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How smart homes are used to support older people: An integrative review

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Abstract

Background: The number of healthy older people is increasing, and most of them want to live in their own homes for as long as possible. Smart home technology can support living at home, but synthetised knowledge of previous studies about their suitability for the everyday lives of older people is rare.

Methods: Data for this integrated review were obtained by searching the PubMed, CINAHL and Scopus databases from 2012 to 2019, based on inclusion and exclusion criteria, and then carrying out quality appraisals of the papers that were selected.

Results: We identified 944 papers, and 16 were included in the review. According to our analysis, smart home solutions for older people focused on devices for daily and healthy living and older people's safety. The smart home solutions they discussed were used to help older people carry out everyday activities and lead healthier and more fulfilled lives, by improving their physical safety and social communication. Older people reported that smart homes improved their sense of security, quality of daily life and activities and provided them with information about the care they could receive. However, research on older people playing an active role in developing smart home technology was lacking.

Conclusion: The existing literature focused on evaluating daily activities with routine measurements. There has been a lack of research that has focused on older people's experiences as the end users of this technology. However, the papers lacked data on how older people could maintain their social relationships and become more proactive in daily living.

Implications for practice: With further development, smart homes can be used to support older people to perform daily activities and help them maintain their social relationships. These steps will ensure that they can continue to live independently in their own homes for longer.

KEYWORDS

automation, home care, independence, older people, smart homes, technology, integrative review

1 | INTRODUCTION

Most older people are healthy and like to live in their own homes, as they prefer to be in a familiar environment (de Bruin et al., 2018; Sherman, Forsberg, Karp, & Tornkvist, 2012). Smart home technology includes various communication and network devices that use monitors, sensors, applications and robotics (Cook, D. J. 2012), and it can help healthy older people to continue to live independently in their own home as they age (Brims & Oliver, 2018; Cho & Kim, 2014). Technology has been used in older people's homes to collect data on using electronic domestic appliances, such as coffee makers and washing machines, and control everyday routines, such as turning lights on and off and opening and closing doors and windows (Austin et al., 2016). Different robots have been used to decrease social loneliness and as domestic aids to assess daily activities, such as medication, eating, bathing, getting dressed and mobility (Wu et al., 2014). In this paper, smart homes are used as a generic concept for technology that supports older people to continue to live in their own home by monitoring and supporting them in their everyday lives.

Living longer at home is more topical than ever, as life expectancy is increasing in most countries. Older people's abilities to stay independent have increased without a parallel increase in major functional limitations (Christensen, Doblhammer, Rau, & Vaupel, 2009; Sherman et al., 2012). As people age, they have greater experiences and understanding of life and they have the capacity to find different ways to manage daily activities when they develop disabilities and diseases (Donahue, Piazza, Griffin, Dykes, & Fitzpatrick, 2008; Rodriquez-Blazquez et al., 2012). Therefore, ageing is increasingly seen as a meaningful period of life that focuses on older people's interaction with society (Bökberg et al., 2015; MacKean & Abbott-Chapman, 2012; Tan, Chan, Wang, & Vehviläinen-Julkunen, 2016).

In addition, there is a global emphasis on goals that ensure that older people get the support they need so that they can continue to live independently in their own homes. According to data from the European Union, 28.5% of Europeans aged 65 and over live alone (Eurostat, 2017). They have been reported to have worse health and well-being than younger people and their need for regular help starts to increase as they age (Sherman et al., 2012). However, social and healthcare services in Western countries face economic pressures, with limited healthcare professionals and financial resources, and institutional care is often more costly than home care (Burt et al., 2012).

Despite the fact that most older people want to live in their own homes for as long as possible (de Bruin et al., 2018; Turjamaa, Hartikainen, Kangasniemi, & Pietilä, 2014), some dislike it because they feel that their home is a lonely and unsafe environment. Therefore, it is essential to take into account older people's rights to make decisions about their own lives (Jacobs, 2018; Zhang et al., 2011). Smart home systems can help older people, but they also pose significant ethical challenges, such as privacy, autonomy, dignity, safety and trust, and it is important to consider these issues (Sánchez, Taylor, & Bing-Johnsson, 2017).

What does this research add to existing knowledge in gerontology?

- Organisations who develop smart home technology have done little to take the views of older people and other stakeholders into account.
- The smart home technology that is currently available helps to maintain older people's independence with regard to everyday activities.
- Social and healthcare professionals can use the information on smart home technology to develop home care services for older people.

What are the implications of this new knowledge for nursing care with older people?

- Understanding how smart home technology helps older people to carry out everyday activities adds a new perspective to how they can live independent healthy lives.
- This review provides social and healthcare professionals with objective and reliable data on older people's everyday activities at home that can be used to develop home care services.

How could the findings be used to influence policy or practice or research or education?

- Future smart home technology could be more effective and client-centred if they sought the views of older people.
- The development of smart home technology requires continuous collaboration between technical and social and healthcare professionals and older people, including long-term research into the end-users' experiences and their ideas for future development.

Based on the previous reviews, smart homes for older people have been investigated with regard to monitoring technology in their own home (Peetom, Lexis, Joore, Dirksen, & Witte, 2014) and how smart home technology supports older people with diseases such as dementia (Raei & Bouchachia, 2016). In addition, Morris et al. (2013) evaluated the effectiveness of smart home solutions to assist older people, so that they could live safely and independently at home. However, due to rapid changes in the care of older people and the development of new smart home technology, a more up-to-date review of the literature was needed.

2 | AIM

The aim of this integrative review was to identify and synthetise previous knowledge about the smart home solutions used to support older people's everyday life. This knowledge could then be used

to develop home care solutions and support older people so that they could stay in their own home for longer. The research questions were as follows:

1. What research has been carried out into smart home technology that supports older people in their own home?
2. What are the experiences of the end users of smart home technology?

3 | METHODS

3.1 | Literature review

We used a five-stage integrated review method (Whittemore, 2007) to identify and synthetise previous knowledge. The first stage was to identify the research question, based on previous knowledge, and this showed that the previous research was fragmented and had been conducted using a number of research methods.

3.2 | Data collection

The second stage was data collection, and two authors (AP and MK) carried out searches using the PubMed, CINAHL and Scopus electronic databases. The search strategy was based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA, 2015) and is presented in a flow diagram (Figure 1). To ensure we identified the latest research on this rapidly changing subject, we limited our searches to 2012–2019. We also restricted our searches to peer-reviewed papers that were published in English and contained abstracts. The search terms used were "smart home" OR "home automation" OR "wireless home automation system*" OR domotic* OR "assistive domotic*" OR "embedded health system*" AND gerontology OR geriatrics OR old* OR elderly OR senior OR aged OR aging. Domotic is a technical term that relates to smart home technology.

We selected 944 original papers, and then narrowed it down to 121 titles, before reviewing 69 abstracts and then 16 full texts. Papers were included if they focused on smart homes and older people's care and were excluded if they focused on technical aids without smart technology, such as telehealth devices or digital services. We also excluded studies on older people with intellectual disabilities.

3.3 | Quality appraisal

The third stage was to assess the papers using a combination of quality appraisal criteria (Caldwell, Henshaw, & Taylor, 2011; Gifford, Davies, Edwards, Griffin, & Lybanon, 2007; Greenhalgh, Robert,

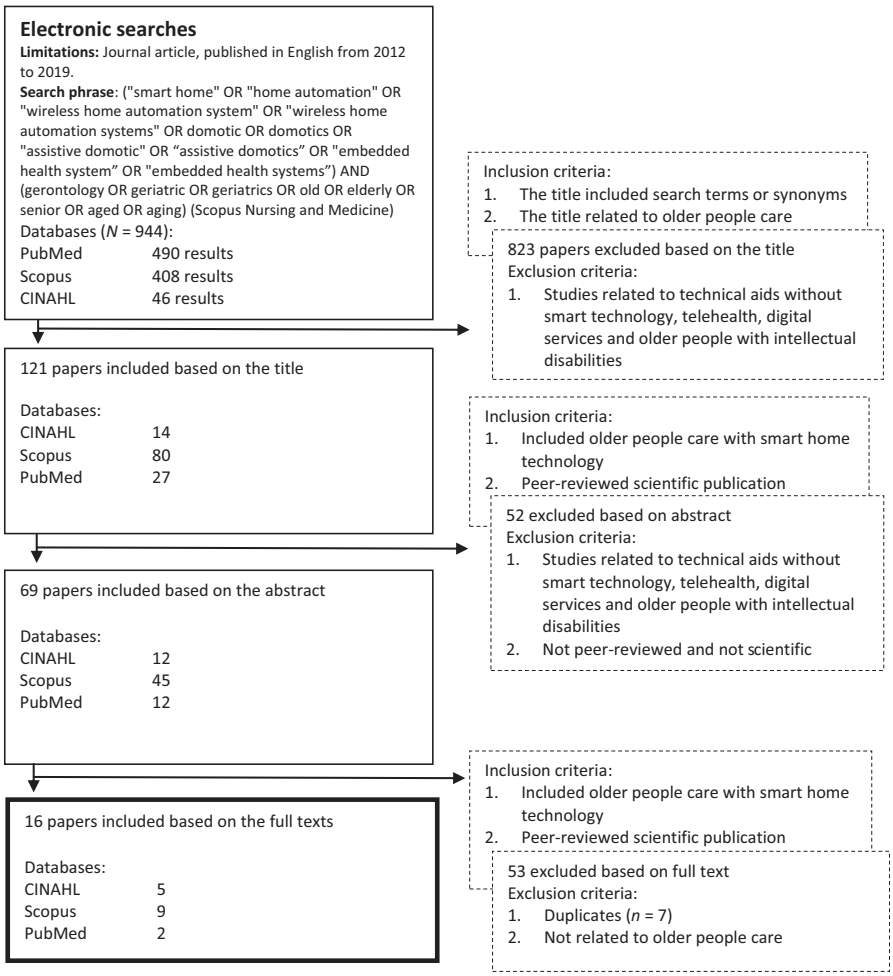

FIGURE 1 Literature searches and the selection process for the original intervention studies

TABLE 1 Quality appraisal criteria (Caldwell et al., 2011; Gifford et al., 2007; Greenhalgh et al., 2004)

Author(s), year	Akl et al. (2017)	Alberdi et al. (2018)	Austin et al. (2016)	Blasco et al. (2014)	Bock et al. (2016)	Cook et al. (2015)	Dawadi et al. (2013)
Questions							
Common							
Was the rationale for the undertaking the research clearly stated?	Y	Y	Y	Y	Y	Y	Y
Were the aim and objectives of the research clearly presented?	Y	Y	Y	Y	Y	N	Y
Was the theoretical framework/literature review comprehensive?	Y	Y	Y	Y	Y	Y	Y
Was the background of the research up-to-date?	Y	Y	Y	Y	Y	Y	Y
Was the study design appropriate for the research questions?	Y	Y	Y	Y	Y	Y	Y
Was the methodology clearly identified?	Y	Y	Y	N	Y	Y	Y
Was the methodology clearly justified?	Y	Y	N	N	N	N	N
Were ethical issues clearly identified and addressed?	N	N	N	N	N	N	N
Was ethical approval sought and received?	N	N	Y	N	N	Y	N
Was informed consent obtained?	N	N	N	N	N	N	N
Were the results presented in a clear way?	Y	Y	Y	Y	Y	Y	Y
Was the discussion comprehensive?	N	Y	Y	Y	N	N	N
Were the conclusions clearly presented?	Y	Y	Y	Y	Y	Y	Y
Qualitative							
Were the concepts clearly defined?							
Was the context of the study clearly described?							
Was the selection of the participants clearly reported?							
Were a sufficient amount of cases included?							
Was the data collection appropriately described?							
Was the data analysis clearly reported?							
Were sufficient data presented?							
Were the credibility and conformability clearly addressed?							
Were the authors' positions clearly stated?							
Quantitative/device test study							
Was the population clearly identified?	Y	N	Y	Y	Y	Y	Y
Was the sampling method clearly reported?	N	N	N	N	N	N	Y

Gaugler et al. (2019)	Jekel et al. (2016)	Lussier et al. (2019)	Mehrabian et al. (2014)	Peek et al. (2016	Pigini et al. (2017)	Ravishankar et al. (2015)	Sacco et al. (2012)	Suryadevara & Mukhopadhyay, (2013)
Y	Y	Y	Y	Y	Y	Y	Y	Y
Y	Y	Y	Y	Y	Y	N	Y	Y
Y	Y	Y	Y	Y	N	Y	Y	Y
Y	Y	Y	Y	Y	N	Y	Y	Y
Y	Y	Y	Y	Y	Y	Y	Y	Y
Y	Y	Y	Y	Y	N	Y	N	Y
Y	N	Y	N	N	N	N	N	N
N	N	N	N	Y	Y	N	Y	N
N	Y	N	Y	Y	Y	Y	Y	N
Y	Y	N	Y	Y	Y	Y	Y	N
Y	Y	Y	Y	Y	N	Y	Y	Y
Y	Y	Y	Y	Y	N	N	N	N
N	Y	Y	N	Y	N	N	N	Y
Y			Y	Y	N	Y		
Y			Y	Y	N	Y		
Y			Y	Y	Y	Y		
Y			Y	Y	Y	N		
Y			N	Y	Y	Y		
Y			Y	Y	N	N		
Y			Y	Y	Y	Y		
N			N	Y	N	N		
N			N	Y	N	N		
Y	Y	Y	Y		Y		Y	N
Y	N	N	Y		N		Y	N

(Continues)

TABLE 1 (Continued)

Author(s), year	Akl et al. (2017)	Alberdi et al. (2018)	Austin et al. (2016)	Blasco et al. (2014)	Bock et al. (2016)	Cook et al. (2015)	Dawadi et al. (2013)
Was the size of the sample clearly reported?	Y	N	Y	Y	Y	Y	Y
Was the instrument/device sufficiently described?	Y	Y	Y	Y	N	Y	Y
Was the instrument's validity and reliability clearly stated?	N	N	na	na	N	na	N
Was the data collection appropriately described?	N	Y	Y	Y	Y	Y	Y
Was the response rate reported?	na	na	na	na	N	na	na
Was the data analysis clearly reported?	Y	Y	Y	Y	Y	Y	Y

Abbreviations: Y, yes; N, no; NA, not applicable.

Macfarlane, Bate, & Kyriakidou, 2004). This comprised 13 common criteria, nine specific criteria for qualitative papers and eight specific criteria for quantitative papers (Table 1). Two authors (AP and MK) evaluated the papers independently, and any disagreements were resolved by consensus. We included all 16 papers that we evaluated at the full-text stage of the review.

3.4 | Data abstraction

The fourth stage was data analysis and interpretation (Whittemore, 2007). Firstly, we read the selected papers several times to get an overview of the content. Then, we extracted the data by tabulating the papers according to the author(s), years, countries, aims, methods and results (Table 1). After that, we analysed the content of the papers according to our research questions and then integrated them to synthesise the results. The synthesis consisted of two main content themes: smart home solutions for older people and the experiences of end users of smart home technology. There were also five sub-themes: smart home devices for daily activities and healthy living, smart home devices for older people's safety, sense of security and everyday activities for older people, quality of life and daily activities for family members and information provided for home care professionals. The analysis was conducted by one researcher (AP) until the tabulation and analysis were completed during shared discussions with all the researchers.

4 | RESULTS

4.1 | Description of the selected papers

The selected papers (Table 2) included two qualitative interview studies (Peek et al., 2016; Ravishankar, Burleson, & Mahoney, 2015) and six descriptive quantitative studies (Akl, Snoek, & Mihailidis, 2017; Alberdi et al., 2018; Austin et al., 2016; Bock et al., 2016; Jekel, Damian, Storf, Hausner, & Frölich, 2016; Lussier et al., 2019). There were also five research papers on device tests (Blasco, Marco, Casas, Cirujano, & Picking, 2014; Cook, Schmitter-Edgecombe, & Dawadi, 2015; Dawadi, Cook, & Schmitter-Edgecombe, 2013; Sacco et al., 2012; Suryadevara & Mukhopadhyay, 2013). Some of the papers used more than one research method (Gaugler et al., 2019; Mehrabian et al., 2014; Pigini et al., 2017). They were published between 2012 and 2019. All of the studies included older people, two also included formal and informal caregivers (Blasco et al., 2014; Mehrabian et al., 2014) and one also included home care professionals (Bock et al., 2016). The main focus of five studies was smart home devices for daily activities and healthy living. Of the 16 studies we selected, seven looked at smart home devices with regard to the quality of daily activities (Alberdi et al., 2018; Blasco et al., 2014; Cook et al., 2015; Dawadi et al., 2013; Lussier et al., 2019; Ravishankar et al., 2015; Suryadevara & Mukhopadhay, 2013), four examined older people's safety related to physical environment (Bock et al., 2016; Cook et al., 2015; Dawadi et al., 2013; Pigini et al., 2017), four looked at physical activity (Austin et al., 2016; Dawadi et al., 2013; Gaugler et al., 2019; Pigini et al., 2017) and two focused on social isolation and loneliness (Austin et al., 2016; Jekel et al., 2016). Some of the studies looked at more than one area.

Seven of the studies were conducted in the United States (Akl et al., 2017; Austin et al., 2016; Bock et al., 2016; Cook et al., 2015; Dawadi et al., 2013; Gaugler et al., 2019; Ravishankar et al., 2015), two in France (Mehrabian et al., 2014; Sacco et al., 2012), one in Spain and United Kingdom (Blasco et al., 2014), one in Spain and the United States (Alberdi et al., 2018) and one each in Germany (Jekel et al., 2016), the Netherlands (Peek et al., 2016), New Zealand (Suryadevara & Mukhopadhay, 2013), Italy (Pigini et al., 2017) and Canada (Lussier et al., 2019).

4.2 | Smart home solutions for older people

Our analysis showed that smart home solutions for older people focused on devices for daily and healthy living and older people's safety (Table 3).

Gaugler et al. (2019)	Jekel et al. (2016)	Lussier et al. (2019)	Mehrabian et al. (2014)	Peek et al. (2016	Pigini et al. (2017)	Ravishankar et al. (2015)	Sacco et al. (2012)	Suryadevara & Mukhopadhyay, (2013)
Y	Y	Y	Y		Y		Y	N
Y	N	Y	N		N		Y	N
N	N	N	Y		N		Y	na
Y	Y	Y	Y		Y		Y	N
na	na	na	N		na		na	N
Y	Y	Y	Y		Y		Y	Y

4.2.1 | Smart home devices for daily activities and healthy living

Based on the results of our review, smart home devices for daily and healthy living had been described as a tools that could be used to evaluate and determine the quality of completed activities (Blasco et al., 2014; Dawadi et al., 2013; Lussier et al., 2019; Ravishankar et al., 2015), the time and duration of daily activities (Suryadevara & Mukhopadhyay, 2013), the use of furniture, objects and domestic appliances (Cook et al., 2015; Lussier et al., 2019; Suryadevara & Mukhopadhyay, 2013) and *physical* (Alberdi et al., 2018; Austin et al., 2016; Dawadi et al., 2013) *and social activity* (Austin et al., 2016; Jekel et al., 2016). They were operated by sensors (Lussier et al., 2019; Suryadevara & Mukhopadhyay, 2013), self-learning algorithms (Alberdi et al., 2018; Cook et al., 2015; Dawadi et al., 2013) and by evaluating telephone use (Austin et al., 2016; Jekel et al., 2016). The evaluation was related to *the quality of the daily activities* (Cook et al., 2015; Dawadi et al., 2013) *and social contacts* (Austin et al., 2016; Jekel et al., 2016) of older people in their normal environments. The detailed data derived from the smart home sensors could be used to *evaluate how older people coped* with diverse activities, such as dressing and cooking, with changes in their cognitive health status and assess the overall *quality of tasks* by using learning algorithms (Dawadi et al., 2013; Lussier et al., 2019). In addition, evaluating telephone use made it possible to find out how long the telephone calls lasted and information was also obtained about the numbers selected and the frequency of incoming and outgoing calls (Austin et al., 2016; Jekel et al., 2016). This helped to measure their interaction with other people and organisations. The *use of furniture and the objects* in the rooms, such as beds, toilets, chairs and sofas, was monitored using pressure sensors (Suryadevara & Mukhopadhyay, 2013) and vibration sensors (Cook et al., 2015).

Physical activity was monitored by motion sensors attached to interior ceilings, technology was worn by the older person and video cameras (Austin et al., 2016; Dawadi et al., 2013; Lussier et al., 2019). The motion sensors typically operated by using infrared light and detected any movement in their range (Akl et al., 2017; Cook et al., 2015). The data transmitted by the motion sensors were used to calculate the probability of the older people's presence in a specific room at a particular time of day (Akl et al., 2017). Furthermore, the sensors that monitored the room spaces measured the amount of movement in the room (Bock et al., 2016; Cook et al., 2015; Dawadi et al., 2013; Lussier et al., 2019).

Physical activity and movement at home were measured using wearable sensors. The sensors could monitor whether there was more than one person in the home at the time, for example an older person plus a visiting relative (Austin et al., 2016). The wearable sensors were used to measure three-axle acceleration and determine the position of the older people by using a gyroscope (Cook et al., 2015).

Older people's physical activity and movement at home were also monitored by video cameras that could evaluate their ability to walk and manage daily activities, as well as predict falls and monitor the individuals present in a room, such as visitors (Austin et al., 2016; Sacco et al., 2012). The older people's behavioural patterns could be established by combining the data obtained from the sensors (Lussier et al., 2019; Suryadevara & Mukhopadhyay, 2013). In addition, various activities were recognised and analysing these made it possible to determine the nature of the activities as well as the relationships between the older people's health and these behaviours (Cook et al., 2015).

4.2.2 | Smart home devices for older people's safety

Smart home devices for older people's safety were related to the *physical environment of the home* (Bock et al., 2016; Cook et al., 2015; Dawadi et al., 2013) *fall prevention* and *social isolation and loneliness* (Austin et al., 2016; Jekel et al., 2016). The *physical environment of the home* was monitored by sensors, such as those that measured the amount of light, temperature and movement in the environment (Bock et al., 2016; Cook et al., 2015; Dawadi et al., 2013; Gaugler et al., 2019). In addition, door sensors were installed on cupboard

TABLE 2 Summary of the studies covered by the review

Author(s), year, country, quality appraisal points (score/max)	Aim	Methods
Akl et al. (2017), USA, 13/21	To build generalised linear models of older adults' home activities, which were monitored using unobtrusive sensor technology	Quantitative study. Time series measured at baseline and once a year for 3 years. Subjects were 68 people aged 70 years or older living at home. Weekly online questionnaires, statistical analyses
Alberdi et al. (2018), Spain, USA	To evaluate the possibility of using unobtrusively collected activity-aware smart home behavioural data to measure any decline in functional health	Longitudinal smart home data based on a mean of 17 sensors placed in the homes of 29 older adults for an average of >2 years. Data were compared to bi-annually collected data using the Instrumental Activities of Daily Living-Compensation and Clinical Assessment Using Activity Behavior algorithm
Austin et al. (2016), USA, 15/21 Scopus	To describe a system to measure loneliness by assessing in-home behaviour using wireless technology motion and contact sensors, phone monitors and computer software, as well as algorithms developed to assess key behaviours of interest	Quantitative longitudinal study lasting 8 months and carried out in the homes of 16 older people. Email-survey. Analysed by using mixed effects model
Blasco et al. (2014), Spain, UK, 13/21	To present a novel design, implementation and assessment of a wireless smart kitchen provided by Ambient Assisted Living Services	Device test study where participants visited two living laboratories equipped with sensors. The system was evaluated by 63 older adults, who would be end users, and 31 formal and informal carers
Bock et al. (2016), USA, 12/21	To demonstrate the implementation of a smart home system, using an open, extendable platform in a real-world setting. To develop an application to visualise real-time data	Quantitative study using an open source Lab of Things platform in a house of 11 residents over 3 months. A rapid iterative testing and evaluation approach was adopted to design a visualisation interface by engaging gerontological experts. 19 older people and caregivers were engaged to inform further design revisions
Cook et al. (2015), USA, 13/21	To investigate how smart environments can observe and understand the behavioural impact of ageing and ageing-related conditions, including Parkinson's disease and mild cognitive impairment	Device test study performed in a smart home environment. Smart home and wearable sensors were used to collect data, while 84 older people performed complex activities during daily living. The data were analysed using machine learning techniques
Dawadi et al. (2013), USA, 14/21	To describe the smart home and machine learning technology that automatically predicted the quality of activity in smart homes and automatically assessed cognitive health based on the quality of activity	Device test study. Studied 263 volunteers who performed activities in a smart home test area. Outputs from learning algorithms, including principal component analysis, support vector machine and logistic regression algorithms, were used to quantify the quality of smart home activities and predict the cognitive health of participants
Gaugler et al. (2019), USA	To evaluate whether, and how, remote activity monitoring improved caregiver outcomes for family members providing care for people living with Alzheimer's disease or another form of dementia	Experimental mixed-method study of 132 people living with dementia and 64 family caregivers. Baseline and 6-month quantitative survey data and qualitative information

Device/solution, function	Key findings
Wireless, sensor technology in participants' homes in the bedroom, the bathroom, the kitchen and the living room. Sensors automatically transmitted data to a database, where the information was stored	Using the sensor and clinical data for 68 subjects, including 15 who transitioned to mild cognitive impairment during the monitoring period, the authors demonstrated that the subjects' home activities could be modelled well using independent inhomogeneous Poisson processes. Mild cognitive impairment was detected in older adults, with an average area under the receiver operating characteristic curve of 0.716 and an average area under the precision-recall curve of 0.706, using activity models estimated over 12 weeks
Passive infrared sensors were placed in homes: in kitchen devices, bedroom and living room chairs and beds. The sensors tracked the movements and activities of the inhabitants by triggering raw sensor-data streams every time a sensor event was detected	The results show that the total scores and subscores could be predicted by the algorithm using smart home data on activity, as well as predicting reliable change in these scores. Positive and negative fluctuations in everyday functioning were harder to detect using in-home behavioural data, yet changes in social skills were shown to be predictable
Wireless motion sensors, contact sensors, phone monitors and computer software that detected movement in several rooms	Loneliness was negatively associated with the total hours spent outside the home. Results show that loneliness is significantly associated with both time out-of-home and number of computer sessions. Loneliness was also significantly related to the total number of computer sessions: each extra computer session was associated with an increase in loneliness score of 0.77 points. The model also demonstrated that the correlation between true loneliness and predicted out-of-sample loneliness was 0.48
Wireless smart kitchen that provided advice on the use of household appliances and detected emergency situations and provided users with warnings	The system had good usability and physical, sensory and cognitive accessibility. Most (90%) of the users who evaluated the system found it accessible and the overall usability score was 3.85/5, where one was poor and five was excellent
Lab of Things platform consisted of Aeon Labs Z-wave door/window sensors and an Aeon Labs multi-sensor that collected data on motion, temperature, light and humidity. The applications used to process the sensor data created graphs based on the measured level of activity and values obtained from the environment	Family members felt comfortable using the application, but older adults felt it would be difficult to learn to use the application and had trouble understanding its use. A key for older adults was ensuring that the collected data could be used by family members, physicians or caregivers
Smart home and wearable sensors. The smart home was fitted with infrared sensors on the ceiling, which detected motion inside. There were also magnetic doors, lights and temperature sensors and vibration sensors on selected items, such as a dustpan, watering can and medicine dispenser	The results indicated that smart homes, wearable devices and common computing technologies can be useful for monitoring activity behaviour and analysing the data to pinpoint differences between healthy older people and older people with Parkinson's disease or mild cognitive impairment. The technologies can be used to perform in-home health monitoring as well as early detection of functional changes associated with Parkinson's disease and mild cognitive impairment. The technologies can also assist with treatment validation by providing an ecologically valid setting in which residents are monitored in their own homes while performing their normal routines
Smart home with motion sensors on the ceiling, door sensors and item sensors on selected kitchen items. Sensors were in the living room, a dining area, kitchen, bedrooms and bathroom. Each sensor event identified the date, time, sensor identifier and sensor message	When all the samples were included, the authors obtained a statistically significant correlation ($r = 0.54$) between the direct observation scores and predicted quality of the activities. Similarly, reasonable classification accuracy was obtained using a support vector machine classifier, with an area under the receiver operating characteristic curve of 0.80 and a g-mean of 0.73 when the authors divided participants into two different cognitive classes: those with dementia and those with good cognitive health
The motion sensors used by the remote activity monitoring system were placed throughout the home. The sensors operated jointly and exchanged information on movement using an online dashboard that stored and displayed the data. The sensors operated jointly and exchange information on movement	The remote activity monitoring (RAM) did not exert statistically significant effects on caregiving outcomes over a 6-month period. Qualitative analyses identified that characteristics of caregivers and care recipients and living arrangements determined how caregivers perceived the remote activity monitoring. Caregivers who used random access memory technology and cared for relatives with less severe cognitive impairment and difficulty navigating around the home were more likely to indicate statistically significant increases in competence and self-efficacy, respectively

(Continues)

TABLE 2 (Continued)

Author(s), year, country, quality appraisal points (score/max)	Aim	Methods
Jekel et al. (2016), Germany, 15/21	To investigate the potential of a smart home environment for assessing key activities of daily living in people with mild cognitive impairment	Quantitative study with 21 people aged 65–80 years. Parameters were assessed in the smart home environment and a questionnaire was also used. The participants with mild cognitive impairment were compared with healthy controls. The data were analysed using statistical analyses
Lussier et al. (2019), Canada	To explore whether the simple and wireless technology used in two different smart environments could add value to performance and rater-based measures of instrumental activities of daily living when it came to predicting mild cognitive impairment in older adults	Functional performance analysis in smart apartments with sensor-based observations of 26 cognitively healthy adults and 22 older adults with mild cognitive impairment
Mehrabian et al. (2014), France, 22/30	To evaluate the acceptance of home telecare technology by older people suffering from cognitive impairment and their caregivers	Mixed-method study that comprised 30 older people with mild cognitive impairment, 32 with Alzheimer's disease and 30 caregivers. Semi-structured interviews. Qualitative material analysed by inductive thematic analysis. Quantitative data reported as means and standard deviations, chi-square tests and paired *t* tests
Peek et al. (2016), Netherlands, 21/22	To explore which factors influenced the level of use of various types of technology by older people who were ageing in place and to describe these factors in a comprehensive model	A qualitative explorative field study was set up, involving home visits to 53 community-dwelling older people aged 68–95, who were living in the Netherlands. The data were analysed using thematic analysis
Pigini et al. (2017), Italy	To develop and test an innovative personal health system that integrated standard sensors and wearable and environmental sensors to allow home telemonitoring of vital parameters and detection of anomalies in daily activities	The prototype (SMARTA) was tested with 15 healthy adults, 13 elderly people with cardiac diseases and four clinical operators in a real home setting. After the test session, the data were collected by using an assessment survey with structured and open-ended questions
Ravishankar et al. (2015), USA, 12/22	To present strategies for user-centric approaches to identify the technical and design challenges of developing, deploying and using functional assessment systems in homes occupied by older people	Qualitative study. Case studies of four healthy adults aged 65 and over—two males and two females—over a period of 2 weeks, with activity-related interviews before and after using the systems. The interviews were analysed using inductive analysis
Sacco et al. (2012), 16/21 France	To demonstrate that it is possible to use a video monitoring system to obtain quantifiable assessments of instrumental activities of daily living in people with Alzheimer's disease and mild cognitive impairments	Device test study with 64 people over 65 years of age. Quantitative and qualitative parameters and ecological assessments of instrumental activities of daily living were captured using video cameras, and per-protocol analyses were carried out
Suryadevara and Mukhopadhay (2013), New Zealand, 9/21	To describe the ability of a low-cost, robust, flexible and data-driven intelligent smart home system to determine how well older people cope with living alone	Device test study. Over a period of 33 weeks, the system collected data on different events. The study participants were older people living in their own home

doors, external doors, fridges and windows. For example, the sensors detected when the doors were opened and closed and recognised their current status (Austin et al., 2016; Bock et al., 2016; Cook et al., 2015; Dawadi et al., 2013).

Fall detection systems were used that were based on images retrieved from a video camera. These systems were able to recognise different positions and place them in one of four predetermined categories, namely standing up, lying down, crouching and falling. They

Device/solution, function	Key findings
Activity sensors and video cameras were used to monitor six everyday life tasks, such as unpacking objects from a suitcase, boiling water and making a phone call	People with mild cognitive impairment needed more time than healthy controls (1,384 vs. 938 s, $p < 0.001$) and scored less total points (48 vs. 57 points, $p < 0.001$) to solve the tasks. When subtasks were analysed, intergroup differences were observed for making a phone call, operating the television and retrieving objects. The participants with mild cognitive impairments showed more searching and task-irrelevant behaviour than the healthy controls. The task performance was correlated with cognitive status and the questionnaires on key activities of daily learning, but not with the participants' ages
Twelve sensors were connected to a server using wireless Z-wave. Sensors were installed in the five living areas: bedroom, living room, dining room, kitchen and bathroom. Scripted tasks of motion, contact and electric sensors and performance-based measures were used	Participants with mild cognitive impairment spent more time in the kitchen and looking into the fridge and kitchen cabinets than cognitively healthy participants. Measures were negatively associated with the memory and executive performances of participants and significantly contributed to predicting mild cognitive impairment
Study focused on telecare system service that detected some emergencies, provided cognitive stimulation exercises, enabled video calls with professionals, family and friends and provided reminders about taking medicines and performing tasks. In addition, some sensors for doors, fires, water and falls were included	Participants were largely positive reactions about the technology. The cognitive stimulation programme of the home telecare service was the most positively received, followed by the emergency function. The participants generally agreed that home telecare and smart houses could significantly improve their quality of life. However, some technical and ethical concerns about the provision, installation and monitoring of the systems needed to be addressed before the system was implemented
The technology comprised assistive devices, entertainment appliances, home automation, home and personal care appliances, home fitness equipment, information and communication technology devices, telephones and transportation devices	The level of technology use in the context of ageing in place was influenced by six major themes: challenges posed by independent living; behavioural options; personal thoughts on technology use; the influence of social networks; the influence of organisations and the role of the physical environment
The device used integrated sensors to provide a gateway, middleware and clinical governance system. This measured body weight, heart rate, ear temperature, blood pleasure, blood oxygen saturation and glycaemia. It detected falls and recorded a single derivation electrocardiogram. Environmental sensors were connected to a home automation system to monitor water taps and when the refrigerator and dishwasher doors were opened and closed	The test users considered the device very useful for monitoring their health (2.7/3), improving security at their home (2.7/3) and reducing stress of repeated outpatient visits (2.6/3). The moderate system reliability of 65%–70% revealed some technical issues, mainly related to sensor integration, while the patient's user interface showed excellent reliability (100%)
The participants tested a smart home system with sensors that guided activities such as dressing and brushing teeth and instrumental activities of daily living, including making coffee and taking medication	The results informed strategies for user-centred functional assessments and assistive technology design and implementation with the potential to assist ageing in place. They did this by providing information capture, analysis and delivery of in-home functional assessments
Video monitoring system	In phase 1, the daily activity scenario score differentiated Alzheimer's disease from the normal control groups. In phase 2, the score differentiated patients with mild cognitive impairment and normal control group. The derived scores provide a pragmatic, ecological, objective measurement that may improve the prediction of future dementia and lead to earlier therapeutic interventions
A wireless monitoring system was used to detect the use of electronic household objects, such as microwaves, kettles, toasters, room heaters and televisions, and non-electronic objects, such as beds, chairs, toilets and sofas	The process helped healthcare providers to see how well older people performed daily activities as a basis for assessing their care needs

were programmed to survey the floor area, so that they would not create an alert if, for example, the person was lying on a sofa. Falls were detected if three conditions were met: the person was lying down or crouching, they were detected on the floor area and they stayed in that position for more than a preset time, indicating that they were unable to get up. In addition, smart homes and wearable technology were used to detected body movements associated with Parkinson's disease, as these differ from healthy older people (Cook et al., 2015.).

TABLE 3 Smart home devices and authors

Themes	Contents	Author and year
Smart home solutions for older people		
For daily activities and healthy living	Quality of daily activitiesOlder peoples coping Quality of tasks Use of objects	Alberdi et al. (2018) Cook et al. (2015) Blasco et al. (2014) Dawadi et al. (2013) Gaugler et al. (2019) Lussier et al. (2019) Pigini et al. (2017) Ravishankar et al. (2015) Suryadevara and Mukhopadhyay (2013)
For older people's safety	Physical circumstances Physical activity Social isolation and loneliness	Akl et al. (2017) Austin et al. (2016) Bock et al. (2016) Cook et al. (2015) Dawadi et al. (2013) Jekel et al. (2016) Sacco et al. (2012) Suryadevara and Mukhopadhyay (2013)
End-users' experiences of smart homes		
Older people	Sense of security Everyday activities	Bock et al. (2016) Mehrabian et al. (2014) Peek et al. (2016)
Family members	Quality of life Daily activities	Bock et al. (2016) Mehrabian et al. (2014)
Home care professionals	Information provided	Suryadevara and Mukhopadhyay (2013)

4.3 | Experiences of end users of smart home technology

The papers we reviewed showed that smart home solutions influenced older people, their relatives and home care providers. They also provided feedback on the impact they had on security, everyday activities, quality of life, daily activities and their ability to provide information (Table 3).

4.3.1 | Older people: sense of security and everyday activities

From the perspective of older people, smart homes were related to a sense of security and everyday activities. In particular, older people with reduced cognitive abilities or Alzheimer's disease had varying views on how smart homes affected their perceived sense of security. While older people felt smart home systems would be useful in emergency situations, they did not feel it would improve their sense of security if they were alone when a problem arose. Indeed, many said they would rather be with another person, such as a spouse, family member or healthcare professional in an emergency situation (Mehrabian et al., 2014). However, some respondents felt that smart homes improved their sense of security, as they lived far away from their relatives.

Many older people with some degree of cognitive impairment felt that smart homes would benefit individuals with more severe impairments than them. However, many also said that smart homes could help them perform everyday activities. (Mehrabian et al., 2014.), but some found it difficult to master the technical applications provided by smart homes and struggled to understand the purpose of the applications (Bock et al., 2016.). Many of the older people who tested the functionality of smart homes felt they had no need for the technology or external assistance, as they felt they were capable of taking care of themselves (Peek et al., 2016).

4.3.2 | Family members: quality of life and daily activities

Older people's family members viewed smart home solutions from the perspective of quality of life and daily activities. In general, they voiced more positive views than their older relatives about the benefits, including improving the older people's quality of life (Gaugler et al., 2019). They talked about how they trusted the smart home system to monitor their older relative and how this freed them up to spend less time with them. Most family members felt smart homes could help their older relative cope with their daily activities. (Mehrabian et al., 2014.) The information obtained from the smart home technology about the older people's activities and health was considered appropriate and simple and did not contain overly personal details (Bock et al., 2016).

4.3.3 | Home care professionals: information provided

For home care professionals, the smart home applications provided information about the current status of their older client's daily activities (Suryadevara & Mukhopadhyay, 2013) and enabled them to evaluate whether the current level of care services was adequate. The smart home system could store and analyse the data transmitted by the sensors, so that the well-being of the older people could be assessed (Suryadevara & Mukhopadhyay, 2013).

5 | DISCUSSION

Our results were similar to those of previous reviews, where smart home technology was used to build up a picture of how they could provide an illness-centred approach (Raei & Bouchachia, 2016) and how effective the technology was with regard to helping older people feel safe and independent at home (Morris et al., 2013; Peetom et al., 2014). However, the world we live in, and the way we care for older people, is constantly changing and new smart home technology is being developed. As a result, this integrative review provides new, synthetised knowledge about the smart home solutions used in older people's homes.

Our review shows that smart homes supported older people's daily activities and healthy living, by improving the quality of their

daily activities, tasks and how they used objects in everyday life (Morris et al., 2013, Peetom et al., 2014, Raei & Bouchachia, 2016), as reported in the previous studies. They also improved their ability to cope. In addition, smart homes were used to improve older peoples' physical safety and their safety with regard to daily activities. End users said that smart homes improved their sense of security, quality of daily life and activities and provided information that could help organisations to develop the care they received.

This discussion focuses on the three key observations to emerge from our review. The first observation was *the content of the studies*. We found that most studies produced scientific knowledge about smart home solutions for daily living and security. Daily living focused on physical activities and managing everyday activities, such as the time and duration of daily activities and the use of furniture and domestic appliances. These aspects were described in a variety of ways. However, this diversity did not include issues such as devices to help older people take their medication, which previous studies have identified as a major element of older people's comprehensive health conditions (Hamilton, Gallagher, Ryan, Byrne, & O'Mahony, 2011; Turjamaa, 2014).

This observation also included smart home solutions and security at home. Smart home devices for older people's safety were related to their circumstances at home, their physical activity and their sense of security. However, one study (Mehrabian et al., 2014) showed that older people felt that smart homes would be useful in emergency situations, but did not improve their sense of security in such situations.

The second observation was smart home devices for *activities of daily and healthy living*. According to our results, these were described as tools that could be used to evaluate and determine the quality, time and duration of daily activities and the use of furniture and domestic appliances. A study by Liu, Strouliab, Nikolaidisc, Miguel-Cruza, and Rincona (2016) acknowledged the importance of the different technology used to monitor daily living activities at home, especially in older people with complex needs.

However, our review showed that the research into smart homes consisted of evaluating daily living activities with routine measurements and observations. We did not find any detailed studies that evaluated and demonstrated their potential to contribute to older people's ability to live independently (Uddin, Khaksar, & Torresen, 2018). In addition, older people were seen as passive end users and did not play an active role in the development of smart home technology.

Therefore, the knowledge about how smart homes supported older people who lived at home differed substantially from the aim of making older people more physically active. It is evident that keeping older people physically active helps them to maintain the activities needed for daily living and that more diverse smart home solutions are needed. As one study found, computer-based games that required people to be physically active helped to improve the cognitive and physical abilities that are directly involved in everyday living (Maillot, Perrot, & Hartley, 2012).

Our results indicate that the current planning and development of smart homes has been limited to the field of technology and has not taken advantage of the health science knowledge that is available. It is noteworthy that there is a need to discuss providing smart home solutions and devices with different participants, such as older people, technology experts and healthcare professionals. One reason for this is that this client-centred approach will help older people to remain active and live independently at home by providing what they really need and will use.

The third observation was the *challenges posed by the studies*. One essential issue was the methods used in the studies. Most of the studies were based on a single experiment on a smart home solution or devices, for example where sensors were installed throughout the smart home to monitor older people's physical activities and movement. In addition, the data collection periods were short or the aim was to improve the usability of an existing solution or device. However, long-term monitoring is needed to detect the slight changes that occur in older people and to produce predictions based on those behaviours. Furthermore, combining the data transmitted by sensors can provide a fairly comprehensive analysis of an older people's ability to cope at home, by providing an accurate and objective picture of their movements (Cook et al., 2015; Suryadevara & Mukhopadhyay, 2013) On the other hand, the large amount of sensors that are needed may make such technology costly for the user and researchers. In addition, many of the participants who took part in studies that were based on video images felt that their privacy was violated, even when steps were taken to ensure they could not be identified from footage (Austin et al., 2016; Mehrabian et al., 2014).

Finally, the results showed that recent research on smart homes was technology-oriented. The different solutions that were presented in the studies we reviewed highlighted different technologies, including monitors, sensors, applications and robotics (Alberdi et al., 2018; Lussier et al., 2019).

It is evident that technical professionals have made a lot of decisions about how smart home solutions should be developed. However, it is important for all stakeholders to work together to develop and test different solutions in smart home environments and that this process should respect the way that older people and other stakeholders want their needs to be met (Gaugler et al., 2019; Mehrabian et al., 2014).

It is clear that taking older people's views into account will become ever more important in the future because older people will become increasingly frail in later life due to diseases and disabilities as the population ages. On the other hand, older people are vulnerable when it comes to exercising their right to participate in, and influence decisions, related to living independently at home. However, actively involving healthy older people in research could help researchers to build client-centred solutions that support older people living at home.

5.1 | Limitations

This review had some methodological limitations, which should be considered when evaluating the results. We rigorously identified previous studies by following the PRISMA (2015) process, as outlined in the flow diagram (Figure 1) and the whole review process was conducted with the collaboration of the research group. Despite this, and

the high quality of the databases we used, some relevant articles may have been missed due to the search strategy, inconsistent search terminology, indexing problems or the filters used. In addition, our review did include grey or theoretical literature. However, to reduce these risks, and to improve the validity of the search, we used the broadest possible search terms and considered all potential studies that covered the research topic. In addition, the validity of the search strategies was optimised by consulting an experienced informatician and the studies were selected with the collaboration of all the authors.

Implications for Practice

- Studies of smart homes technology have focused on evaluating daily activities with routine measurements.
- Smart homes can be used to support older people to perform daily activities and help them maintain their social relationships.
- More research on different smart home solutions is needed to improve existing and emerging technical solutions and to understand how they meet the needs and desires of older people.

AUTHOR CONTRIBUTIONS

Study design: RT, AP, MK; Data collection and analysis: RT, AP, MK; and Writing of the manuscript: RT, AP, MK.

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