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The Effectiveness of Smart Home Technologies to Support the Health Outcomes of Community-Dwelling Older Adults Living with Dementia: A Scoping Review

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Highlights

- Limited readiness of smart home technology
- The effectiveness of smart home technologies is not clear
- Difficulty in evaluating smart home technologies in real-life

Abstract

Objectives: To map the current state-of-knowledge about the effectiveness of smart home technologies to support the health outcomes of community-dwelling older adults living with dementia. **Design:** A scoping review following the methodological frameworks described by Arksey and O'Malley (2005) and Levac et al. (2010). **Data sources:** Electronic databases and online sources were searched in April 2020 using database specific medical subject headings and keywords about 'smart homes' and 'dementia'. **Methods:** Empirical peer-reviewed articles were included if they were written in English; used a quantitative, qualitative, or mixed method design; and presented the effects of a smart home technology on the health outcomes of community-dwelling adults living with dementia. Methodological and reporting quality of studies was assessed using the Mixed Methods Appraisal Tool – Version 2018. **Results:** Five studies described evaluations of five smart home technology systems with a total of $n = 617$ community-dwelling people living with dementia. Collectively, studies showed potential effectiveness of the technologies on a range of health outcomes (physical activity, activities of daily living, sleep, anxiety, depression, agitation, irritability, risk of falls, cognitive functioning, night-time injury, unattended home exits). However, the overall methodological and reporting quality of studies was low and profiled a research field lacking in rigorous evaluation. **Conclusions:** Based on current evidence, the success of smart home technologies to support people with dementia to live at home remains unclear. Recommendations are provided to inform future research into smart home technologies for community-based dementia care.

Key words: ambient intelligence, Alzheimer disease, independent living, health-related quality of life, technology

1. Introduction

A diagnosis of dementia, including Alzheimer's disease, and the associated increase in physical and psychological care support needs are well-known predictors of long-term care (LTC) admission [1, 2]. However, a recent shift in ageing and aged care policy worldwide has seen focus move towards 'ageing in place' and initiatives that help people with dementia to remain living in their own homes for longer [3]. A range of research has been undertaken in this regard, and a number of dementia-specific programs have demonstrated success in avoiding or delaying admission to LTC [4]. The particular role of affordable and appropriate technology within dementia care has also been highlighted [5], and the development and application of smart home technologies has been at the forefront of much research effort [6, 7].

Broadly, smart home technologies refer to a varied and ever-growing group of devices and appliances within a home environment that are interconnected, via the internet, for automatic and remote control to enhance the home living experience. More specifically, smart homes have been classified into five hierarchical types based on the home containing the following technology [8]: 1. Stand-alone applications and objects that operate in an intelligent way (e.g., smart locks, home security systems); 2. Connected wire or wireless intelligent applications and objects that share information with each other (e.g., sensors, smart home hubs, controllers); 3. Remote, interactive, and automatic systems that rely on internal and external networks from within and outside the home and can involve discreet data collection (e.g., ubiquitous or connected homes); 4. Technologies described in the previous categories, but whereby the data collected is used to tailor the technology to the future needs of the home owner for particular aspects of the home (e.g., learned home); and 5. Technologies that are able to constantly collect data and record activity patterns throughout the home in order to control for future needs of the home owner (e.g., attentive home).

When looking at the application of different smart home technologies for community-dwelling people living with dementia, there are evident opportunities for use across the trajectory of the disorder, from diagnostic assessment to long-term and tailored care management [6]. For this reason, a considerable number of individual studies have documented the development and use of smart home technologies within older populations and people with dementia specifically [9]. Nevertheless, the research field as a whole has been hindered by poor methodological quality, inadequate reporting, and limited readiness of the technology for real-world application [e.g., 9, 10-12]. Further, the dearth of studies testing actual effectiveness has prevented valid conclusions to be drawn across research projects [9] and, as yet, the success of smart home technologies to help people with dementia to live at home remains unclear [11].

Considering the dynamic and accelerating landscape of technology development for healthcare, as well as the amount of known work being conducted into the application of smart home technologies and dementia, it is imperative that extant studies be collectively reviewed for effectiveness of purpose. To this end, the current scoping review aims to provide an up-to-date overview of the state-of-knowledge about the effectiveness of smart home technologies to support the health outcomes of community-dwelling older adults living with dementia. The study is guided by the broad exploratory research question: *Do smart home technologies help support older adults with dementia to remain living at home?* It also seeks to answer four targeted research questions that were formulated after undertaking a series of initial searches: 1. *What type of smart home technologies are used?* 2. *What health outcomes do smart home technologies target?* 3. *What evidence is there for the effectiveness of smart home technologies to support the health outcomes of people living with dementia living at home?* and 4. *What is the quality of the current evidence-base?*

2. Method

2.1. Design

The study employed a scoping review framework that followed the five stages described by Arksey and O'Malley [13] and Levac et al. [14]: determining the research questions; identifying studies; selecting studies; charting study data; and synthesising and summarising results. Scoping reviews are particularly useful when mapping knowledge on a research area that has been limited previously by a lack of randomised controlled trial (RCT) evidence [13, 14]; and when examining the extent, range, and nature of a research area to help identify gaps in knowledge and guide future research and practice [13, 14]. Given the known paucity of RCTs involving smart home technologies for healthcare, and our aim of providing a state-of-knowledge update on the field, we therefore considered the scoping review the most appropriate method to appraise the literature.

2.2. Eligibility Criteria

Eligibility criteria for study selection were developed using an adapted Population-Intervention-Comparison-Outcome framework [15, 16]. We included empirical studies that were written in the English language and published in a peer-reviewed journal or conference proceeding; had qualitative, quantitative, or mixed method research designs; described a smart home technology intervention undertaken in a home environment (i.e., personal residence) with community-dwelling older adults who lived either alone or with others (such as family members) and had dementia; and measured the effects of the smart home technology on health outcomes for the person with dementia such as, but not limited to, health-related quality of life (i.e., physical, mental, emotional, social functioning), wellbeing (i.e., life satisfaction, positive emotions), and healthcare use and costs (i.e., admission to acute care, LTC).

2.3. Search Strategy

To identify peer-reviewed published empirical studies, we searched seven electronic databases on April 20, 2020: MEDLINE; CINAHL; EMBASE; PsycINFO; Cochrane Library; Web of Science; and The Joanna Briggs Institute EBP Database. Searches were limited to articles written in English and involving human participants only; we applied no date restrictions. We developed the search terms via an iterative process, with various combinations of database specific medical subject headings and keywords tested for accuracy. The final terms used in searches of titles and abstracts are shown in Table 1 and the search strategy for each database can be found in the online Supplementary Material. We then hand-searched the reference lists of all eligible studies and ran a search in Google Scholar to identify relevant onward citations of all eligible studies. Our search also identified 30 literature reviews of smart homes of various foci, and we assessed the included articles within each for eligibility in our study. As a final step, we also hand-searched the individual websites of key journals and organisations.

Table 1

Medical subject headings (MeSH) and keywords used in the searches

#	MeSH (in subject headings)	Key words (in title and abstract)
#1	("wireless technology" OR "technology") **OR**	("smart home*" OR "smart home technolog*" OR "smart home system*" OR "smart living environment*" OR "home automation" OR "home automation system*" OR "automated home*" OR "intelligent system*" OR "intelligent home*" OR "ubiquitous home*" OR "ubiquitous environment*" OR "wireless home*" OR "wireless home* network*" OR "dometic*" OR "ambient assisted living" OR "home monitoring" OR "home monitoring technology" OR "monitoring system*")
#2	("dementia" OR "cognitive dysfunction") **OR**	("dementia" OR "Alzheimer* disease" OR "dementia care" OR "cognitive* impair*")
#3		Search #1 **AND** Search #2

2.4. Study Selection

Articles retrieved during the searches were exported into Endnote X9 (Clarivate Analytics, Philadelphia, PA, USA). After duplicates were removed, the second author independently screened the titles and abstracts of studies against the inclusion criteria. The first and second author then independently assessed the full texts of the shortlisted articles and agreed on the inclusion/exclusion of all 49 articles (Figure 1).

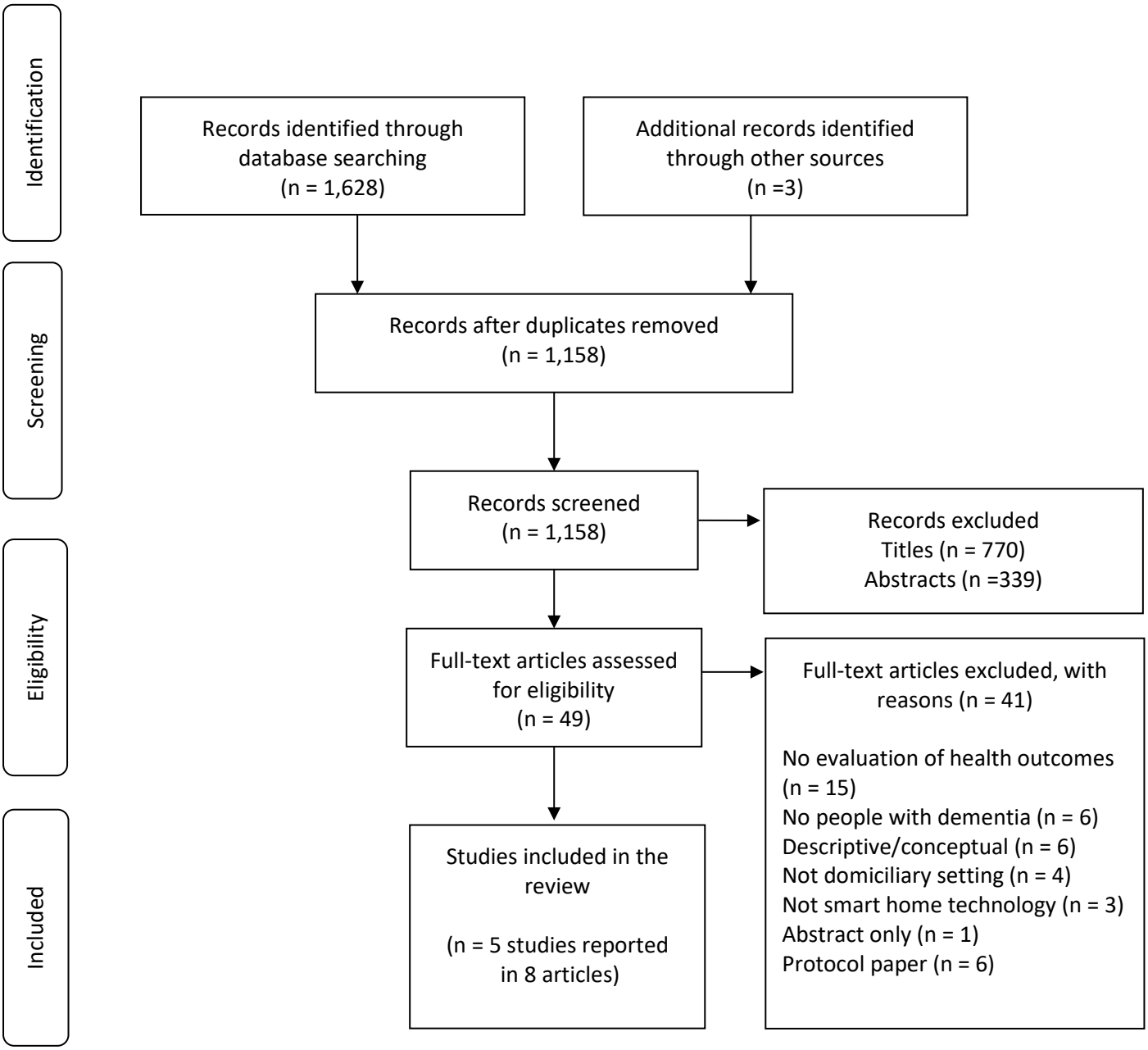

Figure 1

Study search and selection process

2.5. Assessment of Study Quality

The focus of a scoping review is on mapping the breadth and depth of a research area and, therefore, it is not typical for the quality of studies to be assessed [13, 14]. However, as outlined, we know that inadequate study design and poor quality reporting has hindered

understanding about effectiveness to-date [9, 11, 12]. Building on these reviews, we have therefore chosen to specifically explore study quality as a research question, and we assessed the methodological and reporting quality of all included studies using the Mixed Methods Appraisal Tool (MMAT) – Version 2018 [17]. This tool is commonly used in literature reviews of qualitative, quantitative, and mixed method studies, and has been updated in 2018 for enhanced content validity [18, 19]. Authors two and three independently completed this assessment, rating each included study against the MMATs prescribed criteria relevant to study design. The two authors then verbally discussed their appraisals and reached consensus on an overall assessment of quality for each study (online Supplementary Material). Given that the MMAT discourages the use of a score to represent methodological quality [17], we have presented the outcome of these assessments narratively using the rating criterion of the MMAT as a broad framework.

2.6. Data Charting and Synthesis

Using a data collection template purposed for this review, the second author charted information from included studies about: authors and publication year; country; design; sample; outcome measures; and key findings. For consistency in the data charted for each study, we contacted the corresponding authors of one study to request additional specific information [20]. However, the primary outcome paper for this RCT was not yet published and, as such, the data we have charted is based on what was available within the article identified in the searches. To identify any discrepancies in the charting process, the third author read each article against the corresponding tabulated data. Data were synthesised in a descriptive manner and were reported narratively around the study's four research questions. Owing to differences in both the design and outcome measures used within the small number of studies identified in this review, we were unable to pool data for statistical meta-analysis.

3. Results

3.1. Study Characteristics

The search process yielded 1,631 unique records and, of these, the findings of five primary studies, reported in eight peer-reviewed articles, are included in this scoping review (Table 2). All five studies were published in the last 12 years (2008-2019), and were conducted in seven different countries (Greece, Netherlands, Germany, Belgium, UK, US, France), including a multi-3-country trial [21]. Studies employed mixed method (n = 3) and quantitative designs (n = 2), and these included combinations of research projects involving aspects of RCTs (n = 4), pre-post-controlled trials (n = 2), qualitative interviews/focus groups (n = 3), and/or case studies (n = 1). Notably, the two pre-post-controlled trials commenced as RCTs but transitioned their design following allocation to groups based on either participant refusal to be in the control group, or the participant home environment not meeting the requirements for smart home technology installation and thereby requiring allocation to the control group [21-23].

In total, n = 617 participants were sampled, and individual study sizes ranged from n = 18 to n = 408. Where reported, the age of participants ranged from a minimum of 60 years to 97 years. Three studies included participants with mild cognitive impairment or mild-to-moderate dementia, while two studies also sampled participants with severe dementia. Additionally, three studies permitted inclusion of participants living alone or with another person, whereas the other two studies focused exclusively on either those living with an informal caregiver, or those living alone. In the latter instance, co-dwelling participants were excluded because the smart home technology was unable to distinguish between multiple individuals [24-26].

3.2. Types of Smart Home Technologies

As described in Table 2, five different types of smart home technology systems were evaluated: Dem@Care project, Rosetta system, Technology Integrated Health Management (THIM) system, Night Monitoring System (NMS), and the Home-Based Technologies with Teleassistance System (HBTec-TS). Only one study compared the smart home technology against an active control (non-pharmacological interventions [25]), although another study compared the technology against a control that included the provision of brief educational materials and a small payment at each (nine) data collection point [23]. Across studies, evaluations ranged over time periods of half-a-month to one-year. However, within studies there was also some variability in the length of time that participants had the smart home technology in effective use. Where cited, reasons for this variability were related to recruitment (i.e., dropouts after installation and time taken to find replacement participants), technology installation (i.e., difficulties in scheduling appointments because of the lengthy time (up to two days) to install the technology within homes), and technical difficulties (i.e., periods when the technology did not work or required replacement parts that took time to arrive) [e.g., 21]. From the available data reported in the studies, there was an attrition rate of 18.9% across the smart home technology intervention groups (range: 0% – 38.5%).

Table 2

Characteristics of the studies included in the review

Author (year)	Country	Technology	Study design	Setting & sample	Health outcomes	Key findings
Lazarou et al. [25] Lazarou et al. [24] Stavropoulos et al. [26]	Greece	Dem@Care: personalized sensor-based system that integrates off-the-shelf IoT ambient & wearable devices to support cognitive & functional status	Mixed methods: 3-grp RCT & post-intervention interviews, with system used from 4-12 mths (incorporated *n* = 4 pilot case studies in EG)	N = 18 (6 installed system & psychosocial intervention (EG); 6 psychosocial intervention (CG1); 6 regular care (CG2)) Aged > 60 yrs, with MCI or mild-moderate Alzheimer's	Cognitive function = MMSE; CDR; GDS; NPI; RBMT- story, direct & delayed recall; ROCFT-copy & delayed recall; RAVLT; TRAIL-B; FAS; FRSSD; FUCAS Mood = NPI; PSS; BAI; BDI Physical activity = sensor data ADL = sensor data	EG = Sig. ($p < 0.05$) improvement in physical activity, ADL, & sleep over time EG = Sig. ($p < 0.05$) improvements in cognition, function over time & compared to CG1&2 (MMSE, TEA elevator time,

				disease or dementia, & living alone in their own home	Sleep = sensor data	RAVLT-learning & total)
Hattink et al. [21]	Netherlands, Germany, & Belgium	Rosetta System: fully integrated multifunctional modular system combing 3 assistive technologies that support prompts & reminders, leisure, communication, & safety	RCT in Germany Intended RCT but transitioned to pre-post matched control in the Netherlands & Belgium Evaluation over average of four	N = 42 (19 Netherlands; 11 Germany, 12 Belgium) MCI or dementia (all stages), aged *M* = 79.4 yrs, living in the community, either alone or with informal caregiver	Perceived autonomy = Mastery Scale & WHOQOL-100 Quality of Life = QOL-AD Delayed nursing home admission Use of services Care needs = CANE Cognitive status = MMSE	No significant grp differences on health outcomes over time All users experienced system instability and malfunction

			mths (0.5 - 8mths)			
Rostill et al. [20]	United Kingdom	Technology Integrated Health Management (TIHM) System: continuous remote monitoring via sensors, vital signs monitors, GPS tracker & gateway device that trigger alerts	Mixed methods: 2-arm RCT over 9 mths, & interviews at baseline, mid- and post-intervention Intervention (TIHM installed in home)	N = 408 (204 people with dementia, 204 carers) Half invention: half control Mild to moderate dementia, living at home with either a spouse or have a	Neuropsychiatry symptoms: depression, agitation, anxiety, irritability	Sustained & sig ($p <$ 0.05) reduction in neuropsychiatric symptoms of depression, agitation, anxiety & irritability

		monitored by centralised team of clinicians	Control (usual care)	regular carer (friend or relative)		
Rowe et al. [22], Rowe et al. [23]	United States	Night Monitoring System (NMS): control panel & wireless receiver, motion, door, & bed sensors, text, voice, & alarm sounds	Intended RCT but some participant group assignment so pre-post control over 12 mnths (data collected: 0, 2, 3, 4, 5, 6, 8, 10 & 12 mnth)	N = 53 dementia caregiving dyads (26 intervention: 27 control) Aged *M* = 79.62 (range 62-97), with medically diagnosed AD or dementia, MMSE score *M* = 13.8, history of regular	<u>Primary:</u> Nighttime injuries = American National Standards of reporting injuries Unattended exits from home = carer reports of people with dementia walking completely through a door without carer knowing	When intervention active, people with dementia less likely ($p = 0.058$ n.s.) to sustain injuries & exists than no system, with relative risk reduction of 86% Nursing home placement more

	Intervention (HMS installed in home) Control ($15 payment each data collection, assistance with Safe Return program, & education material unrelated to nighttime activity, sleep, wandering)	nighttime awakenings, not undergoing sleep disorder treatment	likely (p = 0.09 n.s) for nighttime injuries than no event or day event

Tchalla et al. [27]	France	Homes-based Technologies with Teleassistance System (HBTec-TS): nightlight path, remote intercom, electronic bracelet, central telephone hotline	Prospective RCT over 1 yr Intervention (Falls reduction program & HBTec-TS installed in home) Control (Falls reduction program)	N = 96 (49 intervention: 47 control) Aged ⩾65 years, with non-severe (⩾10 MMSE) Alzheimer's disease, living at home, on the frail elderly people register & not in a falls prevention program	<u>Primary:</u> Number of indoor falls <u>Secondary:</u> Nursing home admission Mortality	Incidence of falls intervention = 32.7%: control = 63.8% HBTec-TS & older age sig. predictors of decreased risk of falls Relative risk reduction of falls in HBTec-TS = 48.8% Intervention vs. control comparable

											rates of admissions to nursing home (2:3) & mortality (2:1)

Note. IoT = Internet of Things; RCT = randomised controlled trial; mths = months; EG = experimental group; CG = control group; yrs = years; MCI = mild cognitive impairment; MMSE = Mini Mental State Examination; CDR = Clinical Dementia Rating; GDS = Global Deterioration Scale; TEA = Test of Everyday Attention; RBMT = Rivermead Behavioural Memory Test; ROCFT = Rey-Osterrieth Complex Figure Test; RAVLT = Rey Auditory Verbal Learning Test; TRAIL-B = Trail Making Test Part B; FAS = F-A-S Test; FRSSD = Functional Rating Scale for Dementia; FUCAS = Functional and Cognitive Assessment Test; NPI = Neuropsychiatric Inventory; PSS = Perceived Stress Scale; BAI = Beck Anxiety Inventory; BDI = Beck Depression Inventory; ADL = activities of daily living; sig. = significant; WHOQOL-100 = World Health Organization Quality of Life-100; QOL-AD = Quality of Life in Alzheimer's disease; CANE = Camberwell Assessment of Need for the Elderly; grp = group; GPS = Global Positioning System; n.s. = non-significant.

3.3. Health Outcomes Targeted

There was an assortment of health outcomes assessed across the five studies, with a total of 19 different outcomes reported. Of these, more than one study assessed the effects of the smart home intervention on outcomes relating to participants' cognitive status, levels of depression and anxiety, and rate of admission to LTC. Individual studies also analysed effects in terms of physical activity, activities of daily living, sleep, quality of life, perceived autonomy, agitation, irritability, care needs, night-time injuries, falls, unattended exists from home, service use, and mortality. All studies assessed effects from baseline to intervention-end, and two also collected outcome data during the intervention period (e.g., at mid-point, months 2, 3, 4, 5, 6, 8, and 10 during a 12-month trial).

3.4. Effectiveness of Smart Home Technologies

Collectively, the findings reported in the five studies – albeit small in number and limited in RCT evidence – provided some support for the effectiveness of smart home technologies to support the health outcomes of community-dwelling older adults living with dementia. Four studies reported significant and positive effects in favour of smart home technologies and, importantly, this included the largest known RCT of a smart home technology conducted to-date (n = 408) [20]. Specifically, studies reported within-group effects for improved physical activity, activities of daily living, and sleep, as well as reduced anxiety, depression, agitation, irritability, and risk of falls (48.8% reduction). Between-group effects, when compared to control conditions, were also reported for improved cognitive functioning and an 86% reduction in the likelihood of a night-time injury or unattended home exit. Nevertheless, findings were not absolute on all outcome measures, and no significant effects were reported in terms of rates of admission to LTC, quality of life, perceived autonomy, care needs, service use, or mortality. Additionally, one study found no significant

effects for any of their primary and secondary outcomes when compared to participants receiving usual care [21]. The authors suggested this was due to the smart home technology being in the development stage, which resulted in most participants experiencing system instability and technical malfunction during their use.

3.5. Quality of Evidence

The methodological reporting quality of included studies was relatively low and suggested that research into the effectiveness of smart home technologies for dementia care is still in the early stages (online Supplementary Material). Moreover, the reporting of evaluation outcomes for one smart home technology system within multiple articles indicated the developing nature of the field, with initial case studies, preliminary analysis, and changing names of the system itself preceding the eventual pre-post evaluation [e.g., 24, 25, 26]. When looking at the reporting of the quantitative data, there was a particular lack of rigor in describing the randomisation process (if there was one) and in considering confounding variables on intervention effects. Further, although studies were unable to blind participants to intervention group, most did not specify if they addressed the issue of blinding of outcome assessors. As previously described, there was also some within-study variability in the length of time that participants had the smart home technology in effective use, and not all studies had complete outcome data for analysis (i.e., rates of attrition ranged from 0% – 38.5%). When studies included aspects of qualitative research, it was often as an end-of-intervention evaluation exploring user satisfaction with, and acceptability of, the smart home technology. All studies reported these results in a basic narrative form and did not describe the method of qualitative analysis or how the findings were derived from the data (e.g., inductive thematic analysis using codes and themes). In general, there was also basic use of quotations, and these were often presented with frequencies of opinion rather than contextually based

interpretation. Finally, three studies used mixed method designs to evaluate a smart home technology system. Although limited by the issues highlighted previously for the reporting of qualitative and quantitative data, there was adequate rationale for the use of a mixed method design, and studies integrated and discussed each source of data in an overall evaluation of the technology.

4. Discussion

The last few decades have seen much research conducted into the application of smart home technologies to support healthcare within the community [7, 9, 10, 12], and this has included people living with dementia [6, 11]. However, much of this effort has focused on technology development rather than testing for effectiveness and, as yet, understanding about the success of smart home technologies to support and prolong 'ageing in place' remains unclear [9-11]. Drawing on published empirical data, we have undertaken this scoping review to map and synthesise the most up-to-date evidence to determine what we know about the effectiveness of smart home technologies for people living with dementia at home. To the best of our knowledge, this is the first review of the literature for this purpose and offers timely insight into the state of a rapidly developing field. In this discussion, we consider the findings of our review in the context of four issues: effectiveness, research challenges; technology readiness; and methodological reporting.

The main finding arising from this review is that, based on the published data currently available, we cannot yet reliably determine the effectiveness of smart home technologies to support people with dementia to remain living at home. There is some evidence within individual studies of positive effect (in terms of improved physical activity, activities of daily living, sleep, anxiety, depression, agitation, irritability, cognitive functioning, falls, night-time injury, and unattended home exits), but just five studies were

included in this review and these were mostly small in sample size. Further, although all studies set out to undertake evaluation using the 'gold standard' RCT [28], only three were able to do so, thereby prohibiting more definitive inferences to be drawn about effectiveness. This finding is similar to that reported in earlier reviews [9, 11, 12], and again serves to highlight that developing a technology and taking it through to evaluation remains a lengthy process, and that more studies are needed.

However, when reflecting on these data and applying a different lens, what we can suggest our review *does* show is the inherent difficulty in evaluating smart home technologies in real-life contexts. As described, the traditional RCT design was not possible in two studies, despite it being the original intention. Specifically, these studies transitioned to a non-randomised design during recruitment as participants either refused to take-part in the trial unless they received the technology, or because the participant home living environment could not accommodate the installation [21-23]. Additionally, there were also instances of the technology system being turned off within the home [e.g., 22], as well as requested withdrawal from participants after the installation phase [e.g., 21]. The cost of installing the technology within homes was also often prohibitive and time-consuming, and this contributed to typically small study size samples. Taken together, these issues emphasise the challenges of undertaking technology-based research within everyday settings – particularly using the preferred RCT design – and we add our voice to the growing collective advocating innovation in alternate pragmatic- or adaptive-based research designs to advance the area further [e.g., 29, 30]. Moreover, our findings also reinforce the importance of including measures of user perceptions and acceptance within evaluation studies (as was done in three studies), as these factors are known important drivers in smart home technology usage and, ultimately, effectiveness [31]. Echoing the recommendations of previous authors [10, 32], we therefore also encourage that future studies aim to include the experiences and preferences of

end-users (e.g., people with dementia and their carers) explicitly in the development and evaluations of the smart home technologies.

A previous review of smart home technologies for health monitoring within older adults cited low readiness of the technologies for use [12] and, in the current review, similar conclusions can be drawn. Within included studies there were reports of system instability and malfunction [e.g., 20, 21], as well as systems that could not account for everyday living situations and thereby limited recruitment to certain participants (e.g., lone-dwelling participants due to the technology's inability to distinguish between multiple individuals [24-26]). We also found that most of the articles identified in the original searches were either focused on the smart home technology development phase or were laboratory-based evaluation studies. Such findings reflect the emerging status of the field as a whole and show that efforts are still largely focused on the early development and evaluation of prototype-stage smart home technology systems. In light of this, and the known ongoing evaluation of at least one system identified in this review (i.e., TIHM system, Surrey and Borders Partnership NHS Foundation Trust [33]), we recommend similar literature appraisals be undertaken every few years so that knowledge is updated regularly and that progress of the research area can be monitored.

Finally, our findings again reiterate what previous researchers have concluded about the overall field of smart home technologies for community-based healthcare: more rigorous evaluation and enhanced reporting is needed [9, 12]. The studies included in this review were limited in their methodological reporting of both quantitative and qualitative effects. However, when undertaking the study selection process generally, we also found that there were often multiple articles from one study but, because these were not clearly signposted, it was difficult to determine their relationship. Similarly, we also found instances where the same smart home technology system was called different names in different publications.

While this likely reflects the iterative development process of the technology (i.e., prototype #1 to #2), it presents challenges in objectively reviewing the evidence and, to this end, we encourage the use of reporting guidelines to enhance the transparency and quality of future articles [34].

4.1. Implications

Given the lack of evidence underpinning the current state-of-knowledge about the use of smart home technologies in community-based dementia care, implications at this stage are largely focused on further research rather than clinical application. With this in mind, we propose the following recommendations. Overall, more evaluation of smart home technology systems for effective use with people with dementia is needed, and particularly in studies with larger sample sizes. Researchers should consider alternate and innovative designs to the traditional RCT and should also aim to incorporate qualitative evaluation of end-user' perceptions of the technology within the process. To enable comparison and pooling of data, future studies would benefit from evaluating the technology using a more homogenous group of health outcomes. Work is currently underway to establish a core set of evaluation outcomes within non-pharmacological community-based dementia care, and we encourage technology researchers to explore the initial 'long-list' as a starting point in future smart home studies [35, 36]. Researchers should use and adhere to reporting guidelines when preparing the study results for publication in order to improve the low level of methodological reporting currently characterising the field as a whole. Nevertheless, despite the recommendations just described, there is also a real need for evaluation of the technology to occur only when it is at a level of sufficient development. Low readiness of technology, as characterised by ongoing and disruptive technical issues, was an issue for some studies within this review, and we therefore urge future research to only consider moving to the evaluation

stage once the technology appears stable within the laboratory setting. Finally, given the volume of work being undertaken in this area and the pace at which new technology is being developed, we recommend reviews of the literature be undertaken and published regularly so as to monitor the progress of the field.

4.2. Limitations

Only five studies were included in the review, all of which were heterogeneous in their evaluation of smart home technology systems and had (except for one trial) minimal sample sizes. Second, only articles that were written in English, peer-reviewed, published, and met all our inclusion criteria were permitted. Third, the absence of a meta-analysis prohibits generalisability of the findings in terms of a common effect and restricts discussion of the current evidence-base to a narrative interpretation only.

5. Conclusions

This scoping review found that, despite much research in the area, the success of smart home technologies to support people with dementia to live at home remains unclear. There were limited published evaluations of smart home technologies within community-based dementia care and it was evident that, overall, research is challenged by issues of study design, low readiness of the technology, and methodological reporting. Based on the current evidence, recommendations are made to help inform future research and to advance the field beyond the current state-of-knowledge.

Authors' Contributions

WM conceptualised the review and undertook title and abstract screening and full-text review. JM was involved in title and abstract screening, full-text review, quality appraisal, and data extraction. KL undertook quality appraisal and data extraction. A first draft of the manuscript was prepared by JM and WM, and all authors conceptually commented on, revised, and approved the final version of the manuscript.

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Declarations of Interest

None.

Summary Points

What was already known on the topic?

- A growing number of studies have documented the development and use of smart home technologies to support health outcomes within older populations and people with dementia specifically.
- Few studies, however, have tested actual effectiveness of smart home technologies within community-based dementia care, and this has prevented valid conclusions to be drawn across research projects.

What this study added to our knowledge?

- Based on the limited published evidence currently available, the effectiveness of smart home technologies to support people with dementia to stay living at home remains unclear.
- Research into smart home technologies in community-based dementia care is challenged by issues of study design, low readiness of the technology, and methodological reporting.
- Evidence-based recommendations are provided to inform future research into smart home technologies for community-based dementia care, and to advance the field beyond the current state-of-knowledge.

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core outcome set for people living with dementia at home in their neighbourhoods and communities: Study protocol for use in the evaluation of non-pharmacological community-based health and social care interventions. *Trials, 19*(1), 247. https://doi.org/10.1186/s13063-018-2584-9

Appendix A. Supplementary Material (Online only)

Table 1

Search strategy

Database	Search#	Search Terms	Limiters	Retrieved
MEDLINE (via EBSCO)	S1	TI (“smart home*” OR “smart home technolog*” OR “smart home system*” OR “smart living environment*” OR “home automation” OR “home automation system*” OR “automated home*” OR “intelligent system*” OR “intelligent home*” OR “ubiquitous home*” OR “ubiquitous environment*” OR “wireless home*” OR “wireless home* network*” OR “dometic*” OR “ambient assisted living” OR “home monitoring” OR “home monitoring technology” OR “monitoring system*”) OR AB (“smart home*” OR “smart home technolog*” OR “smart home system*” OR “smart living environment*” OR “home automation” OR “home automation system*” OR “automated home*” OR “intelligent system*” OR “intelligent home*” OR “ubiquitous home*” OR “ubiquitous environment*” OR “wireless home*” OR “wireless home* network*” OR “dometic*” OR “ambient assisted living” OR “home monitoring” OR “home monitoring technology” OR “monitoring system*”) OR MH "wireless technology" OR MH "technology"	English Language Human	248
	S2	TI (“dementia” OR “Alzheimer* disease” OR “dementia care” OR “cognitive* impair*”) OR AB (“dementia” OR “Alzheimer* disease” OR “dementia care” OR “cognitive* impair*”) OR MH "dementia" OR MH "cognitive dysfunction"		
	S3	S1 AND S2		
CINHAL Complete (via EBSCO)	S1	TI (“smart home*” OR “smart home technolog*” OR “smart home system*” OR “smart living environment*” OR “home automation” OR “home automation system*” OR “automated	English Language Human	230

		home*” OR “intelligent system*” OR “intelligent home*” OR “ubiquitous home*” OR “ubiquitous environment*” OR “wireless home*” OR “wireless home* network*” OR “dometic*” OR “ambient assisted living” OR “home monitoring” OR “home monitoring technology” OR “monitoring system*”) OR AB (“smart home*” OR “smart home technolog*” OR “smart home system*” OR “smart living environment*” OR “home automation” OR “home automation system*” OR “automated home*” OR “intelligent system*” OR “intelligent home*” OR “ubiquitous home*” OR “ubiquitous environment*” OR “wireless home*” OR “wireless home* network*” OR “dometic*” OR “ambient assisted living” OR “home monitoring” OR “home monitoring technology” OR “monitoring system*”) OR MH "wireless technology" OR MH "technology"	Exclude Medline records	
	S2	TI (“dementia” OR “Alzheimer* disease” OR “dementia care” OR “cognitive* impair*”) OR AB (“dementia” OR “Alzheimer* disease” OR “dementia care” OR “cognitive* impair*”) OR MH "dementia" OR MH "cognitive dysfunction"		
	S3	S1 AND S2	English Language	133
PsycINFO (via OVID)	S1	('smart home*' or 'smart home technolog*' or 'smart home system*' or 'smart living environment*' or 'home automation' or 'home automation system*' or 'automated home*' or 'intelligent system*' or 'intelligent home*' or 'ubiquitous home*' or 'ubiquitous environment*' or 'wireless home*' or 'wireless home* network*' or 'dometic*' or 'ambient assisted living' or 'home monitoring' or 'home monitoring technology' or 'monitoring system*').mp.	Human	
	S2	('dementia' or 'Alzheimer* disease' or 'dementia care' or 'cognitive* impair*').mp.		
	S3	S1 AND S2		
Embase	S1	'smart home*' OR 'smart home technolog*' OR 'smart home system*' OR 'smart living environment*' OR 'home automation'	English Language Human	411

		OR 'home automation system*' OR 'automated home*' OR 'intelligent system*' OR 'intelligent home*' OR 'ubiquitous home*' OR 'ubiquitous environment*' OR 'wireless home*' OR 'wireless home* network*' OR 'dometic*' OR 'ambient assisted living' OR 'home monitoring' OR 'home monitoring technology' OR 'monitoring system*':ab,ti,kw	Pubmed not Medline	
	S2	'dementia' OR 'alzheimer* disease' OR 'dementia care' OR 'cognitive* impair*':ab,ti,kw		
	S3	S1 AND S2		
Joanna Briggs Institute EBP Database (via OVID)	S1	(('smart home*' or 'smart home technolog*' or 'smart home system*' or 'smart living environment*' or 'home automation' or 'home automation system*' or 'automated home*' or 'intelligent system*' or 'intelligent home*' or 'ubiquitous home*' or 'ubiquitous environment*' or 'wireless home*' or 'wireless home* network*' or 'dometic*' or 'ambient assisted living' or 'home monitoring' or 'home monitoring technology' or 'monitoring system*') AND ('dementia' or 'Alzheimers disease' or 'dementia care' or 'cognitive* impair*')).mp.	None	10
Cochrane Library	S1	('smart home*' or 'smart home technolog*' or 'smart home system*' or 'smart living environment*' or 'home automation' or 'home automation system*' or 'automated home*' or 'intelligent system*' or 'intelligent home*' or 'ubiquitous home*' or 'ubiquitous environment*' or 'wireless home*' or 'wireless home* network*' or 'dometic*' or 'ambient assisted living' or 'home monitoring' or 'home monitoring technology' or 'monitoring system*'):ti,ab,kw	None	32
	S2	('dementia' or 'Alzheimer* disease' or 'dementia care' or 'cognitive* impair*'):ti,ab,kw		
	S3	S1 AND S2		

Web of Science: Core Collection	S1	TS=(“smart home*” OR “smart home technolog*” OR “smart home system*” OR “smart living environment*” OR “home automation” OR “home automation system*” OR “automated home*” OR “intelligent system*” OR “intelligent home*” OR “ubiquitous home*” OR “ubiquitous environment*” OR “wireless home*” OR “wireless home* network*” OR “dometic*” OR “ambient assisted living” OR “home monitoring” OR “home monitoring technology” OR “monitoring system*”) OR TI=(“smart home*” OR “smart home technolog*” OR “smart home system*” OR “smart living environment*” OR “home automation” OR “home automation system*” OR “automated home*” OR “intelligent system*” OR “intelligent home*” OR “ubiquitous home*” OR “ubiquitous environment*” OR “wireless home*” OR “wireless home* network*” OR “dometic*” OR “ambient assisted living” OR “home monitoring” OR “home monitoring technology” OR “monitoring system*”)	English Language	564
	S2	TS=(“dementia” OR “Alzheimer* disease” OR “dementia care” OR “cognitive* impair*”) OR TI=(“dementia” OR “Alzheimer* disease” OR “dementia care” OR “cognitive* impair*”)		
	S3	S1 AND S2		

Notes. All searches were conducted on 20 April 2020 by the second author (JM).
Records identified through database searching, *n* = 1,628.
MEDLINE: MH = MeSH2020; TI = title; AB = abstract.
CINHAL Complete: MH = CINAHL Exact Subject Headings; TI = title; AB = abstract.
PsycINFO: mp = title, abstract, heading word, table of contents, key concepts, original title, tests & measures, mesh.
Embase: ab,ti,kw = abstract, title, keyword.
Joanna Briggs Institute EBP database: mp = title, abstract, heading word, table of contents, key concepts, original title, tests & measures, mesh.
Cochrane Library: ti,ab,kw = title, abstract, keyword.
Web of Science: Core Collection: TS = topic; TI = title.

Appendix B. Supplementary Material (Online only)

Table 2

Assessment of methodological and reporting quality of included studies using the Mixed Methods Appraisal Tool - Version 2018

Design	Criteria	Responses			
		Yes	No	Can't tell	Comment
Lazarou et al. [24], Stavropoulos et al. [26]					
1. Qualitative	1.1. Is the qualitative approach appropriate to answer the research question?	1			
[Case studies]	1.2. Are the qualitative data collection methods adequate to address the research question?	1			
	1.3. Are the findings adequately derived from the data?	1			
	1.4. Is the interpretation of results sufficiently substantiated by data?	1			
	1.5. Is there coherence between qualitative data sources, collection, analysis and interpretation?	1			
Lazarou et al. [25]	* *experimental group included the n = 4 case studies described in Lazarou et al. [24], Stavropoulos et al. [26]*				
1. Qualitative	1.1. Is the qualitative approach appropriate to answer the research question?	1			
[Interviews]	1.2. Are the qualitative data collection methods adequate to address the research question?	1			
	1.3. Are the findings adequately derived from the data?			1	Brief description
	1.4. Is the interpretation of results sufficiently substantiated by data?			1	
	1.5. Is there coherence between qualitative data sources, collection, analysis and interpretation?			1	
2. Quantitative randomized controlled trials	2.1. Is randomization appropriately performed?			1	Statement only
	2.2. Are the groups comparable at baseline?			1	Not described
	2.3. Are there complete outcome data?	1			
	2.4. Are outcome assessors blinded to the intervention provided?	1			
	2.5 Did the participants adhere to the assigned intervention?	1			

5. Mixed methods	5.1. Is there an adequate rationale for using a mixed methods design to address the research question?	1			Not explicitly explained
	5.2. Are the different components of the study effectively integrated to answer the research question?	1			
	5.3. Are the outputs of the integration of qualitative and quantitative components adequately interpreted?	1			
	5.4. Are divergences and inconsistencies between quantitative and qualitative results adequately addressed?	1			
	5.5. Do the different components of the study adhere to the quality criteria of each tradition of the methods involved?		1		See analysis of separate components

Design	Criteria	Responses			
		Yes	No	Can't tell	
Hattink et al. [21]					
1. Qualitative	1.1. Is the qualitative approach appropriate to answer the research question?	1			
	1.2. Are the qualitative data collection methods adequate to address the research question?	1			
	1.3. Are the findings adequately derived from the data?	1			
	1.4. Is the interpretation of results sufficiently substantiated by data?	1			
	1.5. Is there coherence between qualitative data sources, collection, analysis and interpretation?			1	No comparison of participants with different stages of dementia
2. Quantitative randomized controlled trials	2.1. Is randomization appropriately performed?			1	Statement only
	2.2. Are the groups comparable at baseline?	1			Some differences were included as covariates
	2.3. Are there complete outcome data?	1			Attrition was ~20%, but it was from a small sample
	2.4. Are outcome assessors blinded to the intervention provided?			1	Not specified
	2.5 Did the participants adhere to the assigned intervention?		1		

3. Quantitative non-randomized	3.1. Are the participants representative of the target population?		1		Different target samples in different countries
	3.2. Are measurements appropriate regarding both the outcome and intervention (or exposure)?	1			
	3.3. Are there complete outcome data?		1		
	3.4. Are the confounders accounted for in the design and analysis?	1			
	3.5. During the study period, is the intervention administered (or exposure occurred) as intended?		1		
5. Mixed methods	5.1. Is there an adequate rationale for using a mixed methods design to address the research question?	1			Not explicitly explained
	5.2. Are the different components of the study effectively integrated to answer the research question?	1			
	5.3. Are the outputs of the integration of qualitative and quantitative components adequately interpreted?	1			
	5.4. Are divergences and inconsistencies between quantitative and qualitative results adequately addressed?	1			
	5.5. Do the different components of the study adhere to the quality criteria of each tradition of the methods involved?		1		See analysis of separate components

Design	Criteria	Responses			
		Yes	No	Can't tell	
Rostill et al. [20]					
1. Qualitative	1.1. Is the qualitative approach appropriate to answer the research question?			1	Clinical review, not primary outcome paper (pending publication)
	1.2. Are the qualitative data collection methods adequate to address the research question?			1	
	1.3. Are the findings adequately derived from the data?			1	
	1.4. Is the interpretation of results sufficiently substantiated by data?			1	
	1.5. Is there coherence between qualitative data sources, collection, analysis and interpretation?			1	
2. Quantitative randomized controlled trials	2.1. Is randomization appropriately performed?			1	
	2.2. Are the groups comparable at baseline?			1	
	2.3. Are there complete outcome data?			1	
	2.4. Are outcome assessors blinded to the intervention provided?			1	

	2.5 Did the participants adhere to the assigned intervention?			1	
5. Mixed methods	5.1. Is there an adequate rationale for using a mixed methods design to address the research question?			1	
	5.2. Are the different components of the study effectively integrated to answer the research question?			1	
	5.3. Are the outputs of the integration of qualitative and quantitative components adequately interpreted?			1	
	5.4. Are divergences and inconsistencies between quantitative and qualitative results adequately addressed?			1	
	5.5. Do the different components of the study adhere to the quality criteria of each tradition of the methods involved?			1	

Design	Criteria	Responses			
		Yes	No	Can't tell	
Rowe et al. [22], Rowe et al. [23]					
3. Quantitative non-randomized	3.1. Are the participants representative of the target population?	1			
	3.2. Are measurements appropriate regarding both the outcome and intervention (or exposure)?	1			
	3.3. Are there complete outcome data?		1		
	3.4. Are the confounders accounted for in the design and analysis?	1			
	3.5. During the study period, is the intervention administered (or exposure occurred) as intended?	1			System disabled by $n = 1$ formal carer

Design	Criteria	Responses			
		Yes	No	Can't tell	
Tchalla et al. [27]					
2. Quantitative randomized controlled trials	2.1. Is randomization appropriately performed?	1			
	2.2. Are the groups comparable at baseline?	1			
	2.3. Are there complete outcome data?	1			
	2.4. Are outcome assessors blinded to the intervention provided?			1	Not specified
	2.5 Did the participants adhere to the assigned intervention?	1			