INFORMATICS IN PRIMARY CARE

Research article

Does smart home technology prevent falls in community-dwelling older adults: a literature review

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ABSTRACT

Background Falls in older Australians are an increasingly costly public health issue, driving the development of novel modes of intervention, especially those that rely on computer-driven technologies.

Objective The aim of this paper was to gain an understanding of the state of the art of research on smart homes and computer-based monitoring technologies to prevent and detect falls in the community-dwelling elderly.

Method Cochrane, Medline, Embase and Google databases were searched for articles on fall prevention in the elderly using pre-specified search terms. Additional papers were searched for in the reference lists of relevant reviews and by the process of 'snowballing'. Only studies that investigated outcomes related to falling such as fall prevention and detection, change in participants' fear of falling and attitudes towards monitoring technology were included.

Results Nine papers fulfilled the inclusion criteria. The following outcomes were observed: (1) older adults' attitudes towards fall detectors and smart home technology are generally positive; (2) privacy concerns and intrusiveness of technology were perceived as less important to participants than their perception of health needs and (3) unfriendly and age-inappropriate design of the interface may be one of the deciding factors in not using the technology.

Conclusion So far, there is little evidence that using smart home technology may assist in fall prevention or detection, but there are some indications that it may increase older adults' confidence and sense of security, thus possibly enabling aging in place.

Keywords: accidental falls, fall prevention, elderly, home monitoring, housing for the elderly, smart homes.

What this paper adds?

- This paper consolidates the evidence on home-centred monitoring technologies for preventing and detecting falls, decreasing the fear of falling and increasing fall-related confidence in community-dwelling older adults.
- There is some evidence that monitoring technology may increase older adults' confidence and feelings of safety, possibly promoting aging in place and prolonging independent living.

- Older adults' attitudes towards fall detectors and smart home technology were generally positive, and privacy concerns diminished with increasing health needs of monitored elders.
- Enablers for adoption of smart home technology include user-friendly technology that comes with technical support, and an interface that has been specifically designed for older users and tested by this user group.

INTRODUCTION

Falls and fall-related injuries are a significant healthcare and community burden. Each year, about 30% of people aged 65 years and over experience a fall, and 10% have multiple falls. In 2010, 2.3 million fall injuries among older adults were treated in emergency departments throughout the USA, and more than 662,000 of these patients were hospitalised.[1] The direct medical costs of falls in the USA are estimated at 30 billion dollars.[2] Falls, even without associated injuries, may result in a fear of falling, a condition that typically results in self-limiting physical and social activity by the faller in an attempt to avoid further falls. Reduced activity may lead to reduced physical and cognitive fitness, thus further increasing the risk of further falls. Fear of falling, decreased feeling of safety and lower functionality may affect older persons' ability for independent living and aging in place.[3]

Some of the most important fall risk factors, such as impaired balance and mobility, reduced muscle strength, low level of physical activity and fear of falling, may be modified by a suitable intervention.[3] For example, there is strong evidence that various types of exercise, especially Tai Chi, are effective in reducing falls by up to 35%.[4] One way of fall prevention that appears suitable for modification is environment alteration to improve home safety for older people. Numerous studies performed so far have shown that home safety interventions do not reduce the risk of falling in the general population, but can be effective in persons at higher risk of falling, such as those that are visually impaired.[4] The development of monitoring technology combined with increasing pervasiveness of the Internet stimulated the development of monitoring systems, where the monitored subjects and monitoring call centres may be quite distant. Home monitoring aimed at fall prevention or early detection of falls is being slowly introduced in assisted-living facilities and in community accommodations.[5]

The primary goal of fall detection technologies is to distinguish falls from activities of daily living and then contact authorities who can quickly assist the individual. Presently, the majority of smart home technology projects include 'first-level telehealth' systems, such as individual alarm services between a patient and a hospital or carer, with devices that have to be actively triggered by the patient to sound an alarm.[6] 'Second-level telehealth' systems involve the use of sensors to continuously monitor movement, while utilising specific algorithms and alert systems to inform caregivers and others of potential falls. These systems may be classified as passive, as users do not need to activate them and they automatically detect a fall and seek help. Motion and pressure sensors can be placed around the living facility on walls, ceilings and floorboards, while location and position sensors, like accelerometers and gyroscopes, can be placed on older adults themselves. Algorithms are utilised to set thresholds for alert notification, tailored to each older adult by monitoring patterns of movement and behaviour.[7] At present, passive systems where the whole home environment is wired, monitored and analysed to detect accidents and send an alarm to a call centre are sparse at the community level, and very few papers investigating the effectiveness of home monitoring on fall-related health outcomes have been published.

The aim of this paper is to provide a review of the literature investigating home-centred monitoring technologies for preventing and detecting falls, decreasing the fear of falling and increasing fall-related confidence in the community-dwelling elderly.

METHODS

Search

Medline, Embase and Cochrane databases were searched using synonyms and MeSH (Medical Subject Headings) terms. Three strings of terms were used in isolation and in combination: (1) falls, falls reduction, falls prevention, preventing falls, reducing falls, accidental falls, fear of falling; (2) smart homes, smart houses, housing for the elderly, house monitoring and (3) older people, elderly. Google was searched for 'grey literature' articles on fall prevention, in both research and government report categories. Articles were downloaded to endnote, and duplicates were removed. Text and reference lists of major relevant reviews were searched for other relevant papers. The process of 'snowballing' was used to look up authors and 'similar papers' in the databases. The search was conducted in August 2012.

Inclusion and exclusion criteria

We included studies that investigated home safety packages that contained technology involved in fall detection directly, that is fall detectors, and indirectly, that is mobility mapping devices, such as bed and chair occupancy sensors and motion sensors placed inside the house. We have included studies that investigated outcomes of interest, such as fall rates, fear of falling, attitudes towards the monitoring technology and main concerns regarding its adoption. Studies of all designs published in peer-reviewed journals and 'grey literature' reports were included.

Studies that investigated the efficacy of sensors that could affect safety and well-being and increase independence for older people, such as automatic door openers, light switches, outside

motion detectors and door opening sensors that are not related to falling, were excluded. We have excluded technical papers that evaluated the technology system from a technical point of view and did not measure human-related outcomes. Articles were selected by one author (EP), and the process of selection was confirmed by the second author (CC). Disagreements were discussed until a consensus was reached.

Study quality assessment

The quality of the studies was analysed by using the Qualitative Assessment Tool for Quantitative Studies.[8] The study quality was assessed on the basis of study components that included (1) selection bias, (2) study design, (3) confounders, (4) blinding procedures, (5) data collection methods and (6) withdrawals and dropouts. Each study component received a scoring of 'weak', 'moderate' or 'strong'. A study that received four strong ratings with no weak ratings in any of the components mentioned earlier was rated as 'strong'. Studies with fewer than four strong ratings with one weak rating were rated as 'moderate', and those with two or more weak ratings were rated as 'weak'. Non-comparative studies with small samples and qualitative design were rated as 'very weak'. Study quality assessment was performed independently by two authors (EP and CC). Disagreements were discussed until a consensus was reached.

RESULTS

Fifty-eight papers were identified from the computerised database search. Forty-four papers were excluded after reviewing the titles and abstracts. Fourteen full text papers were retrieved for consideration. Nine papers resulting from six studies that investigated the effect of smart home technology systems on fall-related outcomes fulfilled all the inclusion and exclusion criteria and were included in the review. One grey literature report evaluating implementation of a government telecare programme, found by the Google search, was also included.[9] The details of article selection are presented in Figure 1. The search found no published studies that used devices for monitoring balance and gait parameters at home to predict the risk of falling. Four of the studies (published in seven papers) were of qualitative design,[10–16] one study was comparative, with non-randomised control,[17] and one was a randomised control trial.[18] In the qualitative studies, interviews and discussions included themes such as (1) self-perception of need, privacy concerns and willingness to adopt smart home technology;[10,11] (2) participants' perceptions of the usefulness of specific devices and sensors, problems or concerns regarding the technology and suggestions for the research team;[12–14] (3) acceptance of optical and wearable sensors for the prediction and detection of falls at home[15] and (4) sense of safety and security and concerns regarding technology.[16] The outcomes reported in the controlled studies included fear of falling, feeling of safety, fear of crime and level of outside activity;[17] and health and functioning status, attitudes towards technology, and the level of technology use.[18] The quality of evidence was assessed as very weak for the qualitative studies, weak
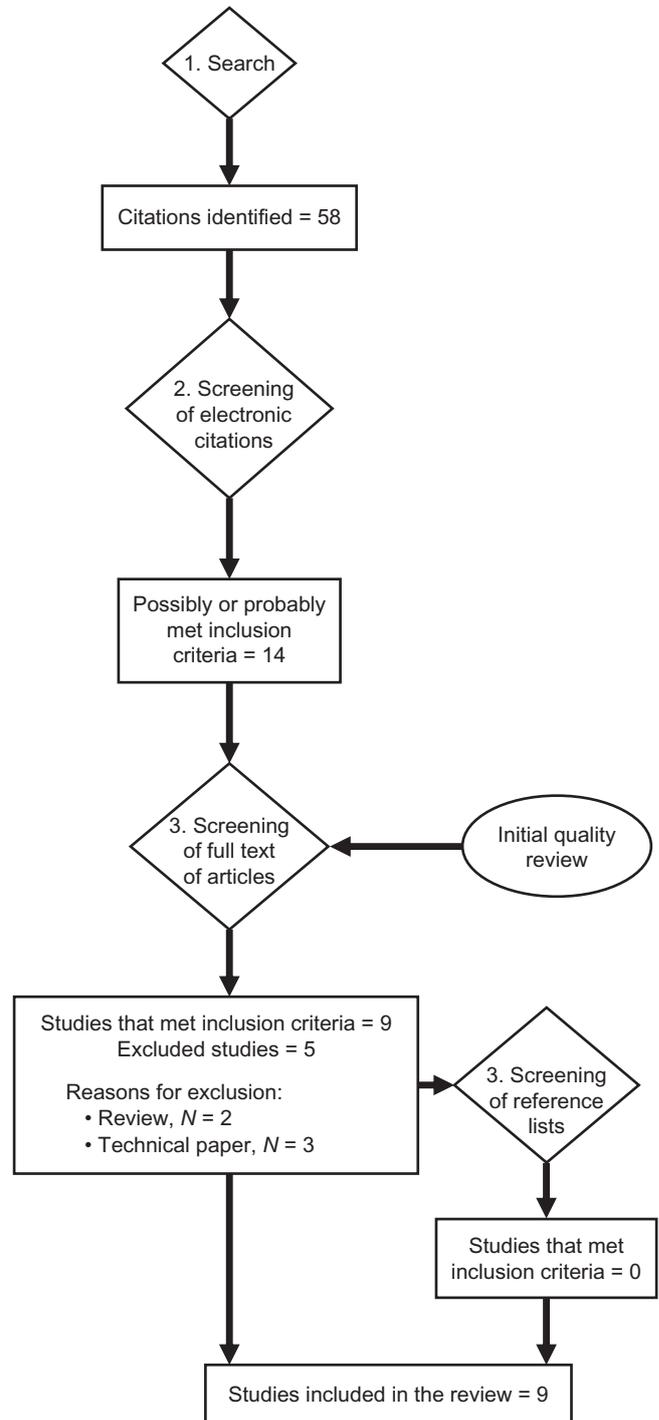

Figure 1 Flow diagram for article inclusion/exclusion.

for the comparative study and moderate for the randomised controlled trial. Characteristics and results of the studies are presented in greater detail in Table 1.

Findings from the qualitative studies

The qualitative studies investigated attitudes of older people towards smart home technology. Data were collected using semi-structured interviews. The total number of participants was very small (ranging from 14 to 22 individuals), and was divided into three to four focus groups. The emerging themes were as follows. Participants' attitudes towards technology in all studies were generally positive, with the majority indicating that they would agree to the installation of these

Table 1 Study characteristics and outcomes of included studies

Study	Study characteristics	Intervention, outcomes	Results
Courtney 2008a[10] and Courtney et al. 2008b[11]	N = 14, three focus groups Aim: to investigate the attitude and willingness to adopt safe house technology Participants: older adults living in continued care retirement facility (not nursing homes) Design: qualitative, semi-structured interview Quality assessment: very weak	System: included fall detectors, bed and motion sensors, and kitchen sensors Outcomes: qualitative interview and discussion included themes such as self-perception of need, privacy concerns and willingness to adopt smart home technology	Perception of own health was more important than privacy consideration when accepting technology Although privacy can be a barrier for older adults' adoption of smart home technology, their own perception of their need for the technology can override their privacy concerns

Demiris et al. 2004,[14] 2008a[12] and 2008b[13]	N = 15, three focus groups
	
	Aim: to investigate attitude towards technology and to evaluate perceptions of the usefulness of devices and sensors installed in their homes and willingness to adopt particular devices
	
	Participants: community dwellers, living in continued care retirement facility, ranging from independent living to assisted living in USA
	
	Design: qualitative, semi-structured interview
	
	Quality assessment: very weak
		System: preventing or detecting falls, assisting with visual or hearing impairments, improving mobility, reducing isolation, managing medications and monitoring physiological parameters
		
		Sensors included: bed sensor, sensor mat, motion sensor, gait monitor, stove sensor and video sensor
		
		Outcomes:
		
		qualitative discussion included questions about participants' perceptions of the usefulness of specific devices and sensors. The interview protocol allowed for residents to report any problems or concerns regarding the technology and identify any suggestions for the research team
			• Participants rated devices as
			  ○ useful: bed sensor, sensor mat, motion sensor and gait monitor
			  ○ useful but intrusive: video sensor
			  ○ not useful: stove sensor
			• Systems rated as most useful were related to
			  ○ emergency help
			  ○ prevention and detection of falls
			  ○ monitoring of physiological parameters
			• Concerns were related to user-friendliness of the devices, lack of human response and the need for training tailored to older learners
			• Participants did not express privacy concerns
			• Attitude was generally positive

Govercin et al. 2010[15]	N = 22 in three focus groups, Aim: to investigate acceptability of assistive devices for fall detection and fall prevention Participants: community dwellers, Germany, focus groups consisted of (1) moderately to severely disabled participants with mild to severe risk of falling, (2) slightly disabled older persons with low fall risk and (3) healthy relatives of patients with severe risk of falling Design: qualitative, semi-structured interview Quality assessment: very weak	System: wearable and optical fall sensors; devices including cameras and motion sensor-technology. Outcomes: qualitative discussion focused on the acceptance of optical and wearable sensors for the prediction and detection of falls at home.	• Participants considered fall prediction and fall detection systems as equally important • Two major reasons for buying wearable and/or optical fall prediction and fall detection devices by people at risk of falling were security and mobility • Acceptability was dependent on risk of falling, privacy was important for those at low risk and wearable devices were more acceptable than optical • Participants preferred wearable inertial sensors to the optical sensor system because of their wide range of use • Non-stigmatising sensor at the user's wrist, with an emergency option, was the most preferred option
van Hoof et al. 2011[16]	N = 18 Aim: to investigate the attitude towards smart home technology and its effect on independent living Participants: community-dwelling older people with complicated needs, mostly mobility, but also including disabled and psych problems (with tendency to wander), Netherlands Design: qualitative, semi-structured interview Quality assessment: very weak	System: unattended autonomous surveillance (UAS) consists of over ten wireless sensors placed in various parts of the home, Internet-connected master unit and a call centre. Sensors, which can be installed in different configurations, may include mobility monitoring, voice response, fire detection and wandering detection. Monitoring the movements of a client allows the system to recognise a fall incident. Visual cameras may be activated in emergency Outcomes: qualitative interview included themes such as sense of safety and security and concerns regarding technology	• Attitude towards the technology was generally very positive • The systems increased the sense of safety and security and helped to postpone institutionalisation • False alarms were also regarded as a sign that the ambient intelligence technology is functioning • Negative aspects of the system: long installation, too many cables, should not look weird and care centre should be able to help with malfunctioning tech

Table 1 Study characteristics and outcomes of included studies (Continued)

Brownsell, et al. 2008[17]	N = 56 Aim: to investigate the effect of safe house technology on fear of falling, safety, outside activity and personal health Participants: community-dwelling older people living in retirement housing, UK Design: comparative, duration 12 months Quality assessment: weak	Relevant systems included the following: falls package: fall detectors and automatic light switch bed and chair occupancy devices, movement detectors, door contact monitors and electrical usage less relevant systems: security and wandering client alert, and internet café Outcomes: fear of falling, SF36, level of outside activity, feeling of safety, fear of crime	After a 12-month monitoring period, there was • no change in the fear of falling • no change in eight of the nine SF-36 domains • only social functioning domain was higher by 8% in the intervention group (P = 0.049) Positive trends (almost significant) were seen in • the average number of occasions spent outside: the intervention group went out five times per week; the control group reduced outings to 4.4 per week (P = 0.58) • increase in the length of time spent out of the home: the intervention group increased the length of time spent out of the home from an average of 3.6 to 4 h per week; the control group reduced the number of hours from 2.6 to 2.4 (P = 0.028) • improved feelings of safety during the day and night: during the day, there was a 1% increase in the intervention group and a 1% fall in the control group (P = 0.027); at night, the changes were 3% and 25%, respectively (P = 0.008) • a reduction in the fear of crime: reduced by 10% in the intervention group and increased by 6% in the control group (P = 0.56) • the Internet cafe was used by 25% of people for at least 20 min per week Limitation: falls packages were taken up by less than 50% of participants, while 100% took security packages
Tomita et al. 2007[18]	N = 114 Aim: to test the feasibility and effectiveness of currently available off-the-shelf smart home technology X10, participants attitudes towards technology and whether it helps living independently for longer Participants: frail elders, without cognitive impairment, who lived alone, USA Design: RCT, 2-year follow-up attrition: 26% and 34% in the intervention and control groups at 2 y Quality assessment: moderate	System: X10 is a home-automated system, mainly for remotely controlling lights and appliances, could be connected to a program on the computer and programmed. Some external devices, that is motion sensors on the outside, were added, but no fall detectors. Whole cost: $400 Outcomes: health and functioning status, attitudes towards technology and the use of technology	• Participants benefited from the smart home technology, and 91% recommended its use by others • The treatment group maintained physical and cognitive status, whereas the control group declined significantly in both (FIM cognition P = 0.006). This result could be an artefact; the effect may be explained by demographic differences between groups (attrition from the groups after randomisation caused intervention group becoming younger and less sick) • The primary reason for non-use of technology was related to 'failure'. Participants chose only those functions that did not fail and that were most suitable and beneficial for them • Failure was not necessarily a malfunction of the system but rather a combination of unfriendly features of X10 and participants' unfamiliarity with the system

devices in their own homes. Participants emphasised that devices installed in their homes could be of great benefit when they are (1) reliable, (2) user friendly, (3) effective at detecting a range of emergencies, (4) independently operating, requiring no or minimal action on the part of the user, (5) cost effective, especially in terms of maintenance costs, and (6) unobtrusive.[12] Participants did not feel that these devices interfered with their daily activities.[11,13] Smart home technology was not accepted uniformly, with some of the sensors and devices being perceived as more useful than others, and the preference for selection was generally dependent on the participants' perceived health needs. The fall sensors were regarded as the most useful.[10,11] Privacy concerns were indentified as a potential barrier for older adults with the adoption of smart home technology. However, participants' perception of their health needs usually overrode privacy concerns. The stronger were the health needs, the less important were privacy concerns when considering smart home technology,[10,11] with participants with high health needs expressing readiness to accept optical monitoring devices.[15] The most prominent reason for using the smart home technology identified by participants was to improve their safety and security, especially in terms of fall reduction.[15,16] Wearable sensors were preferred to the optical system because they worked outside the home and increased participants' mobility without compromising safety. For example, a non-stigmatising sensor worn on the user's wrist, with an emergency option to be used in case of falling, was the preferred option.[15] Participants were concerned with the obtrusiveness of the systems, associated with the physical aspects of the technology such as a lengthy installation process and a system that clashed with users' aesthetic sensibilities and was not physically integrated into the architecture.[16] Participants also felt that the care centre should be able to help with malfunctioning technology.[16]

Findings from the controlled studies

A comparative study of Brownsell and colleagues investigated the effect of safe home technology on the fear of falling, feeling of safety, level of outside activity and personal health in 56 elderly people living in the community.[17] Participants were able to choose a system to be installed from the following packages: (1) a falls package, consisting of fall detectors and an automatic light switch; (2) a mobility mapping package, consisting of bed and chair occupancy devices, movement detectors, door contact monitors and electrical usage and (3) a security system and wandering client alert. After a 12-month monitoring period, there was no change in the fear of falling, and generally no change in functional health and well-being of participants. Out of nine SF-36 domains, only the social functioning domain was higher by 8% in the intervention group. Positive trends identified included (1) increased length of time spent outside the home, (2) improved feelings of safety during day and night and (3) reduced fear of crime (for details, see Table 1). The rather inconclusive results of this trial may be related to the size of the sample and the pattern

of technology uptake; while 100% of participants from the intervention group opted for the security packages, only eight opted for fall detectors.

The only randomised control trial of Tomita and colleagues investigated the feasibility, effectiveness and the use of currently available 'off-the-shelf' smart home technology (X10 system).[18] The study measured health and functioning status and attitudes towards the technology among 114 community-living frail elders. The X10 home system is used mainly for remote controlling lights and appliances, but other devices can be connected and programmed into the controller. Although some external devices, such as outside motion sensors, were added in the study, they did not include fall detectors. After two years of monitoring, more people from the intervention group were still living at home and their cognition scores were higher compared with controls. The differences in the cognitive status could be explained by group composition, as a selective attrition of participants which occurred after the randomisation resulted in the intervention group being younger and healthier than the control group. The primary reason for non-use of technology was related to its 'failure', attributed not necessarily to a malfunction of the system but rather to a combination of unfriendly features of the X10 home system and participants' unfamiliarity with the system. Overall, the participants chose only those functions that did not fail and that were most suitable and beneficial for them.

Evaluation of a practical implementation: the government safe house project in West Lothian

A special place in safe home research should be given to the evaluation of the Telecare Development Programme, West Lothian, Scotland, which is the largest scale and most developed telecare service in Europe.[9] It provides second-level telecare services, which were extended from the original first-level telecare system, consisting of a community alarm service. It has been funded since 2006 by the Scottish Government at the cost of £8.35 million. The service now covers over 2700 users out of a potential total of about 10,000 households, 13% of whom have more than a core package. The core package provided by The West Lothian Care Service generally consists of the following wireless devices: (1) a home alert console, which links sensors to a call centre; (2) passive Infrared detectors to monitor movement activity; (3) flood detectors; (4) a heat extreme sensor sensitive to both high and low temperatures and (5) a smoke detector. If required, additional technological devices, such as passive door opening alerts and fall detectors, or active devices such as remote video door entry systems and pendant alarms, are provided.

The emerging conclusions from the evaluation of the costs and benefits of the programme are as follows: (1) the user response to the technology has been overwhelmingly positive, with users reporting an increased sense of personal safety and security; (2) informal carers reported an increased peace of mind; (3) weekly costs of telecare-based care service provision were around £145–185 lower than a West Lothian care home alternative and (4) considerable financial benefits from the Telecare Development

Programme were observed in 2007–2010: (i) 46,500 hospital bed days saved by facilitating speedier hospital discharge; (ii) 225,000 care home bed days saved by delaying the requirement for people to enter care homes and (iii) 46,000 nights of sleepover care and 905,000 home check visits saved by substitution of remote monitoring arrangements. Collectively, these savings are valued at around £43 million—an anticipated benefit to the programme funding cost ratio of 5:1. It should be noted that this evaluation encompasses the entirety of the Telecare Development Programme, and separate evaluation data for the fall prevention component of the programme have not been made available.

DISCUSSION

Principal findings
The field of research on computer technology-driven interventions for fall preventions in the elderly is new, and published evidence is scarce. Only a few studies were found on using fall detectors and related 'smart home' technologies to prevent and detect falls, or to decrease the fear of falling. The level of evidence provided by these studies was very low, generally due to study design and small sample size of these studies. These studies present common themes on attitudes and barriers to the implementation of monitoring technology. Older adults' attitudes towards fall detectors and smart home technology were generally positive, and privacy concerns diminished with increasing health needs of monitored older adults. However, the technology has to be user friendly and come with technical support. Unfriendly and age-inappropriate design of the interface may be one of the deciding factors for not using the technology. The interface should be specifically designed for the elderly users and tested by this user group. An interface tested by young people can be completely unusable for older adults due to differences in perception and brain functioning between different age groups.[19]

Comparison with the literature
The research on the effectiveness of safe home technology to prevent and detect falls is difficult to carry out. The authors of The Canadian Best Practices Guide for the Prevention

of Falls Among Seniors Living in the Community observed some significant research issues, which make the outcomes difficult to detect and blur the outcomes between the results of studies and real-life outcomes: (1) only very large studies can detect differences in fall-related injuries; (2) monitoring falls among community-dwelling seniors is very difficult, as most studies rely on self-report methods of monitoring, which leads to an under-reporting of falls that are not associated with injuries and (3) although it may be expected that a reduction in falls would lead to a reduction in fall-related injuries, there is yet little evidence to support this conclusion.[20]

Limitations of the method
The main limitation of this paper is the limited number of studies that fulfilled the inclusion criteria and the quality of the included studies. The studies were generally of qualitative design, and the investigated samples were small and subject to selection bias. This potentially restricts the generalisability of results.

Call for further research
Further research is needed to answer with any certainty whether smart home technologies will affect fall-related health outcomes. Studies that employ a comparative design investigate larger samples and use more direct outcome measures such as fear of falling, which are essential to gather conclusive evidence on the subject.

CONCLUSION

There is as yet little published evidence on the impact of smart home technology on fall prevention, early fall detection or fear of falling. The lack of evidence appears to be due to the scarce amount of research in this area. There is some evidence that monitoring technology may increase older adults' confidence and feelings of safety, possibly promoting and prolonging independent living.

Acknowledgement

Conflict of Interest
Authors declare no potential conflicts of interest.

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