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Passive Remote Monitoring and Aging in Place: A Scoping Review

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Résumé

La surveillance à distance passive est une technologie relativement nouvelle qui peut aider les personnes âgées à vieillir à domicile et dans leur communauté. Cependant, les connaissances actuelles sur l'efficacité de cette technologie pour accroître l'indépendance des personnes âgées font défaut. Par conséquent, nous avons effectué une revue de la portée des études examinant la télésurveillance passive afin de synthétiser les preuves de l'efficacité de la technologie en tant qu'intervention. Notre recherche initiale dans les bases de données Embase, CINAHL, PubMed et Scopus a identifié 486 articles uniques. Parmi ceux-ci, 14 articles répondaient à nos critères d'inclusion. Les résultats montrent que ces technologies sont utilisées de manière innovante et diversifiée pour aider les personnes âgées vieillissant à domicile et leurs aidants. Des recherches plus approfondies sur ce sujet sont nécessaires.

Abstract

Passive remote monitoring is a relatively new technology that may support older adults to age in place. However, current knowledge about the effectiveness of this technology in extending older adults' independence is lacking. Therefore, we conducted a scoping review of studies examining passive remote monitoring to systematically synthesize evidence about the technology's effectiveness as an intervention. Our initial search of Embase, CINAHL, PubMed, and Scopus databases identified 486 unique articles. Of these, 14 articles met our inclusion criteria. Results show that passive remote monitoring technologies are being used in innovative and diverse ways to support older adults aging in place and their caregivers. More high-quality research on this topic is needed.

Aging in Place

Older adults want to determine where and how they live, with many preferring to live in their own home in the community versus in a care facility (Dalmer, 2019; Iecovich, 2014; Wiles, Leibing, Guberman, Reeve, & Allen, 2012). Aging in place can provide a sense of stability, independence, autonomy, and privacy (Fernandez-Carro, 2016; Hatcher, Chang, Schmied, & Garrido, 2019; Stones & Gullifer, 2016) while potentially reducing health care costs related to residential care (Czaja, 2016; Dalmer, 2019). However, aging in place requires resources, including supports from family and friend caregivers (Abramsson & Andersson, 2016; O'Rourke, Cappeliez, & Guindon, 2003; Pannell, Aldridge, & Kenway, 2012; Wolff et al., 2018). When older adults and their caregivers are not adequately supported, aging in place can create stress, anxiety, and relational tensions (Ahn, 2017; Mittelman, Roth, Clay, & Haley, 2007). Various forms of technology have been developed to provide supports to older adults and their family and friend caregivers.

Technology to Support Aging in Place

Increasingly, technologies have been developed to support older adults to remain living in their own homes. For example, various telehealth technologies have been developed to facilitate older adults' self-management and to record data that health care providers find useful in maintaining the health of their patients, implementing care plans, or determining a diagnosis (Gatto & Tak, 2008; Grant, Rockwood, & Stennes, 2015; Kim, Gollamudi, & Steinhubl, 2017). Wearable technologies include devices worn on the body to activate in the event of an emergency (Blackman et al., 2016) or clothes that contain information-gathering and communication capability such as heart rate, temperature, and movement (Eltis, 2005; Evans et al., 2016; Hanson, Takahashi, & Pecina, 2013). Robots, artificial intelligence, and smart devices can contribute to aging in place through providing social interaction/companionship, safety reminders,

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information, and cleaning (Blackman et al., 2016; Choi, Demiris, & Thompson, 2018; Queirós & da Rocha, 2018). Many of these technologies require active engagement, diligence, and high adherence on the part of the individual being monitored, making them unsuitable for some older adults with mobility and/or cognitive decline, such as patients with advanced Alzheimer's or older adults with multiple illnesses (Kim et al., 2017). Passive remote monitoring (PRM) technologies may thus provide certain advantages.

Passive Remote Monitoring Technologies

PRM technologies involve placing sensors unobtrusively within the home, sending information to health care providers or family/ friend caregivers who can use this information to plan for and provide health care or intervene if necessary (Czaja, 2016; Khosravi & Ghapanchi, 2016). These technologies do not require any actions or input on the part of the person being monitored.

Much of the research on PRM technologies to date has focused on specifics of information system platforms, developing and testing the platforms in pilot projects for function and usability, and investigating the potential of PRM platforms to fill the gaps in health care services (Payandeh & Park, 2020; Wang, 2018). Because of the heterogeneity of research designs, technology involved, and outcomes measured in this area, the evidence of the impacts of in-home PRM technologies, specifically on older adults, their caregivers, and health care and social services, is often difficult to tease out. As the implementation of PRM technologies are advancing very quickly, it is imperative to synthesize current empirical knowledge on the outcomes of these technologies (Berridge, 2019).

Related Systematic Reviews

Systematic reviews have been conducted on technological devices such as wearable sensors (e.g., Baig, Afifi, Gholam, & Mirza, 2019; Majumder, Mondal, & Deen, 2017; Noah et al., 2018) to monitor older adults' health, but our definition of PRM technologies does not include wearable sensors that could be removed by the older person or not activated appropriately. Systematic reviews have also been conducted on smart homes that include monitoring technologies and other technologies to support older adults in their everyday lives to continue living in their own home (Liu, Stroulia, Nikolaidis, Miguel-Cruz, & Rincon, 2016; Turjamaa, Pehkonen, & Kangasniemi, 2019). Lussier et al. (2019) conducted a systematic review specifically on the detection of mild cognitive impairment utilizing in smart home sensors. Smart home technologies do not focus exclusively on PRM technologies and can include technologies that help older adults perform everyday activities.

Study Purpose and Relevance

The purpose of this scoping review was to synthesize research on PRM technology utilized to support community-dwelling older adults and the impact of this technology on older adults, their family and friend caregivers, and the health care system. To our knowledge, there has been no scoping review exclusively on PRM technologies integrated into older adults' homes.

This review makes a timely contribution to the research literature by providing an overview of the current evidence about PRM designed to help older adults live in their homes longer. The results of this scoping review will also be instrumental in identifying gaps in our knowledge and informing future research, including the feasibility of using PRM technology with community-dwelling older adults.

Methods

Design

We conducted a scoping review using the steps outlined by Arksey and O'Malley (2005) and refined by Levac, Colquhoun, and O'Brien (2010). These steps included (1) developing the research question; (2) designing and conducting a search strategy in conjunction with a university librarian with database expertise; (3) selecting relevant studies from the list of retrieved articles, screening first by title, then abstract, then full text; (4) data extraction and charting; and (5) summarizing the studies.

Search Strategy

In consultation with a research librarian, we developed a "decision plan" (Levac et al., 2010) for our search strategy (Table 1). The design of the search strategy was guided by the research question: "What evidence exists about the effects of PRM technologies that support community-dwelling older adults to remain safely in their homes?" The research question was parsed using the elements of Population–Concept–Context (PCC), the methodology recommended by the Joanna Briggs Institute for scoping reviews (JBI, 2015). Search, subject, and MeSH terms were selected for each of these three elements. A search string including these terms was developed and used to search databases. The databases searched were Embase, CINAHL, PubMed, and Scopus. The initial search was conducted in May 2018. A second search was conducted in February 2019 to update the results and include any articles meeting the inclusion criteria that had been published since the initial search. This resulted in the addition of one additional study added to the included studies.

Table 1. Decision plan for developing the search

Element	Category	Search terms	Subject and MeSH terms
Population	Seniors	Senior	65 years
		Older adult	Over 65
		Advanced years	Over 70
		Elder	Over 75
		Geriatric	Over 80
		Later life	Over 85
		Old age	85 years
			Age 80 and over
Context	In-home care	Independent living own-home community dwelling	Independent living activities of daily living
Concept	Passive remote monitoring technologies	Remote monitor	Monitoring, AND physiologic telemedicine

Inclusion criteria

Any peer-reviewed study or dissertation about older adults living in their homes with PRM technology from 2008 until February 2019 in English only.

Exclusion criteria

We did not include review articles, studies about wearable technology, telephone-based care, studies that describe a technology or algorithm (e.g., validation of an AI method or sensor technology), or studies of in-home simulation (e.g., apartments used as labs).

Literature Screening Protocol

A spreadsheet was used to create an article database to conduct article screening by title and abstract. Duplicate articles were identified and removed from the screening process. Screening of articles was conducted in three stages: (1) title screening, (2) abstract screening, and (3) full-text screening. The screening process is detailed in Figure 1.

Following the recommendations of Levac et al. (2010), two reviewers independently screened the articles by title using the inclusion and exclusion criteria. If unsure whether an article should be included based on its title, the reviewers included the article for screening during the next stage. Reviewers' decisions for inclusion of each article in the database were tracked, and discrepancies were flagged and resolved by a third reviewer.

The same process was applied to abstract screening. References of selected articles were searched as well as review articles that were excluded. Another reviewer screened these articles by title and abstract before adding the included articles to the full-text review. At the full-text screening stage, two teams of two reviewers screened articles for relevance by reading the full articles. Independent decisions on each article were compiled in spreadsheets, and one reviewer met with each team to discuss and reconcile discrepancies about inclusion.

Data Extraction and Charting

The review team collectively developed the data charting process, which included selecting and entering data from each included article into a customized spreadsheet. Following the recommendations of Levac et al. (2010), the team first discussed variables to be extracted and developed the data extraction form (Table 2). To test the process, two articles were selected randomly for data extraction by all four reviewers. We then compared our findings for these articles and refined the process to enhance consistency. After this step, two teams of two reviewers were assigned one half of the articles each. Each reviewer independently reviewed the articles and charted the data using the data extraction form. Each pair of reviewers then compared their findings for each article. Where differences were identified, a fifth reviewer went back to the original articles to confirm the correct information was used.

Summarizing the Studies

After charting the data from each study, we collated the results from all team members to create a descriptive numerical summary and synthesize the findings.

Results

Search Results

From an initial 486 unique articles, 14 articles met our inclusion criteria (see Figure 1). Seven articles were quantitative studies, four were qualitative studies, and three used mixed methods to respond to their respective research questions. Of the quantitative articles, one study was a pilot randomized controlled trial (RCT), five were longitudinal observational studies, and one was a pre-post observational study. All four of the qualitative studies used one-on-one interviews, with one using participatory research to develop and test a PRM system for older adults living with dementia and their family/friend caregivers. The mixed methods studies used a
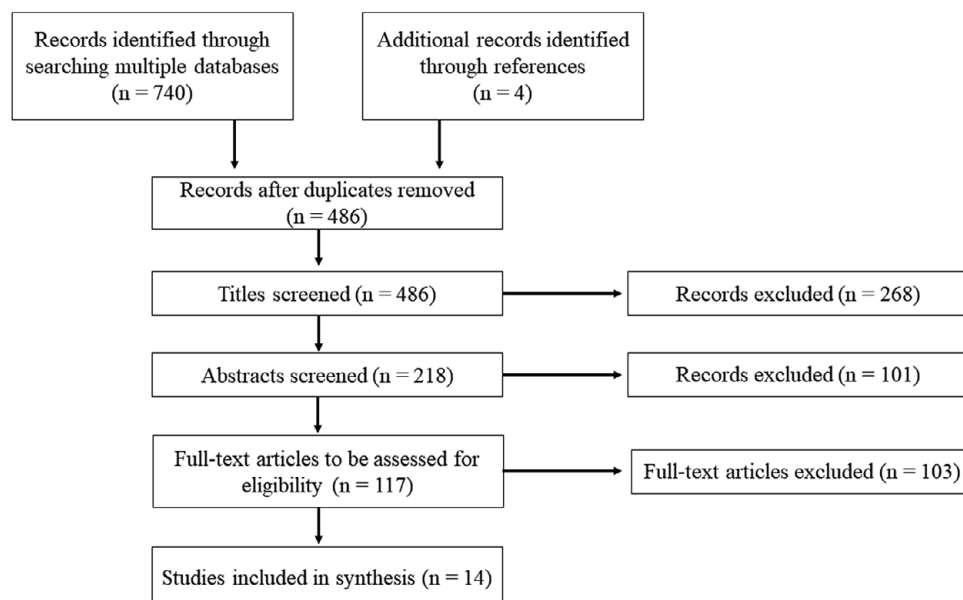

Figure 1. Scoping review screening process.

Table 2. Data extraction template details

Data extraction	Description
Title of article	Title of the article being reviewed
Extractor Initials	Initials of researcher extracting data
Study type	Qualitative, quantitative, mixed methods
Study design (e.g., observational study, RCT)	The methodological/methods of the study
Primary study purpose	The main aims of the study
Additional purposes of study	Secondary aims of the study
Study duration	The time period over which the study happened in weeks
Sample size (*n*)	Total number of participants in the study
Mean age	Average age of participants in the study
Age range	Age range of participants in the study
Gender/sex	Reported gender/sex distribution of participants in the study
Cognitive impairment?	Whether or not any participants in the study had cognitive impairment (Yes/No)
Chronic conditions?	List of chronic conditions that study participants had
Geographical location	The geographical location where the study took place
Setting (home, residential care facility, etc.)	The setting where the participants lived during the study
Rural or urban	How populated the geographical location was
Description of PRM technology used	List of PRM technology(ies) used and how they were used (e.g., bed sensor to assess sleep quality, smart plugs to assess use of appliances)
Description of other types of technology used	List of other technology(ies) used and how they were used (non-PRM) (e.g., tablet with daily measurements)
What passive RM data were collected?	List of variables that were assessed using PRM technology(ies) (e.g., total time in bed awake or asleep)
Who receives PRM data?	Named individuals who were able to view and interpret PRM data collected (as applicable)
Overall intervention description	An overview of the whole intervention that participants experienced
Is the passive remote monitoring technology the intervention or part of the intervention?	Yes/No
Additional intervention(s)? (If yes, describe. If no, state no.)	If applicable, a description of non-PRM interventions that were part of the study
Outcome/dependent variables (quantitative only)	A list of the dependent variables that the study was trying to influence with the intervention
Statistically significant results (quantitative Only)	For studies with a quantitative component, the statistically significant results were listed
Statistically insignificant results (quantitative only)	For studies with a quantitative component, the statistically insignificant results were listed
Themes or key findings (qualitative only)	For studies with a qualitative component the themes/key findings were listed

combination of longitudinal observation, survey, interviews, and case studies (Table 3).

Although the PRM systems in every study collected data about participants, most studies were observational rather than interventional in nature. The observational studies used PRM systems to collect data (i.e., observe client behaviour) but did not initiate any sort of intervention based on the information collected. These studies typically collected data on variables that were likely to predict an adverse health event such as falls, cognitive decline, or institutionalization. Those that used the PRM system as an intervention generally operated by setting conditions that, when met, would trigger an intervention from a third party (e.g., family/friend caregiver or health care team). For instance, Rowe et al. (2009) measured nighttime events for cognitively impaired older adults by using a PRM system that detected when the users were out of bed during certain nighttime hours, waking the in-home caregiver to guide the user back to bed. In the study by Lazarou et al. (2016), participants received tailored, adaptive clinical interventions from

their health care team based on their needs and the observational data continually collected by the PRM system in their home.

The duration of PRM technology use in the home ranged from 4 to 312 weeks. Eight studies were conducted in the United States, two in Germany, and one each in the Netherlands, Japan, Ireland, and Greece. Eight studies were conducted in urban centres; one included both urban and rural settings, and five did not specify whether the context was urban or rural.

Nature of PRM System Configuration

PRM systems in the reviewed articles were determined based on what the investigators wished to understand. Sensor configurations ranged from a single sensor to a large array of sensors, cameras, and other passive monitoring devices (Table 4). PRM system configurations varied significantly in the number of sensors, sensor types, data acquired from systems, and interventions from the systems. The most frequently used sensor type reported in the studies was

Table 3. Characteristics and key findings from included studies

Author, year	Location	Study design	Duration (weeks with PRM)	Sample size	Mean age	Description of passive remote monitoring technology(ies) in home	Key findings
Rowe et al., 2009	United States	Quantitative: Pilot randomized controlled trial	52	53	79.62	Night monitoring system (NMS) which included home security system, infra-red motion sensors, door sensors, and bed sensors.	Reliability of the system and participant satisfaction were high. Overall incidence of injuries and exits was not significantly different between the intervention and control groups. However, use of the system reduced harm during nighttime events and relative risk to participants. Lower likelihood of placement in a facility was associated with daytime events or no events versus nighttime events.
Suzuki & Murase, 2010	Japan	Quantitative: Longitudinal observational study	52	53	80.90	Infrared motion detectors were installed around participants' homes. The information was stored and transferred to a data centre.	Participants who went on frequent outings did not experience any cognitive decline during the study.
Kaye et al., 2011	United States	Quantitative: Longitudinal observational study	115-169	233	83.30	Sensors were of three types: (1) infrared motion detectors; (2) sensor lines for measuring walking speed; and (3) open/closed door sensors on fridge and exit doors.	Participants left their home twice a day on average for a total of 208 min/day. During the study, over half of all participants reported at least one fall, and over one third (35%) reported at least one trip to the hospital or emergency room. Oldest old (>85) were more likely to report a fall event ($p < .01$) and cardiac issues ($p = .03$) compared with the young old.
Van Hoof et al., 2011	Netherlands	Qualitative: interviews	32-92	18	79.20 at first interview ($n = 18$); 80.25 at second interview ($n = 12$)	Motion sensors, door sensors, video cameras, home alarm system/ Unattended Autonomous Surveillance (UAS) system, mobility monitoring, voice response, fire detection/smoke detectors, wandering detection and prevention, and magnetic contacts on doorframes. The system registers how many people are present in the dwelling and in which room a person is located. The system responds when a client is inactive but is predicted to be active.	Ambient intelligence technology can contribute to perceived safety and security. Privacy-related concerns that exist among researchers are not a major concern to users. The system delayed institutionalization for some ($n = 3$) but not others ($n = 5$).
Boise et al., 2013	United States	Quantitative: Pre-post observational study (survey about the technology)	52	119	83	Motion sensors (infrared motion detectors and sensor lines), contact sensors on doors and refrigerators, and computer-use monitor.	72% of participants felt comfortable with accepting monitoring in their homes but 60% reported concerns with monitoring technology. Less than half reported privacy concerns. Most did not like the idea of being video-taped, 20% willing at baseline, 6% at 1-year ($p = 0.04$). Most (72%) were willing to have their data shared with a physician or family member. Worries about personal data in the wrong hands increased from baseline to year 1, both with the cognitively intact and the cognitively impaired groups. Unlike the cognitively intact group, 50% of the cognitively impaired group did not care about being video-taped.

(Continued)

Table 3. *Continued*

Author, year	Location	Study design	Duration (weeks with PRM)	Sample size	Mean age	Description of passive remote monitoring technology(ies) in home	Key findings
Martin et al., 2013	Ireland	Qualitative: Participatory research + 3-month pilot evaluation	13	8	Not reported; participants had early-stage dementia or Alzheimer's disease	NOCTURNAL monitors the activities of participants during the nighttime sleep cycle and provides several automatically triggered therapies, including playing soothing music, showing pictures of loved ones, and guiding participants back to bed through directional lighting.	Overall, participants liked the system, especially its navigability and mobility.
Stone & Skubic, 2013	United States	Quantitative: longitudinal observational cohort study	28	15	67-97 (Mean not reported)	Kinect-based gait analysis system: camera sensor used to monitor gait characteristics in the home.	Continuous, habitual, in home walking speed was stable in most participants and differed from that during performance tests (e.g., TUG test). Results suggest that this system is sensitive to changes in gait that may predict functional improvement (e.g., after rehab) or decline.
Hein et al., 2014	Germany	Mixed methods: survey and longitudinal observational study	20-104	7	66.70	Motion sensors, door sensors (including refrigerator), and computer use monitor.	Sensor data are more useful to caregivers when displayed at various levels of aggregation (visualized) than as raw data. Data from the system objectively confirmed what caregivers subjectively perceived to have occurred. Data from sensors can be mapped directly or indirectly to assessment tools such as the RAI and can detect changes in mobility, health problems, and other behavioural and health changes. The visualizations decreased caregivers' workload.
Marschollek et al., 2014	Germany	Mixed methods: multi-centre longitudinal observational study, survey, and semi-structured interviews	13	14	83.50	Each participant could have up to nine motion detecting sensors placed throughout their home. These included ambient sensors such as door contact switch (up to 3), vibration sensors (up to 3), and motion sensors (up to 3). A mini-computer system with GAL software and a receiver were connected to the computer for storing sensor data.	Technology acceptance was rated very high. No interference with social lives was reported. No one perceived an intrusion into privacy or felt stigmatized by the technology.
Peterson et al., 2014	United States	Quantitative: longitudinal observational study	4	4	Not reported	Pyroelectric motion sensors and motion activated video camera, contact sensors on the refrigerator and doors to home, computer sensors, and phone sensors.	Loneliness and physical activity linked to increased time out of the home.
Thiekle et al., 2014	United States	Quantitative: longitudinal observational study	163	157	84	Infrared motion sensors, research laptop. Participants' most frequented rooms were fitted with sensors. Captured time-stamped walking event data were sent to the laptop.	Low mood was not associated with walking speed, time spent out of residence, room transitions, or computer use. During weeks with low mood, individuals spent 9% (24 minutes) less time out of the house.
Berridge, 2016	United States	Qualitative: interviews	24	20	87	Five motion sensors and a heat sensor. Emergency contacts and social workers receive e-mails summarizing sensor data.	Adoption of technology was low (2%) due to privacy concerns. 20% discontinued use due to privacy concerns.

(Continued)

Table 3. *Continued*

Author, year	Location	Study design	Duration (weeks with PRM)	Sample size	Mean age	Description of passive remote monitoring technology(ies) in home	Key findings
							Social workers able to follow-up based on resident activity captured by RM technology.
Lazarou et al., 2016	Greece	Mixed methods: intervention + case studies	12-16	4	74.25	IP (digital transfer) camera, a bed sleep sensor (measures sleep quality), smart plugs (power consumption sensor for monitoring utility usage), and smart tags (accelerometers to detect object usage).	Improved sleep, physical activity, and activities of daily living.
Berridge et al., 2019	United States	Qualitative: in-depth semi-structured interviews	312	20	Older adults (age not provided)	QuietCare: 5 interconnected sensors (bathroom door, bedroom door, apartment door, refrigerator, and temperature sensor). Family members and social workers can access information about changes in movement/activity.	Immigrant older adults had diverse values, needs, and expectations that influenced their reactions to the PRM system. Results highlight the importance of considering culture and language when designing and implementing PRM systems for older adults.

motion sensors for open spaces ($n = 10$), followed by door sensors (motion sensors that detect doors opening and closing or wireless magnetic contact sensors; $n = 8$), cameras, bed sensors and other sensors ($n = 4$ for each), and smart plugs ($n = 1$). PRM was sometimes combined with wearable ($n = 1$) and active, non-wearable ($n = 3$) technologies. The systems were configured to monitor and record a variety of behaviours, including gait parameters, sleep quality and nighttime activity, time outside of the home, level of daily activity, computer use, ADLs and personal hygiene, and falls and unusual periods of inactivity.

Participants

Research participants ranged from 4 to 233 individuals ranging in age from 49 to 97 years. Eleven of the 14 studies focused exclusively on older adults; one included both older adults and their caregivers, one looked at older adults and their social workers, and one looked primarily at older adults but also included cognitively impaired adults who were not necessarily older. Seven studies included adults with cognitive impairment, and one study included both family/friend caregivers and persons with dementia. The inclusion of caregivers and social workers accounts for the lower bound of the age range of participants (49 years). Eleven studies included both males and females, one study included only females, and two studies did not state the sex of their participants.

Effects of PRM

The included studies investigated the effects of PRM on a wide variety of outcomes ranging from incidence of injuries and falls to older adults' and caregivers' perceptions of safety and privacy. We grouped these outcomes into five main categories: (1) acceptance of PRM, (2) physical health, (3) mental health, (4) requiring higher level of care, and (5) effects on caregivers. Each will be described below, and categories are presented in Table 5.

User acceptance of PRM

Although almost every study ($n = 11$) examined user acceptance of the PRM system employed in their study, this varied considerably across studies, in how it was both conceptualized and measured. Participant satisfaction, perceived safety and security, privacy, technology acceptance, and adoption rate/dropout rate were concepts used by different research teams to get at the idea of participant acceptance of PRM.

Two studies examined participant satisfaction with PRM. Rowe et al. (2009) used the Quebec User Evaluation with Assistive Technology questionnaire (Demers, Weiss-Lambrou, & Ska, 2000) to assess participants' satisfaction with PRM in terms of usability, ease of use, and effectiveness. They found that, on average, users were very satisfied with the nighttime monitoring system used in their study after 7 and 12 months of use. Martin et al. (2013) used a participatory qualitative research design to understand the needs of people with dementia and inform the development of a nighttime monitoring system, which was then tested for three months in participants' homes ($n = 8$). In this study, participant attrition was high because participant-reported dementia disease status was often more advanced than initially stated. However, for those who were able to participate, user acceptance of the PRM was high and several positive themes were identified through one-on-one interviews. These included: promoting independence, maintaining dignity, maximizing social inclusion, managing risk, and providing stimulation.

Table 4. PRM system configurations

	Door sensor	Motion sensor	Bed sensor	Camera	Smart plug	Other sensor	Active, non-wearable	Wearables	Total types of sensors (*n*)
Rowe et al., 2009	X		X						2
Suzuki & Murase, 2010		X							1
Kaye et al., 2011	X	X					X		3
van Hoof et al., 2011	X	X		X		X	X		5
Boise et al., 2013	X	X				X			3
Martin et al., 2013			X						1
Stone & Skubic, 2013				X					1
Hein et al., 2014	X	X	X	X				X	5
Marschollek et al., 2014	X	X							2
Peterson et al., 2014	X	X				X			3
Thiekle et al., 2014		X							1
Berridge, 2016		X							1
Lazarou et al., 2016			X	X	X		X		4
Berridge et al. 2019	X	X				X			3
Total	8	10	4	4	1	4	3	1	

Note: "X" indicates types of technology used in each study.

PRM was perceived as safe and secure by participants in a single qualitative study. Authors van Hoof, Kort, Rutten, and Duijnstee (2011) interviewed 18 older adults in the Netherlands three weeks before or immediately after having a PRM system installed in their home (see Table 4 for configuration of the system). Before installation, respondents expressed a strong desire to age in place and viewed the PRM system as a support tool that would keep them safe and secure. Many participants had already taken the initiative to ensure their safety at home by installing extra locks and/or barred windows to prevent burglary, installing fire detectors, and removing gas cooktops. After installation of the PRM system, most participants reported a heightened sense of safety and security knowing that the system was monitoring them 24/7 and that they would be able to get help if they needed it (e.g., during a fall where they could not get to the phone). However, the technology made one participant feel restless and uneasy, resulting in their having it removed.

The impact of PRM on privacy, as well as the impact of privacy on PRM adoption, was investigated in four studies. In van Hoof et al.'s (2011) study, privacy was only identified as a concern for 1 participant; for the other 17, it was a non-issue. Boise et al. (2013) conducted a longitudinal survey to assess older adults' willingness to share health and activity data with their physician or family members and their concerns about privacy and security after one year of in-home PRM. Of those who were cognitively intact (*n* = 92), 84% (*n* = 77) at baseline and 83% (*n* = 76) at 12 months were receptive to PRM (non-visual monitoring) in their home. For those with mild cognitive impairment (*n* = 27), 92% (*n* = 25) at baseline and 72% (*n* = 19) at 12 months were receptive to PRM in their home. However, responses to people being videotaped at home were quite different. At baseline, only 20% (*n* = 18) of those who were cognitively intact and 45% (*n* =12) of those with mild cognitive impairment were receptive to the idea of videotaped monitoring at home. This dropped to 7% (*n* = 6) and 30% (*n* = 8) for the two groups, respectively, at 12 months. Lastly, participant concerns about privacy with home-based PRM increased over the year of use; 41% (*n* = 38) of the cognitively intact and 32% (*n* = 8) of the mild cognitive impairment groups indicated concerns about their personal privacy at baseline, whereas 52% of both groups reported privacy concerns at 12 months (*n* = 48 and *n* = 12 for cognitively intact and mild cognitive impairment groups, respectively). In contrast, Marschollek et al. (2014) reported that none of their participants felt that their privacy was invaded by the PRM system used in their study, which consisted of door and motion sensors. They also reported that users did not feel stigmatized by having the technology in their homes.

Lastly, Berridge (2016) found that only 20/1,000 (2%) older adults living in independent living residences in an American city were willing to try out the PRM technology; 98% (*n* = 980) rejected it because they felt that it was intrusive and would invade their privacy. In addition, 20% of users (*n* = 5) later discontinued its use for the same reasons. However, some users felt that because there were no cameras involved, their privacy was adequately protected. They also expressed that PRM felt less invasive than having a paid caregiver come into their home and provide personal care. In this care model, social workers were the recipients of residents' data. While social workers felt that it provided them with valuable data to follow-up with residents, they also had to be careful about how they approached residents so that they did not feel like they were "being spied on".

Table 5. Effects of PRM on outcomes by category

Outcome	Studies
User acceptance of PRM	
Participant satisfaction	Martin et al., 2013; Rowe et al., 2009
Perceived safety and security	van Hoof et al., 2011
Privacy	Berridge, 2016; Boise et al., 2013; Marschollek et al., 2014; van Hoof et al., 2011
Technology acceptance	Berridge et al., 2019; Boise et al., 2013; Marschollek et al., 2014
Adoption rate/Drop-out rate	Berridge, 2016
Physical health	
Falls	Kaye et al., 2011; Stone & Skubic, 2013; Tchalla et al., 2012
Physical function/ Physical activity/ADLs	Kaye et al., 2011; Lazarou et al., 2016; Peterson et al., 2014; Stone & Skubic, 2013; Suzuki & Murase, 2010
Sleep	Kaye et al., 2011; Lazarou et al., 2016; Martin et al., 2013; Rowe et al., 2009
Unsafe exits from home	Rowe et al., 2009
Mental health	
Cognitive decline	Suzuki & Murase, 2010
Stigma	Marschollek et al., 2014
Loneliness	Peterson et al., 2014
Mood	Thiekle et al., 2014
Requiring higher level of care	
Delayed institutionalization	Rowe et al., 2009; van Hoof et al., 2011
Trips to hospital/ER	Kaye et al., 2011
Effects on caregivers	
Social workers: improved knowledge and follow-up on client needs	Berridge, 2016
Decreased caregiver workload	Hein et al., 2014

Three studies reported findings about technology acceptance. The findings of Boise et al. (2013) and Marschollek et al. (2014) are reported above. In addition, Berridge, Chan, and Choi (2019) found that cultural values and beliefs had a significant impact on the low acceptance of PRM technology by immigrant older adults in the United States. For example, Russian-born older adults unanimously rejected PRM, citing a preference for "hands-on" care from people rather than "a piece of plastic". Meanwhile, Chinese- and Korean-born older adults expressed a desire not to burden their children by having them receive system alerts; they often accepted the PRM technology reluctantly to please their social worker.

Adoption rate/drop-out rate was reported in one study. As mentioned above, Berridge et al. (2016) reported that only 2% ($n = 20/1000$) of older adults adopted the available PRM system and that 20% ($n = 5$) of adopters eventually discontinued its use due to privacy concerns.

Physical health

More than half (8/14) of the included studies examined the effects of PRM on physical health outcomes (Kaye et al., 2011; Lazarou et al., 2016; Martin et al., 2013; Petersen, Austin, Kaye, Pavel, & Hayes, 2014; Rowe et al., 2009; Stone & Skubic, 2013; Suzuki & Murase, 2010; Tchalla et al., 2012; Thielke et al., 2014). Outcomes studied included falls, physical function and ADLs, physical activity, sleep, and unsafe exits from one's home.

Three studies examined the incidence and outcome of falls using PRM. Kaye et al. (2011) found that 56% ($n = 130$) of participants reported having at least one fall over the year-long study. Falls were self-reported weekly (not measured by the PRM system) and were significantly associated with older age. No associations were tested between falls and other data collected by the PRM system. Stone and Skubic (2013) examined the feasibility, validity, and reliability of assessing fall risk using continuous in-home gait monitoring with the Microsoft Kinect camera and conducted gait analysis with the collected video data. These results showed that, for most people, gait analysis of the video data was comparable to validated physical performance tests that assess fall risk: the habitual gait speed (HGS) test and the timed up and go (TUG) test. However, there were certain situations, such as apartments with limited walking spaces and individuals with limited mobility, that reduced the effectiveness of the analysis. Tchalla et al. (2012) focused on reducing falls at night by using a motion sensor-activated light path that was activated when the participant would get out of bed. This intervention was shown to significantly decrease fall risk among community-dwelling older adults. In total, the proportion of falls at home was 9.6% for the intervention group ($n = 94$) and 25% for the control group ($n = 96$).

Physical function and physical activity were examined in a handful of studies. Kaye et al. (2011) used sensors to measure walking speed, consistent periods away from the home, computer use, and where participants spent their time within their home.

Participants, on average, left their home twice/day for almost two hours (108 minutes) total time. As noted above, Stone and Skubic (2013) used PRM to assess gait as a way to measure fall risk. Thielke et al. (2014) used PRM to assess walking speed, time spent out of residence, and room transitions. In another study, Lazarou et al. (2016) conducted a tailored, iterative intervention for four older adults with cognitive impairment. In this study, the PRM system collected data, which were then used to inform tailored weekly visits, interventions, and progress updates. The results showed that after the 12- to 16-week intervention, participants experienced significant improvements in moving intensity and ADLs, including bathroom and kitchen presence, as well as reduced time sitting and watching TV. An important finding in this study was that increased moving intensity resulted in longer durations of deep sleep and total sleep.

Few studies used PRM to assess the relationship between physical activity and psychosocial outcomes. For example, Peterson et al. (2014) used PRM to examine the relationship between loneliness and physical activity among older adults. They found that time spent out of the house was not an accurate measure of self-reported physical activity and that it was negatively correlated with loneliness ($r = -0.44$, $p = 0.01$). In another study, Suzuki and Murase (2010) investigated the association between daily activity and cognitive decline. Results indicated that cognitive decline was significantly associated with fewer outings (8.8 vs. 17.3).

Sleep and nighttime activity were other important physical health outcomes addressed in several studies. Three of these involved PRM-enabled sleep interventions. In 2009, Rowe et al. tested a night-monitoring system designed to reduce nighttime injuries and unsafe home exits in persons with dementia. Once motion detectors were activated, the system would alert a designated caregiver, which would allow the caregiver to wake up and assist the older adult. The results showed that when the system was in use, older adults were less likely to sustain an injury or leave their home at night. Another nighttime monitoring system called NOC-TURNAL was developed by Martin et al. (2013), using a participatory research design with people with dementia and their caregivers. This highly customizable tablet-based platform could be linked to a variety of sensors and allowed older adults and their caregivers to monitor the older adults' nighttime behaviours and create tailored triggers to address them (e.g., lighting, music, photographs). Qualitative results suggested that both older adults and their family/friend caregivers felt comforted by having the system in place. It was unclear whether it improved sleep or reduced nighttime events. Lastly, sleep interventions were common in the Lazarou et al. (2016) study that used PRM data to inform and adapt tailored interventions for study participants. All four participants had problems with their sleep at the beginning of the study and experienced improvements in their sleep as a result of the sleep data (total sleep time, time spent in different stages of sleep, sleep interruptions, and time spent awake in bed) generated from the PRM system and used by health care providers to develop effective interventions.

Mental health

Mental health variables investigated in the included studies included cognitive decline, loneliness, and mood (Marschollek et al., 2014; Petersen et al., 2014; Suzuki & Murase, 2010; Thielke et al., 2014). As discussed previously, Suzuki and Murase (2010) found that older adults who went on more outings were less likely to experience cognitive decline. PRM sensors were used to measure outings. Similarly, Petersen et al. (2014) found that older adults

who left their home more often were less likely to report experiencing loneliness. Finally, Thielke et al. (2014) found that during weeks when participants reported low mood, they spent significantly less time out of their residence with no changes in physical activity parameters within the home (e.g., walking speed).

Requiring higher level of care

Two studies measured variables related to requiring a higher level of care (Kaye et al., 2011; van Hoof et al., 2011). In the qualitative study by van Hoof et al. (2011), older adults consistently expressed a strong desire to age in place and perceived PRM as a support tool that could help them avoid going to a nursing home. Kaye et al. (2011) reported that 35% ($n = 82$) of the participants in their study reported at least one trip to the hospital or emergency room during their study. There was no control group in this study and hospital/ER usage was not associated with use of the PRM system.

Effects on caregivers

Some studies provided evidence that PRM systems had significant implications for both formal and family/friend caregivers of older adults. For example, social workers reported that having data from PRM improved their knowledge of clients' needs, allowing more efficient follow-up care with older adults (Berridge, 2016). However, as discussed, the social workers were attuned to participants' privacy concerns and felt that they needed to be cautious in appearing too knowledgeable about participants' needs and thoughtful in their approach to providing participant care. Hein et al. (2014) found that paid caregivers' perceived workload decreased when they had access to PRM data about their clients. Similarly, in the Lazarou et al. (2016) study, family/friend caregivers reported that having access to older adults' data through a computer dashboard provided them with a great sense of relief and comfort. They also reported that this particular intervention had significantly improved the health and well-being of their family member/friend, resulting in decreased stress, improved sleep, and quality of life for themselves as well.

Discussion

The findings from this scoping review reveal very limited research about the effects of PRM technology used in older adults' homes to support aging in place. Most of the studies investigated the use of door and motion sensors, with less focus on other types of PRM technologies. Thus, questions remain about their impact. Significant variability was found in the aims, techniques, and system configurations employed across studies. This is likely the result of both the relative novelty of PRM technology and the limited degree of customization possible with more traditional health technologies or services. In addition, there was significant variation in research design, outcomes of interest, and measurement of outcomes across the included studies. This heterogeneity makes it challenging to compare systems and their effects on older adults and their caregivers, and highlights the appropriateness of conducting a scoping review, rather than a systematic review, to explore the research conducted in this area to date. Our findings are consistent with others' that identified the need for larger studies that (1) are conducted by interdisciplinary research teams, (2) are theory-informed intervention studies, (3) seek longitudinal findings, (4) investigate an intersection of relevant outcomes, and (5) provide insight into the cost-benefits (financial, social, physical) of technology-enabled care (Liu et al., 2016; Noah et al., 2018; Schulz et al., 2015). These

strategies need to be considered against the research challenges of participant recruitment, the short lifespan of technologies, limited insight regarding data collection, data ownership, and privacy concerns regarding commercial technology devices/systems (Liu et al., 2016; Noah et al., 2018; Schulz et al., 2015). This is an evolving field, and we anticipate that new and innovative forms of technology will continue to be available and need to be evaluated.

Although the amount of research is limited, we identified some important findings related to older adults' acceptance of PRM systems. Older adults were more likely to accept home monitoring with systems that were perceived as safeguarding their privacy by not including video functions. This is consistent with the adoption of the technology model for remote monitoring of elders' daily activities proposed by Mahoney (2011). Within this model, loss of privacy/intrusiveness is identified as a key barrier to use while individuals' innovativeness/readiness to adopt PRM technologies is an important pre-disposing factor. Our findings also offer insight into successful PRM implementation strategies that allow increased familiarity of the technologies among older adults, which in turn increased older adults' acceptance and appreciation (i.e., perceived safety) of the technology. For example, Martin et al. (2013) included older adults with dementia or Alzheimer's disease and their caregivers in the intervention design process, an approach that is both client-centred and makes adoption more likely.

There were several topics that were not well addressed by the studies in this scoping review. For example, the studies reviewed took place in urban contexts and none looked at the difference between rural health care and urban health care as they relate to PRM. The importance of this divide is that PRM systems may not be feasible in rural contexts depending on the system, its degree of connectivity, and the infrastructure that exists in a given rural context. The difference is also important for how rural community-dwelling adults interact with technologies such as PRM systems compared with their urban counterparts. Therefore, any discussion of feasibility across a broad region needs to address these issues.

In a similar vein, the research by Berridge (2016) and Berridge et al. (2019) highlighted an absence of the examination of the effects of cultural and economic backgrounds on the acceptance and feasibility of PRM technology. While these studies provided important information about how immigrant and low-income older adults see PRM technology, their studies show that numerous circumstances of older adults are likely to impact acceptability and these circumstances ought to be given more consideration in research design and as a research focus. Future research should examine how the design and implementation of home-based PRM technology impacts: (1) diverse populations, (2) across old-age cohorts, (3) those living alone or with limited social supports, and (4) users' experience among the care team (i.e., older adults, family caregivers, home support workers, clinicians) (Liu et al., 2016; Noah et al., 2018). Among other important insights, the coronavirus disease (COVID-19) pandemic has called attention to the importance of technology across multiple care settings; the use of PRM among isolated (or quarantined) older adults constitutes important future research.

Overall, most of the studies looked at the impact of PRM technologies on client outcomes. Far fewer examined the impact of PRM systems on family/friend caregivers, health care providers, and the health system. The presence of family/friend caregivers is key to whether older adults with complex care needs can remain in their own home (Health Council of Canada, 2012; Williams et al., 2014). Yet this role can create increased risk of physical health problems, stress, burnout, and depression (Williams et al., 2014). While limited, the findings in this review point to PRM contributing to decreased stress among family/friend caregivers. Research is needed to explore the impact of home-based PRM systems on health care providers. Significant privacy, practice, and policy issues need to be considered for individuals providing care in clients' homes. Similarly, there were no studies that conducted a cost analysis to consider the impact of PRM systems on health care utilization and long-term care placement. Evidence of the cost-effectiveness of PRM systems is recommended for inclusion in future research, as it will inform individual, family, and government decisions about implementation and scale-up of PRM systems within the home care setting.

One limitation of our study was that it was conducted in English only. We also included only studies that used PRM technologies in older adults' homes. Therefore, it is possible that there is evidence about PRM technologies in other settings with different populations that are important but outside the scope of the current study. In addition, there is a diverse range of terms used to refer to PRM technology, so while we included as many terms as possible in our search strategy, it is possible that we did not include all of them.

Conclusion

PRM technologies are being used in innovative and diverse ways to support older adults aging in place and their caregivers. Our findings show that there is a need for more high-quality research on this topic. In particular, longitudinal and/or intervention studies examining the impacts of PRM technologies on both users (older adults and caregivers) and health systems are recommended avenues of future research.

References

Abramsson, M., & Andersson, E. (2016). Changing preferences with aging–housing choices and housing plans of older people. *Housing, Theory and Society*, **33**(2), 217–241.

Ahn, M. (2017). Introduction to special issue: Aging in place. *Housing and Society*, **44**(1–2), 1–3. https://doi.org/10.1080/08882746.2017.1398450.

Arksey, H., & O'Malley, L. (2005). Scoping studies: Towards a methodological framework. *International Journal of Social Research Methodology*, **8**(1), 19–32.

Baig, M. M., Afifi, S., Gholam, H., & Mirza, F. (2019). A systematic review of wearable sensors and IoT-based monitoring applications for older adults—A focus on aging population and independent living. *Journal of Medical Systems*, **43**(8), 1–11. https://doi.org/10.1007/s10916-019-1365-7.

Berridge, C. (2016). Breathing room in monitored space: The impact of passive monitoring technology on privacy in independent living. *The Gerontologist*, **56**(5), 807–816.

Berridge, C. (2019). Monitoring the monitors: Medicaid integration of passive remote monitoring technology. *Journal of Gerontological Social Work*, **62**(4), 377–383. https://doi.org/10.1080/01634372.2019.1606872.

Berridge, C., Chan, K. T., & Choi, Y. (2019). Sensor-based passive remote monitoring and discordant values: Qualitative study of the experiences of low-income immigrant elders in the United States. *JMIR mHealth and uHealth*, **7**(3), e11516.

Blackman, S., Matlo, C., Bobrovitskiy, C., Waldoch, A., Fang, M. L., Jackson, P., *et al.* (2016). Ambient assisted living technologies for aging well: A scoping review. *Journal of Intelligent Systems*, **25**(1), 55–69.

Boise, L., Wild, K., Mattek, N., Ruhl, M., Dodge, H. H., & Kaye, J. (2013). Willingness of older adults to share data and privacy concerns after exposure to unobtrusive in-home monitoring. *Gerontechnology*, **11**(3), 428.

Choi, Y., Demiris, G., & Thompson, H. (2018). Feasibility of smart speaker use to support aging in place. *Innovation in Aging*, **2**(suppl_1), 560.

Czaja, S. J. (2016). Long-term care services and support systems for older adults: The role of technology. *American Psychologist*, **71**(4), 294–301. https://doi.org/10.1037/a0040258.

Dalmer, N. K. (2019). A logic of choice: Problematizing the documentary reality of Canadian aging in place policies. *Journal of Aging Studies*, **48**, 40–49.

Demers, L., Weiss-Lambrou, R., & Ska, B. (2000). Item analysis of the Quebec user evaluation of satisfaction with assistive technology (QUEST). *Assistive Technology*, **12**(2), 96–105.

Eltis, K. (2005). Predicating dignity on autonomy: The need for further inquiry into the ethics of tagging and tracking dementia patients with GPS technology. *Elder Law Journal*, **13**, 387–416.

Evans, J., Papadopoulos, A., Silvers, C. T., Charness, N., Boot, W. R., Schlachta-Fairchild, L., *et al.* (2016). Remote health monitoring for older adults and those with heart failure: Adherence and system usability. *Telemedicine and e-Health*, **22**(6), 480–488.

Fernandez-Carro, C. (2016). Aging at home, co-residence or institutionalisation? Preferred care and residential arrangements of older adults in Spain. *Aging and Society*, **36**(3), 586–612. https://doi.org.proxy.hil.unb.ca/10.1017/S0144686X1400138X.

Gatto, S. L., & Tak, S. H. (2008). Computer, internet, and e-mail use among older adults: Benefits and barriers. *Educational Gerontology*, **34**(9), 800–811.

Grant, L. A., Rockwood, T., & Stennes, L. (2015). Client satisfaction with telehealth services in home health care agencies. *Journal of Telemedicine and Telecare*, **21**(2), 88–92.

Hanson, G. J., Takahashi, P. Y., & Pecina, J. L. (2013). Emerging technologies to support independent living of older adults at risk. *Care Management Journals*, **14**(1), 58–64.

Hatcher, D., Chang, E., Schmied, V., & Garrido, S. (2019). Exploring the perspectives of older people on the concept of home. *Journal of Aging Research*, **2019**, 2679680. https://doi.org/10.1155/2019/2679680.

Health Council of Canada. (2012). *Seniors in need, caregivers in distress: What are the home care priorities for seniors in Canada?*. Toronto: Government of Canada. http://www.carp.ca/wp-content/uploads/2012/04/HCC_HomeCare_2d.pdf.

Hein, A., Steen, E. E., Thiel, A., Hülsken-Giesler, M., Wist, T., Helmer, A., *et al.* (2014). Working with a domestic assessment system to estimate the need of support and care of elderly and disabled persons: Results from field studies. *Informatics for Health and Social Care*, **39**(3–4), 210–231.

Iecovich, E. (2014). Aging in place: From theory to practice. *Anthropological Notebooks*, **20**(1), 21–33.

Joanna Briggs Institute [JBI]. (2015). *Methodology for JBI scoping reviews*. The Joanna Briggs Institute: The University of Adelaide, Adelaide, SA, Australia.

Kaye, J. A., Maxwell, S. A., Mattek, N., Hayes, T. L., Dodge, H., Pavel, M., *et al.* (2011). Intelligent systems for assessing aging changes: Home-based, unobtrusive, and continuous assessment of aging. *Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, **66**(suppl_1), i180–i190.

Khosravi, P., & Ghapanchi, A. H. (2016). Investigating the effectiveness of technologies applied to assist seniors: A systematic literature review. *International Journal of Medical Informatics*, **85**(1), 17–26.

Kim, K. I., Gollamudi, S. S., & Steinhubl, S. (2017). Digital technology to enable aging in place. *Experimental Gerontology*, **88**, 25–31.

Lazarou, I., Karakostas, A., Stavropoulos, T. G., Tsompanidis, T., Meditskos, G., Kompatsiaris, I., *et al.* (2016). A novel and intelligent home monitoring system for care support of elders with cognitive impairment. *Journal of Alzheimer's Disease*, **54**(4), 1561–1591.

Levac, D., Colquhoun, H., & O'Brien, K. K. (2010). Scoping studies: Advancing the methodology. *Implementation Science*, **5**(1), 69.

Liu, L., Stroulia, E., Nikolaidis, I., Miguel-Cruz, A., & Rincon, A. R. (2016). Smart homes and home health monitoring technologies for older adults: A systematic review. *International Journal of Medical Informatics*, **91**, 44–59.

Lussier, M., Lavoie, M., Giroux, S., Consel, C., Guay, M., Macoir, J., *et al.* (2019). Early detection of mild cognitive impairment with in-home monitoring sensor technologies using functional measures: A systematic review. *IEEE*

Journal of Biomedical and Health Informatics, **23**(2), 838–847. https://doi.org/10.1109/JBHI.2018.2834317.

Mahoney, D. F. (2011). An evidence-based adoption of technology model for remote monitoring of elders' daily activities. *Ageing International*, **36**(1), 66–81.

Majumder, S., Mondal, T., & Deen, M. J. (2017). Wearable sensors for remote health monitoring. *Sensors*, **17**(1), 130. https://doi.org/10.3390/s17010130.

Marschollek, M., Becker, M., Bauer, J. M., Bente, P., Dasenbrock, L., Elbers, K., *et al.* (2014). Multimodal activity monitoring for home rehabilitation of geriatric fracture patients—Feasibility and acceptance of sensor systems in the GAL-NATARS study. *Informatics for Health and Social Care*, **39**(3–4), 262–271.

Martin, S., Augusto, J., McCullagh, P., Carswell, W., Zheng, H., Wang, H., *et al.* (2013). Participatory research to design a novel telehealth system to support the night-time needs of people with dementia: NOCTURNAL. *International Journal of Environmental Research and Public Health*, **10**(12), 6764–6782.

Mittelman, M. S., Roth, D. L., Clay, O. J., & Haley, W. E. (2007). Preserving health of Alzheimer caregivers: Impact of a spouse caregiver intervention. *The American Journal of Geriatric Psychiatry*, **15**(9), 780–789.

Noah, B., Keller, M. S., Mosadeghi, S., Stein, L., Johl, S., Delshad, S., *et al.* (2018). Impact of remote patient monitoring on clinical outcomes: An updated meta-analysis of randomized controlled trials. *NPJ Digital Medicine*, **1**(1), 1–12.

O'Rourke, N., Cappeliez, P., & Guindon, S. (2003). Depressive symptoms and physical health of caregivers of persons with cognitive impairment: Analysis of reciprocal effects over time. *Journal of Aging and Health*, **15**(4), 688–712.

Pannell, J., Aldridge, H., & Kenway, P. (2012). *Market assessment of housing options for older people*. London, UK: New Policy Institute.

Payandeh, S., & Park, J. (2020). Passive observer of activities for aging in place using a network of RGB-D sensors. *International Journal of Telemedicine and Applications*, **2020**, Article ID 8867926. https://doi.org/10.1155/2020/8867926.

Petersen, J., Austin, D., Kaye, J. A., Pavel, M., & Hayes, T. L. (2014). Unobtrusive in-home detection of time spent out-of-home with applications to loneliness and physical activity. *Journal of Biomedical and Health Informatics*, **18**(5), 1590–1596.

Queirós, A., & da Rocha, N. P. (2018). Ambient assisted living: Systematic review. In A. Queirós, & N. Rocha (Eds.), *Usability, accessibility and ambient assisted living*. Human–Computer Interaction Series. Switzerland, AG: Springer Nature.

Rowe, M. A., Kelly, A., Horne, C., Lane, S., Campbell, J., Lehman, B., *et al.* (2009). Reducing dangerous nighttime events in persons with dementia by using a nighttime monitoring system. *Alzheimer's & Dementia*, **5**(5), 419–426.

Schulz, R., Wahl, H. W., Matthew, J. T., DeVito, A., Beach, S. R., Czaja, S. J. (2015). Advancing the aging and technology agenda in gerontology. *The Gerontologist*, **55**(5), 724–734.

Stone, E. E., & Skubic, M. (2013). Unobtrusive, continuous, in-home gait measurement using the Microsoft Kinect. *Transactions on Biomedical Engineering*, **60**(10), 2925–2932.

Stones, D., & Gullifer, J. (2016). 'At home it's just so much easier to be yourself': Older adults' perceptions of aging in place. *Aging and Society*, **36**(3), 449–481.

Suzuki, T., & Murase, S. (2010). Influence of outdoor activity and indoor activity on cognition decline: Use of an infrared sensor to measure activity. *Telemedicine and e-Health*, **16**(6), 686–690.

Tchalla, A. E., Lachal, F., Cardinaud, N., Saulnier, I., Bhalla, D., Roquejoffre, A., *et al.* (2012). Efficacy of simple home-based technologies combined with a monitoring assistive center in decreasing falls in a frail elderly population (results of the Esoppe study). *Archives of Gerontology and Geriatrics*, **55**(3), 683–689.

Thielke, S. M., Mattek, N. C., Hayes, T. L., Dodge, H. H., Quiñones, A. R., Austin, D., *et al.* (2014). Associations between observed in-home behaviors and self-reported low mood in community-dwelling older adults. *Journal of the American Geriatrics Society*, **62**(4), 685–689.

Turjamaa, R., Pehkonen, A., & Kangasniemi, M. (2019). How smart homes are used to support older people: An integrative review. *International Journal of Older People Nursing*, **14**(4), e12260. https://doi.org/10.1111/opn.12260.

van Hoof, J., Kort, H. S. M., Rutten, P. G. S., & Duijnstee, M. S. H. (2011). Aging-in-place with the use of ambient intelligence technology: Perspectives of older users. *International Journal of Medical Informatics*, **80**(5), 310–331.

Wang, J. (2018). Mobile and connected health technologies for older adults aging in place. *Journal of Gerontological Nursing*, **44**(6), 3–5. https://doi.org/10.3928/00989134-20180509-01.

Wiles, J. L., Leibing, A., Guberman, N., Reeve, J., & Allen, R. E. (2012). The meaning of "aging in place" to older people. *The Gerontologist*, **52**(3), 357–366.

Williams, A. P., Peckham, A., Watkins, J., Warrick, N., Tam, T., Rudoler, D., *et al.* (2014). Caring for caregivers: Facing up to tough challenges. *Healthcare Quarterly*, **17**(3), 20–23.

Wolff, J. L., Mulcahy, J., Huang, J., Roth, D. L., Covinsky, K., & Kasper, J. D. (2018). Family caregivers of older adults, 1999–2015: Trends in characteristics, circumstances, and role-related appraisal. *The Gerontologist*, **58**(6), 1021–1032.