims	No. of relevant studies (Study design)	Participants (sample size, n)	Cognitive status	Country of origin Setting/context	Appraisal instruments used; Appraisal rating	AMSTAR2 rating
Wearable Technology/Sensors								
Bezold *et al*. 2021 [54]	Systematic review	To assess the wearable sensors for fall risk assessment in older adults with or without cognitive impairment.	5 of 28 studies • Prospective cohort (n = 5)	Older adults (aged ≥60 years) in relevant studies including PlwD or MCI (n = 685)	• Specialist dementia care home residents MMSE <24 (n = 1) • MMSE ≥19 (n = 1) • MMSE ≥18 (n = 1) • Dementia included but no information on how selected (n = 1) • No information on cognitive status (n = 1)	Countries: • Not specified Settings: • Nursing home (n = 3) • Community (n = 2)	Newcastle-Ottawa Scale: Rating 5 (n = 1) Rating 6 (n = 3) Rating 7 (n = 1)	Critically low
Weizman *et al*. 2021 [60]	Systematic review	To assess wearable sensors for gait analysis in adults over 60 living with dementia.	3 of 6 studies: • Cross-sectional (n = 1) • Cohort (n = 2)	Older people (aged >65 years) with existing dementia (n = 200 including control group)	• Dementia diagnosis using MMSE, no further details (n = 1) • M-ACE score < 9 (n = 1) • Specialist dementia care home residents MMSE <20 (n = 1)	Countries: • Germany (n = 2) • UK (n = 1) Settings: • Nursing home (n = 1) • Community (n = 1) • Controlled environment (n = 1)	Custom 12-item quality assessment checklist based on Downs & Black No overall ratings	Critically low
Virtual Reality								
Dermody *et al* 2020 [57]	Systematic Review	To evaluate the effectiveness of VR apps delivered using commercially available immersive headsets to improve physical, mental, or psychosocial health outcomes in community-dwelling older adults	1 of 7 studies: • Quasi-experimental (n = 1)	Community-Dwelling Older Adults>60 years old living with dementia (n = 39)	• AD, but no information on how assessed (n = 1)	Country: • Not specified • Settings: Community setting (n = 1)	JBI critical appraisal instrument GRADE: Moderate (n = 1)	Low

(*Continued*)

Table 1. Continued

Author/year	Type of review	Study aims	No. of relevant studies (Study design)	Participants (sample size, n)	Cognitive status	Country of origin Setting/context	Appraisal instruments used; Appraisal rating	AMSTAR2 rating
Environmental sensor-based systems/video systems								
Brims and Oliver 2019 [55]	Systematic review with meta-analysis	To assess the effectiveness of assisted technology (AT) in improving the safety of PlwD in a domestic setting	3 studies • RCT (n = 3)	Older people (aged >65 years) with a diagnosis of dementia and living at home (n = 245 participants)	• Alzheimer's type with range of severity, but not defined (n = 1) • Mild dementia, no further info (n = 1) • Mild to moderate AD, no further info (n = 1)	Countries: • USA (n = 1) • Australia (n = 1) • France (n = 1) Settings: • Domestic setting (n = 3)	Effective Practice and Organisation of Care (EPOC) criteria: Low risk (n = 2) Unclear risk (n = 1)	Low
Chan *et al*. 2021 [56]	Systematic review	To assess the evidence of digital technology on Fall prevention and management of behavioural and psychological symptoms of dementia (BPSD) in long-term care	3 of 17 studies: • RCT (n = 1) • Quasi-experimental (n = 1) • Pre-post test (n = 1)	Older adults with a diagnosis of dementia (n = 182 participants)	• MMSE (moderate – severe) no further information (n = 2) • No information (n = 1)	Countries: • Not specified Settings: • Long-term care facilities (n = 3)	Downs and Black checklist: Good quality (n = 1) Fair quality (n = 2)	Critically low
Exergaming and commercial games consoles								
Prosperini *et al*. 2021 [58]	Systematic review and meta-analysis	To evaluate systematically the efficacy of exergames for balance dysfunction in neurological conditions and to identify factors of exergaming protocols that may influence their effects	3 of 47 studies: • RCT (n = 3)	Adults (aged ≥18 years) affected by dementia or MCI (n = 82)	• MMSE no further information (n = 2) • MCI but no further info (n = 1)	Countries: • Not specified Settings • Supervised outpatient (n = 2) • Home setting (n = 1)	PEDro scale: High quality (n = 2) Fair quality (n = 1)	Critically low
Van Santen *et al*. 2018 [59]	Systematic review	To provide an overview of the cost-effectiveness of exergaming and its effects on physical, cognitive, emotional, and social functioning, as well as the quality of life in PlwD	3 studies: • Pilot RCT (n = 2) • Pre-post test with control group (n = 1)	People with Dementia (n = 71 participants)	• Dementia diagnosis, no further information (n = 1) • History of mild AD in notes and MMSE score between 18 and 29 (n = 2)	Countries: • USA (n = 2) • Greece (n = 1) Settings: • Community or assisted living facility (n = 3)	Cochrane RoB High (n = 1) Low (n = 2)	Low
Apps								
No reviews met the inclusion criteria.								

Glossary of terms: MMSE, Mini-Mental State Examination; M-ACE, Mini-Addenbrooke's Cognitive Examination; MCI, Mild cognitive impairment; AD, Alzheimer's disease.

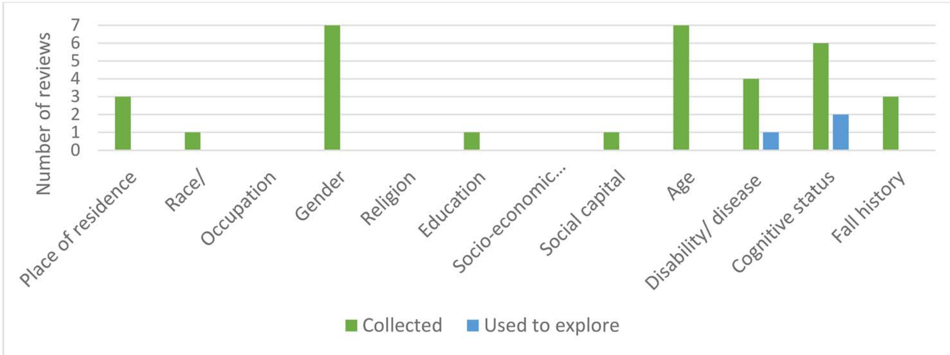

Figure 2. Progress-Plus factors.

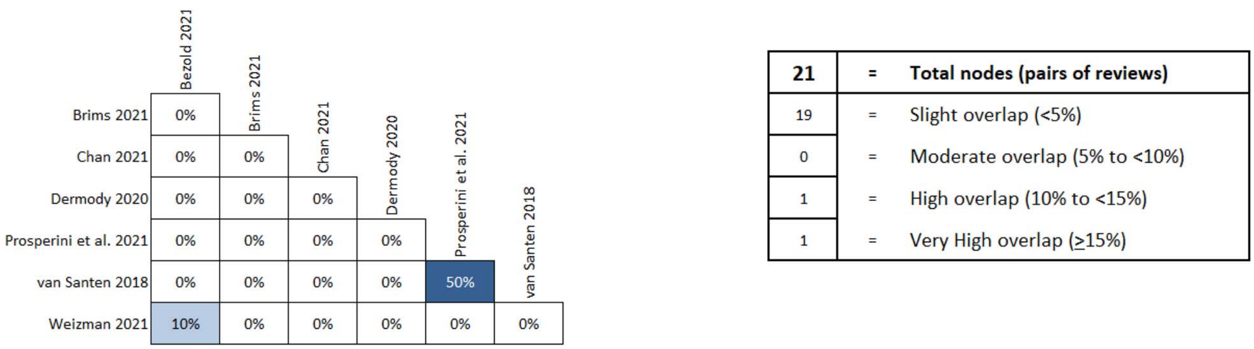

Figure 3. Visual representation of the degree of overlap in primary studies included in systematic reviews (corrected covered area (CCA) values).

(AT)) [55, 56]. Assessed technologies included bed sensors, sensor nightlights, teleassistance services and electronic support bracelets either alone or as part of a package.

The most recent review was assessed as critically low quality; we present evidence from both reviews. There was no overlap between reviews, with evidence from four unique RCTs (289 participants) and two other relevant studies (138 participants). The first review [55] reported that the only RCT (44 participants, fair quality), and a quasi-experimental study (78 participants, fair quality) found no evidence of an effect on falls. A pre-post intervention (60 participants, good quality) showed a significant reduction in falls, but only after the intervention (bed alarms) was removed, meaning the effect does not relate to the intervention.

The second review, comprising evidence from three RCTs, was older and rated as low quality [56]. A meta-analysis showed a reduction in falls (Risk Ratio (RR) 0.50, [95% CI 0.32–0.78], two RCTs, 118 participants), but this was impacted by unclear risk of bias in the largest study and heterogeneous interventions. The third RCT reported a significant effect of a home safety package including assistive technology (AT) on risky behaviours.

Differences in findings may be due to small study sizes and heterogeneity of study designs, interventions and outcome measures.

Portable technology

Exergaming and commercial games consoles

Two reviews assessed exergaming for falls reduction [58, 59]. Technology used included 'Wii-Fit', 'Wii balance board' and 'FitForAll' platforms delivering strength and balance training. The reviews had high overlap (50%) and the most recent was judged critically low in quality [58]; we report evidence from this, with supplementary data from the second [59]. Evidence from three unique RCTs (82 participants), and one controlled pre-post study (19 participants) was included in the first review. Subgroup analysis of participants with MCI or AD showed a significant effect size from two high quality and one medium quality RCTs, in favour of the technology ($g = 0.93$, 95%, 0.37–1.49) on measures of balance. The small size of this subgroup and the wide confidence intervals reduce our confidence in the finding. The non-randomised study in the second review reported significant improvements on several physical function tests but was very small and assessed as low quality.

Apps

We did not find any relevant reviews that assessed app-based interventions.

Table 2. Classification of technology included in primary studies according to the FARSEEING taxonomy [25]

Technology location	Description of the technology	Brims and Oliver [57]	Chan *et al* [58]	Prropserini *et al* [60]	Van Santen *et al* [61]	Dermody *et al* [59]	Bezold *et al* [56]	Weizman *et al* [62]
Technology location								
(D1.1) Body worn or body fixed	Body worn: Device is worn on or near the body (e.g. trousers pocket). Small movements of the device relative to the body are possible and the sensor location can be changed over time. Body fixed: The device is attached to the body (e.g. by transparent film, neoprene belt). Movements of the device relative to the body are minimised. For data analysis it is important to categorise the possible sensor locations during recording (e.g. trouser pocket, jacket).	(✓)				✓	✓	✓
(D1.2) Located in the environment	Is located in the environment chosen, rather than moving around with the person.	✓	✓					
(D1.3) Portable	Can be moved within the environment, but is not body worn, or body fixed			✓	✓			
Technology type								
(D2.1) System	A system is a set of interacting or interdependent components forming an integrated whole or a set of elements and relationships, which are different from relationships of the set or its elements to other elements or sets	✓	✓	✓	✓	✓	✓	✓
(D2.2) Device	A device is a mechanical or electronic piece of equipment made or adapted for a particular purpose and may include one or more sensors in order to produce a novel output based on a developed algorithm.							
(D2.3) Sensor	A converter that measures a physical quantity and converts it into a signal which can be read by an observer or by an (mostly electronic) instrument.							
(D2.4) Actuator	Converts a signal into a physical action. Actuators can be mechanical, electric, hydraulic and pneumatic (e.g. electric motor, LED light).							
Functionality								
D3.1 Alert	For emergency communication between the user and external assistance	✓	✓					
D3.2 Monitoring	Performs continuous observation through body attached or environmental sensors which may be used for later analysis	✓	✓				✓	✓
D3.3 Assessment	Performs a validated measurement of a user to allow for an evaluation to performed by an expert.					✓	✓	✓
D3.4 Persuasive	Interacts with the user through intentional communication motivated through the user's interaction or observation							
D3.5 Communication	A platform that allows information or messages to be transmitted from one user or location to another through a communication media							
D3.6 Delivery	Delivers a direct intervention to the patient e.g. Exergame			✓	✓	✓		
D3.7 Automatic or manual?	Does the system automatically detect the user and record automatically, or does the user have to enter information/operate the system or device							
D3.7.1 Automatic	Automatic System automatically detects the user and records automatically.	✓	✓	(✓)	(✓)	✓	✓	✓
D3.7.2 Manual	Manual The user enters information/operates the system or device.			(✓)	(✓)			

✓ = *primary function of the technology;* (✓) = *technology or parts of technology sometimes used in this function.*

Table 3. Summary of technologies used, findings and conclusions of included reviews

Author/year	Tech used/	Control group	Key Relevant outcomes	Results/Findings	Conclusion
Wearable Technology/Sensors					
Bezold 2021 [54]	Body-worn sensors	n/a	1. Detection of fall status 2. Use of sensors to assess fall risk 3. Classification models (faller and non-faller)	1. Five prospective studies with between six- and 24-month follow-up 2. Sensor placement included lower back, shank, waist, or chest; the sensor data was collected during daily life, a 20-m gait analysis, the TUG, the Tinetti Test or a walking test. 3. For daily life data of gait quality classification models accuracies between 68.0–76.0%, sensitivities of 67.0–78.2% and specificities of 66.3–80.0%.	Fall risk assessment using wearable sensors is feasible in older adults with dementia. Accuracy may vary depending on sensor location, sensor attachment and type of assessment chosen for the recording of sensor data
Weizman 2021 [60]	Wearable Sensor-Based Devices	n/a	1. Objectives 2. Sensor Type and Body Location 3. Gait Assessment Protocol 4. Calculated Parameters	1. Sensor-derived data can successfully achieve the aims of assessing falls prognosis and risk factors, differentiating dementia disease subtypes, environments (lab and real-world) on gait, and exploring the differences in executive functioning during single and dual tasks. 2. Sensor-Based Devices were place at the centre of the body, i.e. trunk, lower back, chest, and lumbar vertebra. 3. Gait valuation was achievable in both laboratory environments and everyday life settings 4. Calculated Parameters include the pace, variability, rhythm, asymmetry, postural control, anterior–posterior acceleration, average kinetic energy, compensation movements, step frequency, and the number of dominant peaks. The linear accelerations and rotational velocity, walking during 24 h, walking bout average duration, longest walking bout duration, walking bout duration variability, standing during 24 h, standing bout average duration, sitting during 24 h, sitting bout average duration, and lying during 24 h, and anterior–posterior and medio-lateral accelerations time-series.	Studies shows that sensor-derived data can be used to analysis gait and assess the risk of falls Different assessment protocols were used in the literature. Development of a standardised protocol is recommended.
Virtual Reality					
Dermody 2020 [57]	Virtual Reality (VR apps using a head-mounted display led to improvements in a number of health outcomes, including pain management, posture, cognitive functioning specifically related to AD, and a decreased risk of falls)	Conventional therapy or no comparison	1. Posture 2. Fall	1. The AD faller had worse postural stability compared with the control group (they had a higher power regarding use of mechanical properties of oscillation for postural adjustments) (−4 to 0 seconds (s), P = 0.02; 0 to 4 s, P = 0.01; 4 to 8 s, P = 0.008). AD participants had a longer time lag in cognitive strategies for postural correction compared with healthy subjects (−4 to 0 s, P = 0.002; 0 to 4 s, P = 0.01). 2. The AD fallers groups had a delayed reaction time for changes in power compared with the control group	There is potential to use VR intervention to improve health outcomes, but more studies are needed.

(*Continued*)

Table 3. Continued

Author/year	Tech used/	Control group	Key Relevant outcomes	Results/Findings	Conclusion
Environmental sensor-based systems/video systems					
Brims and Oliver 2019 [55]	Assistive technology (AT) designed to improve safety, i.e. grab rail, sensor night light, nightlight path, remote intercom, electronic bracelet, teleassistance support centre.	Treatment as usual, including psychosocial support without AT.	1. Improved safety of PlwD in the home: falls (number of people who fell) 2. Improved safety of PlwD in the home: falls (number of falls): 3. Improved safety of PlwD in the home: Risky behaviours and accidents	1. There was 50% lower of the probability of a fall occurring in the AT group (risk ratio 0.50 95% CI [0.32, 0.78]; $Z = 3.03$; $p = 0.002$). 2. Fewer falls in the AT group than in the control group (Incident Rate Ratio = 0.34 95% CI [0.06, 1.91]). 3. A home safety package containing AT significantly reduced risky behaviour and accidents ($F(45) = 4.504$, $p < 0.001$).	The effectiveness of AT in decreasing care home admission is inconclusive. AT can improve safety by reducing fall risk factors, accidents, and other risky behaviour.
Chan 2021 [56]	Digital care technologies, including monitoring system, vigil monitoring system, bed-exit alarms,	Usual care	1. Fall	Mixed results: one study showed a significant result with a mean difference of 3.3 falls per 1,000 bed days ($p = 0.03$) which in favour of removing the alarms. Another two studies show no significant difference between the intervention and control group	Only three studies reported mixed results. The sample sizes were too small to draw meaningful conclusions about the effectiveness of digital care technologies in fall prevention among people with dementia
Exergaming and commercial games consoles					
Prosperini 2021 [58]	Exergames (all three studies use Wii balance board)	Conventional treatments or other rehabilitation interventions or no intervention (i.e. waiting-list control group)	1. Balance 2. Long-term retention (defined as the consolidation of balance improvement beyond the intervention completion) 3. Adverse events	1. Effect size of exergames on balance ($g = 0.93$, 95% CIs 0.37–1.49, $p = 0.001$) (dementia subgroup)	Exergames can improve the balance of people with dementia but the small sample size limits robustness of data.
Van Santen 2018 [59]	Exergaming (One study used FitForAll exergames (physical training) and two studies used a Wii-Fit programme)	Cognitive training or walking programme without exergaming element	1. Physical functioning (Subset of the Senior Fitness Test and Berg Balance Scale) 2. Cognitive functioning 3. Daily life functioning 4. Emotional functioning 5. Quality of life	Two of three showed some statistically significant effects of exergaming on physical, cognitive and emotional functioning in PlwD, although based on a very small sample.	Studies reported mixed results. Very little significant benefit of exergaming on physical, cognitive and emotional functioning among people with dementia
Apps					
No reviews.					

Glossary of terms: TUG, Timed up and go test; VR, virtual reality; AD, Alzheimer's disease; AT, assistive technology; PlwD, people living with dementia; CI, Confidence interval.

Discussion

Summary of findings

We identified limited evidence on the effectiveness of technology to reduce falls or falls risks for PlwD or MCI. The evidence is based on (often low quality) small studies with short follow-up, so is insufficient to recommend any particular technology or to identify whether particular technologies are more effective than others.

Much of the evidence is indirectly relevant to the ability of technology to reduce falls or falls risk. In particular, evidence for wearable and virtual reality technologies only looked at their ability to identify people who have a history of falling using postural and balance data, whilst exergaming reported impacts on secondary measures such as balance. Only environmental sensors were represented by reviews which looked at impact on fall incidence.

We found no convincing evidence that environmental sensors were able to reduce falls and falls risk. Since many environmental sensor interventions were multicomponent, and varied widely in their implementation, it was impossible to isolate evidence for a single element. Studies of exergaming to improve strength and balance reported significant improvements in falls rate with interventions. However, the evidence is weak because it rests on very small numbers of PlwD in RCT subgroups or in non-randomised studies. Very limited available evidence suggests that wearable technology/sensor data may be able to distinguish between PlwD who fall, and those who do not, and also that virtual reality may identify differences in postural stability between PlwD with and without a history of falls.

Gaps in the evidence

For most types of technology we included only two reviews, and for virtual reality we found only one. No reviews assessed use of apps. Due to heterogeneity of study designs, interventions and outcomes we did not conduct meta-analysis. Reviews included few RCTs (and these were small); this may reflect the difficulty of involving older people and PlwD or MCI in RCTs [63, 64]. No studies directly compared different types of technology.

The longest follow-up was between 6 and 12 weeks post-intervention, so we have no information about longer-term effects. Outcome measures varied considerably, partly due to the range of technologies and their development stage. Studies of less well-developed technologies sometimes employed surrogate falls outcomes measures such as gait analysis or levels of risky behaviour and looked at technology as an assessment tool for falls risk rather than an approach to falls reduction. We included these due to the sparsity of evidence, and their potential to inform development of future falls prevention interventions. However, this evidence is only indirectly relevant to fall reduction.

No review reported usability or acceptability of interventions for users, caregivers or staff and only one considered adverse effects. We know that active involvement of end users, throughout design, development and implementation of new technologies is key to their success [65]. Older people are at risk of being digitally excluded and less likely to adopt technology [18, 66–68], and cognitive impairment can exacerbate this, especially for those already less familiar with new technology [21]. PlwD may find technology distressing and unsettling [69, 70], making tailoring of products especially important, and they are frequently excluded from studies of fall prevention technology, reducing broader studies' relevance to these groups [65, 71–73]. Usability and acceptability for older PlwD or MCI and those who live with or care for them, is therefore important [31, 74–76] although challenging. Adaptable designs accommodating the broadest range of user capabilities as possible and designed to support caregiver input are essential for creating inclusive products [25, 77–80].

Characteristics relevant to equity can exacerbate digital and technological exclusion, either individually or in combination, but reviews rarely considered these. Whilst all reviews collected data on gender, age and cognitive status, none reported race/ethnicity, education levels or socioeconomic status (SES). Only two reviews used PROGRESS-Plus factors as a data lens; both used cognitive status and one disability and disease. These factors may all play a role in acceptance and use of technology. Despite this, review authors failed to consider the potential for differential effectiveness in population subgroups, and this should be remedied in further work.

Linked to the equity factor of available support, staff and unpaid carers may be pivotal in successful implementation of technologies for PlwD, and their skills, attitudes and experiences may influence the uptake of new innovations [81]. In one primary study staff directly influenced study outcomes through bias against bed alarms, which were considered unreliable and intrusive. Our overview highlights the need to explore staff roles in successful development and integration of technology into care environments. We did not identify any qualitative or mixed methods reviews, which may have provided us with additional insights on the impact of staff or unpaid carers on technology effectiveness, or the experiences of carers and participants in using technology with PlwD or MCI.

These gaps relate to the multiple barriers to scaling up of technology for older PlwD, (evidence, price, design, trust, awareness, individualisation, commissioning, societal attitudes, staff skills, awareness and attitudes) [81]. A framework such as NASS (non-adoption, abandonment, scale-up, spread and sustainability) can help to ensure effective representation of participants and due consideration of wider contexts in development and implementation [82, 83].

Strengths and limitations

We have identified and synthesised the limited evidence on use of technology to reduce falls and falls risk for PlwD or MCI. At each stage we used transparent and robust systematic review methods, adapted to a rapid overview.

However, we focussed only on published systematic reviews; primary research published after the last review search dates is not included but may be informative [84, 85]. To assess the likely impact of this we undertook some rapid limited post-hoc searching for primary studies published after our search. We identified only a feasibility RCT and a small RCT of a home-based fall prevention exercise programme (Standing Tall) delivered to older PlwD through a tablet computer [86, 87]. This intervention showed promise, had acceptable usability and feasibility, and scored well on participant enjoyment; evaluation of its effectiveness needs a fully powered RCT.

The low or critically low AMSTAR 2 ratings of included reviews were heavily influenced by failure to list excluded studies with reasons, and failure to consider quality of primary studies in the discussion. We have partially mitigated this second issue by considering bias, as reported by the original review authors, in our synthesis and conclusions but were dependent on their assessments (low or moderate quality in most instances). Full assessment using GRADE criteria was beyond the scope of this overview, but our consideration was guided by the domains of risk of bias imprecision and inconsistency. [88].

We were also dependent on the definitions used by review and primary study authors for dementia and MCI, and many reviews did not report definitions used in primary studies. Scores on the MMSE were the most frequently used measure of MCI, but often no upper limit was given and we could not determine the severity of participants' dementia.

Further research and conclusions

Our overview identifies a clear need for more primary research but also highlights the need to ensure that evidence has real-world applicability as well as methodological rigour. Thus, we strongly recommend following the ProFaNE recommendations [89]. There is a need for more, larger and better reported RCTs using TIDieR [90] to clarify the nature of the intervention, perhaps using the FARSEEING [25] and ProFaNE Taxonomies to aid description [91]. Work is needed to develop more standardised outcome measures for falls, ensuring relevance to patients and clinicians and comparability between studies. The overview also highlights that when PlwD or MCI are included in these studies, clear and validated measures must be used to record their type and level of cognitive impairment. In addition to rigorous methodology, adequate sample sizes and adherence to reporting guidelines there needs to be greater consideration of user groups during design and development. This should include consideration of equity factors in recruitment and data analysis. Consideration of wider context is also required to support implementation and success of new technology.

Supplementary Data: Supplementary data mentioned in the text are available to subscribers in *Age and Ageing* online.

Acknowledgements: The authors are grateful to Peter Bower for giving advice on developing the study protocol and commenting on the initial report.

Declaration of Conflicts of Interest: None.

Declaration of Sources of Funding: This paper presents independent research funded by the National Institute for Health and Care Research Policy Research Unit in Older People and Frailty (NIHR Policy Research Programme Reference Number PR-PRU-1217-21,502). CET, CT and GN are partially funded by the National Institute for Health and Care Research Applied Research Collaboration Greater Manchester (Grant Number: NIHR200174). The funders played no role in the design, execution, analysis or interpretation of data or writing the study. The views expressed are those of the authors and not necessarily those of the NIHR or the Department of Health and Social Care.

Data Availability: This is a review of previously published studies; therefore, all the data used in the review are already in the public domain. All data relevant to the included studies are included in the article or uploaded as supplementary information.

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Received 14 June 2023; editorial decision 6 December 2023

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