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Review

Domestic sensor-based monitoring for supporting independent-living older adults: A scoping review

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Abstract

Population ageing is accelerating globally, placing increasing pressure on local health and social care systems. Older people who remain living independently generally have better health outcomes and use fewer care resources. Moreover, many older people express a preference for living independently. Therefore, supporting independent living represents a cost-effective objective for health and care systems. One potential means for supporting such ageing in place is domestic sensor-based activity monitoring technologies; however, to date evidence on their effectiveness, usability, and real-world implementation has been inconclusive. A scoping review has been undertaken following PRISMA-ScR guidance to map the latest evidence on domestic passive sensor-based monitoring for older adults. Twenty-nine studies met the inclusion criteria; the evidence they provide suggests domestic sensors can support monitoring of activities of daily living, detect early functional or cognitive decline, and are generally acceptable to users. However, robust evidence for improved clinical outcomes, cost-effectiveness, and effective integration into health systems remains limited.

Keywords

applications in smart homes, elderly care, sensors, smart environments, technology adoption issues and implications

Introduction

Population ageing presents a major challenge to health and social care systems globally (Camp et al., 2022; WHO, 2021). As people age, they become more likely to experience multimorbidity, functional decline, and increasing care needs, placing sustained pressure on acute services and long-term care provision (Khan et al., 2024). In many countries, this challenge is compounded by workforce shortages and rising demand for community-based support (Barton et al., 2024). Alongside this, many older adults express a strong preference to remain living independently at home, motivating interest in interventions that can support this through early detection of decline, preventing avoidable hospitalisation, and delaying institutional care (Sixsmith et al., 2017). Domestic sensor-based technologies which use passive, in-home sensors to track daily routines and behavioural patterns, have been proposed as a means of supporting independent living without relying on active user engagement (Alwan, 2009; Kim et al., 2022). Through analysis of sensor data, these systems aim to detect patterns of behaviour or deviations from usual activity that may signal emerging health or functional problems, thereby enabling earlier intervention. Despite growing policy and research interest, evidence supporting their effectiveness, usability, and large-scale integration into health systems remains fragmented (Brownsell et al., 2011; Hall et al., 2017).

Existing evidence

Building on early academic work in gerontechnology, that is the study of the use of technology to support older adults to live independently, safely, healthily and well (Graafmans, 2016), studies in the 1990s and early 2000s (Sixsmith and

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Sixsmith, 2000) demonstrated that passive in-home monitoring of movement, appliance use, and daily routines could indicate changes in health status, particularly among frail older adults (Celler et al., 1995; Alwan, 2009). Pilot programmes incorporating early lifestyle monitoring systems showed the feasibility of unobtrusive monitoring but were limited by small sample sizes and short follow-up periods (Porteus and Brownsell, 2000). Subsequent research expanded this work through smart-home and ambient assisted living initiatives (Morita et al., 2023; Singh et al., 2017). Reviews by Brownsell et al. (2011) and Peetoom et al. (2014) concluded that sensor-based monitoring showed promise for supporting independent living, but highlighted weak clinical evidence, inconsistent outcomes, and limited generalisability. More recent studies have incorporated advances in sensor technology, data analytics, and machine learning, and have had an increasing focus on detecting frailty, cognitive decline, and changes in activities of daily living (Kim et al., 2022; Razjouyan et al., 2020). However, contemporary reviews continue to report mixed findings. While qualitative and feasibility studies often demonstrate acceptability and perceived benefits, quantitative evidence for outcomes such as reduced hospitalisation or improved functional independence remains inconsistent (Huang and Oteng, 2023). Cost-effectiveness, long-term effectiveness, and real-world deployments have been particularly under-examined (Camp et al., 2022; Hall et al., 2017). In addition, prior reviews frequently used broad or inconsistent terminology, conflating passive domestic sensors with wearables, telecare alarms, and other digital health tools, limiting clarity for policy and trial design (Sixsmith and Cosco, 2024).

Study objectives

Given the pace of technological development and the growing volume of empirical research, there is a clear need to revisit and update earlier syntheses of the evidence. The scoping review reported here aims to build on foundational work in the field, particularly the review by Brownsell et al. (2011), by systematically mapping evidence published since (that is, between 2010 and 2025) on domestic sensor-based activity monitoring technologies, here defined specifically as passive, in-home sensing systems for older adults. In particular, the review focuses on the effectiveness, usability, and barriers to adoption that are encountered in real-world deployments of these technologies. Given the heterogeneity of study designs, technologies, and intended outcomes, and the continuing evolution of this field, a scoping review methodology is considered appropriate to provide an up-to-date overview and to identify priorities for future research (Munn et al., 2018).

Materials and methods

The review followed established scoping review frameworks by Arksey and O'Malley (2005), further refined by the Joanna Briggs Institute (JBI) (Peters et al., 2021), and is reported in accordance with PRISMA-ScR guidelines (Tricco et al., 2018) shown in the supplemental material to ensure transparency and rigour (Munn et al., 2018). All procedures were predefined in a protocol, with any deviations documented accordingly. The overarching aim of this methodological approach was to map the breadth of evidence on passive AMTs for older people, identify recurring themes, and highlight gaps in the literature.

Study design

The scoping review presented here attempted to answer the question: *What is the current evidence for the effectiveness, usability, and barriers to adoption of domestic sensor-based activity monitoring technologies for supporting the independent living of older people?* A scoping review is appropriate for mapping broad evidence, identifying knowledge gaps, and clarifying key concepts where study designs and outcomes vary widely (Munn et al., 2018). The review followed the key stages outlined in Arksey and O'Malley's framework, refined by JBI: defining the review question, locating relevant studies, selecting eligible studies, charting data, and collating and summarising findings (Arksey and O'Malley, 2005). Each stage adhered to best-practice guidance, with procedures transparently reported through the PRISMA-ScR checklist.

Eligibility criteria

Eligibility criteria were defined using a modified PICO (Population, Intervention, Context, Outcomes) framework, where "Context" replaced "Comparison" to suit the scoping review design (Booth et al., 2019). Included studies focused on adults aged 55 or over living independently in the UK or comparable high-income country settings (i.e., countries with similar demographics, relatively high GDP, and developed community health and social care systems - as this criterion is difficult to formulate as a search term, it was applied at the screening phase), using domestic sensor or smart-home technologies (e.g., passive, ambient, AI-based systems). Outcomes had to relate to independent living (e.g., ADLs, health status, hospitalisation, quality of life, or user experience).

Table 1. Conjunction of search terms by key concept.

Concept	Search terms
Older people	"older adult*" OR "older people" OR elder** OR "ageing population" OR "aging population" OR senior*
Domestic passive sensor monitoring	"domestic sensor*" OR "home sensor" OR "ambient monitor*" OR "smart home" OR "in-home monitor*" OR "remote monitor" OR "sensor-based monitor*"
Independent living at home and community	"independent living" OR "living independently" OR "ageing in place" OR "aging in place" OR "community-dwell*"

Eligible studies described peer-reviewed empirical research (quantitative, qualitative, mixed-methods) published in English between 2010–2025 and available in open-access repositories. Exclusions included paywalled studies, work published in languages other than English or prior to 2010, non-empirical studies, and studies involving institutionalised or younger populations, wearable-only technologies, or unclear methods or outcomes.

Search strategy

Initial exploratory searches were conducted in Google Scholar, PubMed, and the University of Sheffield StarPlus Library to identify common keywords and phrases associated with domestic sensor technologies, older adults, and independent living. The study by Brownsell et al. (2011) served as a key reference point, offering a baseline against which updated evidence could be compared. This pilot phase confirmed that the field had expanded significantly since earlier reviews but remained fragmented, justifying the use of a scoping review methodology. Insights gained from the pilot search informed the development of comprehensive search strings and ensured that the terms selected aligned with the inclusion criteria, following guidance from the JBI (Pollock et al., 2021).

A comprehensive search of the MEDLINE (via Ovid), PubMed, Web of Science, and CINAHL online databases was conducted in July 2025. Searches were limited to English-language publications from 2010–2025. Paywalled and non-peer-reviewed items were excluded where possible via database filters. The key search terms are summarised in Table 1. The full search strategy for each database is provided in supplemental material for transparency. Reference list screening and citation tracking were also undertaken to identify additional studies.

Study selection

The search results were managed using Mendeley reference management software (Reiswig, 2010) for removing duplicates, retracted articles, and non-peer-reviewed items. The remaining records were then screened using Rayyan online review management platform (Ouzzani et al., 2016). Title/abstract screening was conducted by the primary reviewer (AM), with a random sample of 10% independently screened by a second reviewer (SP). Any disagreements were resolved by discussion between the two reviewers. It should be noted that studies were excluded where full-text access was unavailable (i.e., paywalled publications) but is unlikely to have introduced systematic bias given the breadth of the search strategy ($n = 29$).

Data extraction and analysis

Data were extracted systematically within a structured charting framework using the spreadsheet in Microsoft Excel, developed in line with JBI recommendations and Pollock et al.'s (2022) guidance on scoping reviews. It captured study characteristics, intervention details, outcomes, and reported barriers/facilitators.

Outcomes were charted according to categories such as health status, prevention of functional decline, maintenance of independence, hospitalisation reduction, effect on quality of life, usability, barriers and facilitators, and ethical issues. Notes on methodological strengths and limitations were also documented. To avoid bias, studies were charted in alphabetical order by title. Separate evidence tables were developed for quantitative and qualitative or mixed-methods studies to improve clarity. Quantitative outcomes such as statistical results, correlations, and effect sizes were presented in one set of tables, classified by positive, negative, or null findings. Qualitative and mixed-methods results, including participant perceptions and ethical concerns, were synthesised into a summary table with the themes highlighted.

Given the heterogeneity of included studies, findings were synthesised narratively (Campbell et al., 2018). Quantitative results were summarised descriptively, while qualitative findings were analysed thematically. Mixed-methods studies

were integrated to explore convergence between outcomes and user experiences. Quantitative outcomes such as statistical results, correlations, and effect sizes were presented in one set of tables, classified according to whether they represent positive, negative, or null findings. Qualitative and mixed-methods results, including participant perceptions and ethical concerns, were synthesised into a summary table with the themes highlighted. Disagreements or ambiguities during extraction were resolved by discussion. The extracted data tables, as provided in the supplemental material**,** were used for subsequent analysis.

Quality appraisal

Although formal risk-of-bias assessment is not mandatory for scoping reviews (Arksey and O'Malley, 2005; Tricco et al., 2018), study quality was assessed using the NIH tools (Livingston et al., 2014) and OCEBM Levels of Evidence tool (Howick et al., 2011). Studies were classified by design type (e.g., randomized controlled trial (RCT), cohort, qualitative) and assigned an OCEBM evidence level. Methodological limitations such as small sample sizes, short monitoring duration, or lack of validated measures were noted. This approach provided an overview of the quality of evidence without excluding lower-quality studies, consistent with the scoping methodology. It is acknowledged that the OCEBM Levels of Evidence framework was developed primarily for quantitative intervention studies and is not fully suited to qualitative or mixed-methods research; however, for comparative purposes here we apply the framework to qualitative and mixed-methods research following the approach of Livingston et al. (2014). For qualitative and mixed-methods studies, the NIH quality assessment tool was therefore used as the primary quality indicator, with the OCEBM level provided for context. Scores should be interpreted with this caveat in mind.

Ethical considerations

This scoping review used only secondary data. As such, formal ethics approval was not required.

Results

The database search initially identified n = 399 records across MEDLINE (n = 22), Web of Science (n = 244), PubMed (n = 124), and CINAHL (n = 9). After removing 117 duplicates in Mendeley and excluding 2 additional records due to retraction and non-peer-reviewed status, 280 records remained for screening in Rayyan. Of these, 41 full-text articles were assessed for eligibility, with 29 studies ultimately included in the final synthesis, as shown in the PRISMA flow diagram in Figure 1. The included studies comprised quantitative (n = 4), qualitative (n = 11), mixed-methods (n = 13), and one feasibility study (n = 1), indicating a heterogeneous evidence base.

Study characteristics and key findings

Across the included studies, domestic sensor-based monitoring technologies were primarily used to track activities of daily living (ADLs), detect early functional or cognitive decline, and support independent living.

Quantitative studies. Quantitative findings were mixed. Two studies demonstrated significant benefits, including improvements in quality of life, functional outcomes, and early risk detection, alongside the ability to identify markers of cognitive decline. However, the other two studies reported non-significant effects, particularly for outcomes such as hospitalisation reduction. Overall, while some large-scale and longitudinal studies do suggest clinically meaningful benefits, the quantitative evidence remains inconsistent and limited in scope. These studies are summarized in Table 2.

Qualitative studies. Qualitative studies consistently highlighted key barriers and facilitators influencing adoption. Major barriers included ethical issues, privacy concerns, perceptions of surveillance, reduced autonomy, digital literacy challenges, and cost. Ethical considerations, particularly around consent, data use, and autonomy were central across studies. Qualitative benefits included increased feelings of safety, independence, and reassurance for family members The studies are summarized in Table 3.

Mixed-methods studies. Quantitative results from mixed-methods studies explained qualitative findings. In several cases, interventions with limited measurable clinical impact were still perceived positively by users due to increased reassurance and perceived safety. This suggests a disconnect between demonstrable clinical outcomes and user-valued benefits. The studies are summarized in Table 4.

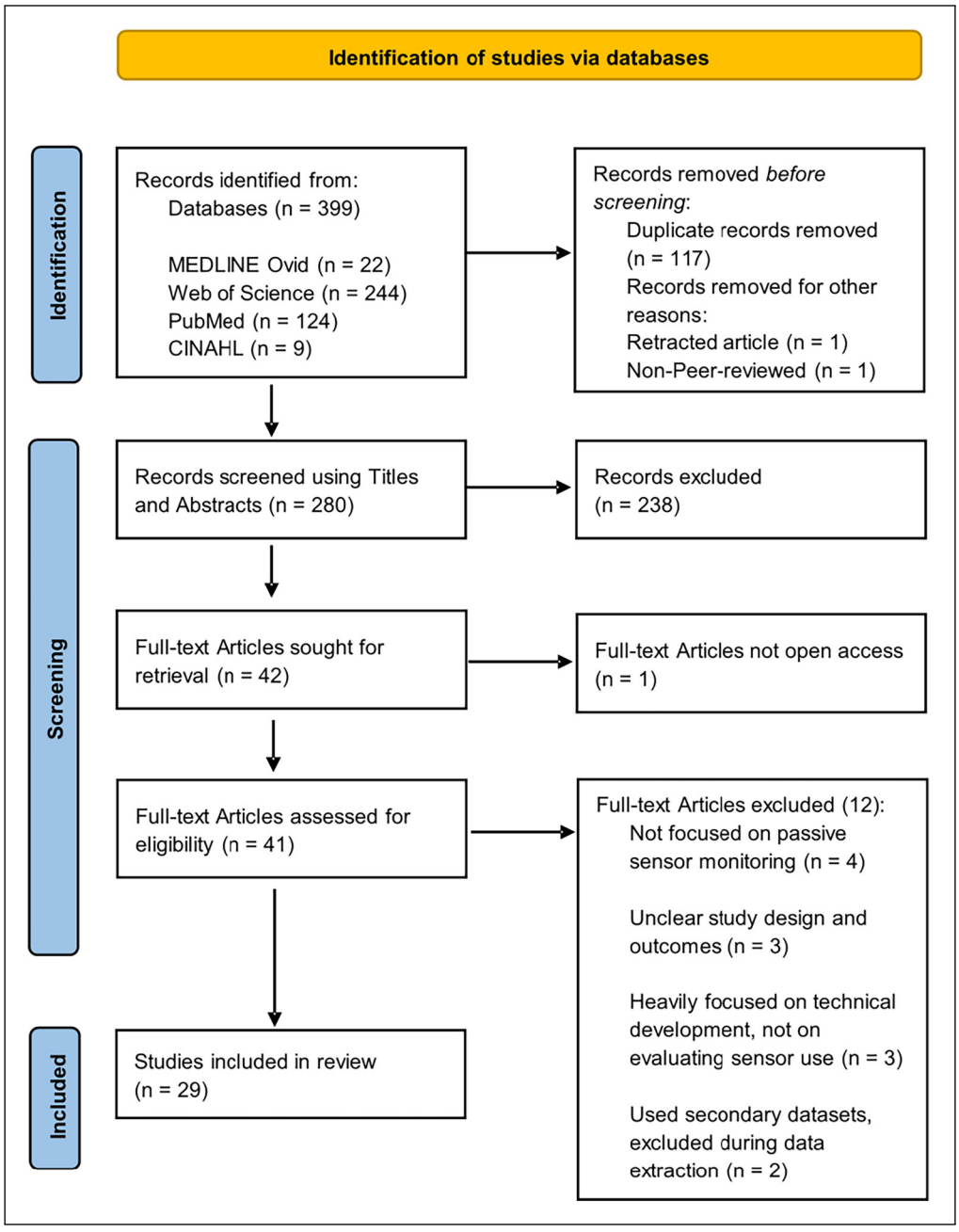

Figure 1. PRISMA 2020 flow diagram for inclusion of studies in scoping review.

Feasibility/developmental study. The feasibility study demonstrated that while technologies are generally acceptable and usable, adoption depends heavily on addressing privacy, trust, and usability concerns rather than technological capability alone. Details of this study are shown in Table 5.

Quality of evidence

Overall, the strength of evidence was moderate. Only 2 studies, both large-scale RCTs, (Donelle et al., 2025; Lu et al., 2025) provided high-quality evidence, both achieving a quality score of 12, corresponding to "high-quality evidence Level 1b", characterised by large sample sizes (N > 100), long monitoring periods (>12 months), and transparent methodologies. Of the remaining studies, 27 were rated as moderate quality, with 2 of these falling into the low-moderate range.

Table 2. Key findings in quantitative studies.

Study	Country	Technology used	Sample & design	Key Findings	Outcome	Effect size / significance
Lu et al., 2025	Australia	Smarter Safer Homes (SSH) Solution; passive sensors	RCT, N = 1086, 12m	Improved quality of life, functional outcomes, early risk detection	Positive	↑ improvements in activity, sleep, time away from home ($p < 0.05$); small-to-moderate effect on ASCOT scores at 6 months (Cohen's $d = 0.377$), but not maintained at 12 months
Lyons et al., 2015	USA	Smart home / ambient pervasive computing (ORCATECH); passive infrared sensor (PIR) sensors	Observational, large cohort, older adults (incl. Alzheimer's), N = 480 homes, 8y	Sensitive digital markers for cognitive decline, feasible for long-term monitoring	Positive	↑ walking speed, improved sleep ($p < 0.05$); computer use decline = dementia progression decline ($p < 0.01$), high sensitivity (McFadden's $R^2 = 0.71$; $p < 0.00001$; ROC curve; AUC = 0.947), high user acceptability (~75%)
Donelle et al., 2025	Canada	Passive Remote Monitoring (PRM)	RCT, N = 313 home care client–caregiver dyads, 12m	Trend toward reduced hospital admissions in Ontario, but not statistically significant. No effect in Nova Scotia.	Null / Mixed	Ontario: Hazard Ratio (HR) = 0.7, 95% CI 0.3–1.4, $p = 0.30$ (not significant). Nova Scotia: HR = 1.1, 95% CI 0.3–3.7, $p = 0.90$ (not significant).
Rawtaer et al., 2020	Singapore	In-home sensors for Mild Cognitive Impairment (MCI) detection	Cross-sectional, N = 49 seniors (MCI & healthy)	Trends for lower activity and more sleep disturbance in MCI, but not significant. High acceptability.	Null / Mixed	No statistically significant differences between MCI and healthy controls for behavioral metrics (steps, sleep, medication adherence); all $p > 0.05$

Table 3. Key barriers, facilitators, and ethical issues in qualitative studies.

Study	Country	Technology	Barriers	Facilitators	Ethical issues
Berridge, 2015a	USA	Passive monitoring system	High refusal, privacy concerns, perceived loss of autonomy, lack of perceived need	Family reassurance, potential for increased safety	Privacy, autonomy, informed consent, user control
Sames and Hutson, 2025	USA	Smart home tech (ambient sensors, Alexa)	Discontinuation, lack of perceived benefit, strong social supports reduce need	Ease of use, family involvement, perceived safety	Autonomy, privacy, informed consent, balancing tech with social support
Berridge, 2015b	USA	Passive monitoring systems	Tension between safety and privacy, lack of transparency, user resistance	Perceived safety, family peace of mind	Privacy, transparency, user agency, need for clear consent
Hargreaves et al., 2017	UK	Lifestyle monitoring	Privacy/surveillance concerns, lack of co-design, fear of being watched	Unobtrusive design, ethical implementation, user involvement	Privacy, co-design, ethical deployment, informed consent
Klemets et al., 2019	Finland	In-home monitoring system (sensors/platform)	Technical issues, data overload, workflow resistance, lack of integration	Supports care planning, potential for improved safety	Data security, privacy, user control
Kavčič et al., 2022	Slovenia	Home-based e-Care Services	Distrust, privacy concerns, reduced human contact, overlap with existing services	Safety, trust, user-centered design	Privacy, trust, autonomy, maintaining human contact
Ghorayeb et al., 2021	UK	Smart home technologies	Privacy, surveillance, data misuse, complexity, misalignment with user needs	Potential for independence, safety, if well-matched to user needs	Privacy, consent, data use, need for ethical alignment with user values
Berridge et al., 2019	USA	Passive remote monitoring sensors	Privacy intrusion, lack of control, cultural misalignment, high discontinuation	Family support, perceived safety, reassurance	Privacy, cultural sensitivity, user control, informed consent
Tiersen et al., 2021	UK	Smart home sensors, user-centered design	Privacy concerns, over-reliance, need for simplicity, personalization	Safety, reassurance, empowerment of caregivers, co-design	Privacy, co-design, user empowerment, ethical personalization
Read et al., 2022	Canada	Passive remote monitoring (CareLink Advantage)	Cost, technical issues, privacy, lack of awareness	Helped older adults stay home, reduced caregiver stress, enhanced care monitoring	Privacy, data security, informed consent, balancing monitoring with autonomy
Bradford et al., 2017	Australia	Smart home sensors, iPad, family portal	Privacy, usability issues, initial skepticism	Peace of mind, health autonomy, improved family communication, motivation for self-monitoring	Privacy, autonomy, user consent, ethical family involvement

Table 4. Integrated quantitative and qualitative findings in mixed-methods studies.

Study	Country	Technology used	Sample & design	Outcome	Effect size/significance	Qualitative findings	Integration of findings
Doyle et al., 2014	Ireland	Ambient home health monitoring	Older adults, mixed methods pilot	Positive	Improved self-management, usability (survey)	Barriers: Tech complexity; Facilitators: Independence, usability; Ethics: User control, privacy	Qualitative and quantitative aligned
Wild et al., 2020	USA	Smart home tech for dementia care	7 retirement communities, n = 95 residents	Mixed/Null	Low methodological quality, unclear effectiveness	Barriers: Lack of rigorous evaluation; Facilitators: Potential for improved ADLs, safety; Ethics: Not detailed	Both showed unclear effectiveness
Obayashi et al., 2023	Japan	In-home passive remote monitoring	Older adults, proof-of-concept	Positive	Qualitative, not quantified	Barriers: Tech unfamiliarity; Facilitators: Independence, care team collaboration; Ethics: Privacy, consent	Both arms found positive user views
Timon et al., 2023	UK	Smart home sensors for dementia	PwD, caregivers, mixed methods	Mixed	Not statistically significant	Barriers: Usability, privacy; Facilitators: Safety, reassurance; Ethics: Consent, autonomy	Qualitative complemented quantitative trends
Aramendi et al., 2018	Spain	Ambient assisted living	Older adults, mixed methods	Positive	Improved activity detection accuracy	Barriers: Sensor errors; Facilitators: Activity monitoring; Ethics: Data security, privacy	Both arms supported feasibility
Urwyler et al., 2017	Switzerland	In-home sensors for cognitive decline	Older adults, mixed methods	Positive	Sensors distinguished cognitive status ($p < 0.05$)	Barriers: Sensor limitations; Facilitators: Early detection; Ethics: Data privacy, consent	Qualitative complemented quantitative findings
Cao et al., 2022	Singapore	Smart home sensors	Older adults, mixed methods	Mixed	Adoption factors significant (survey, $p < 0.05$)	Barriers: Cost, privacy; Facilitators: Safety, family support; Ethics: Privacy, autonomy	Qualitative themes complemented survey results
Timon et al., 2024	UK	Smart home sensors for dementia	PwD, caregivers, mixed methods	Mixed	No significant improvement in outcomes	Barriers: Usability, privacy; Facilitators: Safety, reassurance; Ethics: Consent, autonomy	Qualitative complemented quantitative null results

(Continued)

Table 4. Continued.

Study	Country	Technology used	Sample & design	Outcome	Effect size / significance	Qualitative findings	Integration of findings
Dupuy et al., 2017	France	Smart home activity monitoring	Older adults, mixed methods	Positive	Improved detection of ADLs	Barriers: Sensor errors; Facilitators: Activity monitoring; Ethics: Data privacy, consent	Both arms supported feasibility
VandeWeerd et al., 2020	USA	Passive remote monitoring	313 dyads, RCT + interviews	Mixed/Null	No significant reduction in admissions (HR = 0.7, p = 0.30)	Barriers: No effect on admissions; Facilitators: Some perceived support; Ethics: Privacy, autonomy	Qualitative provided context for null results
Van Kasteren et al., 2017	Australia	In-home sensors for daily routines	3 older adults, 180 days sensor data + interviews	Positive/ Mixed	Sensor data matched self-reported routines	Barriers: Sensor limitations; Facilitators: Routine-based monitoring; Ethics: Privacy, data interpretation	Sensor and interview data aligned
Reeder et al., 2013	USA	Smart home self-management system	10 older adults, mixed methods case study	Positive	Improved self-management, usability (survey)	Barriers: Tech complexity; Facilitators: Independence, usability; Ethics: User control, privacy	Qualitative and quantitative aligned
Choi et al., 2020	USA	Smart home sensors for aging in place	129 older adults, survey + focus groups	Mixed	Perceived usefulness predicted attitudes ($p < 0.05$)	Barriers: Tech skepticism, privacy, cost; Facilitators: Usefulness, safety; Ethics: Privacy, return on investment	Qualitative themes complemented quantitative findings

Table 5. Findings of the feasibility / developmental study.

Study	Country	Technology used	Sample & design	Outcome type	Qualitative outcomes (Barriers, facilitators, ethics)
Bock et al., 2016	USA	IoT smart home devices (sensors, speakers, camera)	37 older adults, 2-month feasibility study	Positive/Feasible	Barriers: Privacy concerns, technical issues (e.g., device reliability), IP camera unpopular; Facilitators: Curiosity, perceived usefulness, safety; Ethics: Privacy, informed consent, user preference

Discussion

This scoping review was undertaken to address ongoing uncertainty regarding the effectiveness, usability, and implementation of domestic sensor-based activity monitoring technologies for older adults, a field that has seen technological advances over the past decade. Early reviews, particularly Brownsell et al. (2011), focused on prototype "lifestyle monitoring" systems with limited analytical capability and weak empirical validation. In contrast, more recent studies incorporate integrated sensor networks, real-time analytics, and decision-support tools, necessitating an updated synthesis of the evidence. Below we present a transversal thematic analysis of the evidence before moving on to a discussion of the implications for policy and practice.

Thematic analysis

Here we present an analysis structured around four cross-cutting dimensions derived from the included evidence: (a) sensor type and technology generation; (b) application purpose; (c) evaluation outcome and implementation maturity; and (d) adoption barriers and facilitators. This cross-dimensional framing moves beyond descriptive reporting to offer an analytically grounded account of where the field stands and where it might usefully go next.

Sensor type and technology generation. A clear progression is evident across the included studies (note here that we refer to when the studies were conducted, if this is apparent, rather than when the results were published). Earlier studies (conducted pre-2015) predominantly used single-modality PIR motion sensors (e.g., Lyons et al., 2015; Porteus and Brownsell, 2000) to detect gross ambulatory activity, with limited ability to discriminate between specific ADLs (Katz et al., 1963). Mid-period studies (conducted 2015–2020) increasingly combined PIR with door/contact sensors, bed and chair occupancy sensors, and smart plug monitors to build multi-room activity profiles (e.g., Timon et al., 2023; VandeWeerd et al., 2020). The most recent generation (studies conducted post-2020) encompasses AI-enabled multi-sensor platforms integrating environmental sensors (temperature, light, humidity), acoustic monitors, wearables, and computer-use tracking, processed via machine-learning pipelines to produce decision-support outputs for clinicians and carers (e.g., Cao et al., 2022; Lu et al., 2025; Morita et al., 2023). This trajectory confirms the transition from standalone passive devices to complex, multi-component smart environment systems which serves as a transition with direct implications for the research agenda. Critically, however, methodological quality has not kept pace with this increased complexity: effectiveness measures remain heterogeneous and contextually variable, a pattern also noted by Kim et al. (2022). In contrast to more restricted reviews (e.g., Read et al., 2022), this study adopts a broader conceptualisation of domestic sensor-based monitoring, encompassing integrated and AI-enabled systems. This approach explains the larger evidence base considered here ($n = 29$ vs. $n = 14$ in the earlier review) and reflects the transition from standalone devices to complex, multi-component interventions. From a smart environment design perspective, three system configurations are represented in the included literature: (i) passive ambient sensor arrays without data processing intelligence (e.g., Bradford et al., 2017; Reeder et al., 2013), where raw sensor data is reviewed manually by carers or clinicians; (ii) rule-based automated alert systems (e.g., Doyle et al., 2014; VandeWeerd et al., 2020), where pre-specified thresholds trigger notifications to care teams; and (iii) machine-learning-enabled predictive platforms (e.g., Lu et al., 2025; Lyons et al., 2015; Morita et al., 2023), where AI components model behavioural baselines, detect anomalies, and generate decision-support outputs. Each configuration has distinct interoperability requirements, data governance implications, and evidence maturity profiles; distinctions that existing reviews have not made explicit and that carry direct implications for the researchers designing next-generation ambient assisted living systems. The inclusion of qualitative and mixed-methods studies further strengthens the analysis by capturing usability, ethical concerns, and implementation challenges that purely quantitative syntheses overlook.

Application purpose. Across the 29 included studies, three primary application purposes can be distinguished, each with a distinct evidence profile. First, ADL monitoring for independence preservation is the most prevalent purpose (n = 18 studies), with sensors deployed to track functional routines such as sleep, nutrition, mobility, and medication-taking. Outcomes here are predominantly qualitative or mixed-methods, with acceptability and perceived safety as the dominant findings (e.g., Bradford et al., 2017; Ghorayeb et al., 2021; Tiersen et al., 2021). Second, cognitive decline surveillance is addressed by a smaller but growing cluster of studies (n = 7) using sensor data to generate digital biomarkers of cognitive status, with Lyons et al. (2015) and Rawtaer et al. (2020) demonstrating sensitivity of walking speed, sleep disruption, and computer-use patterns as early indicators of mild cognitive impairment. Third, clinical outcome optimization, including hospitalisation reduction, fall prevention, and functional independence is the least evidentially mature purpose (n = 4 quantitative studies), with mixed results: Lu et al. (2025) demonstrate significant improvements in quality of life and activity ($p < 0.05$), while Donelle et al. (2025) find no statistically significant effect on hospital admissions (HR = 0.7, 95% CI 0.3–1.4, $p = 0.30$). This disparity suggests that technological capability has advanced more rapidly than effective application, with more work necessary to understand how to exploit the opportunities offered to the utmost.

Evidence robustness. A key contribution of this review is the explicit stratification of studies – and the evidence they provide – by implementation maturity, using OCEBM evidence levels and study design as proxies. Three maturity tiers are evident. At feasibility and proof-of-concept level (OCEBM Level 4–5, feasibility, pilot and proof-of-concept/first-principles studies), the majority of included studies (n = 17) establish that domestic sensors are technically deployable and broadly acceptable to older adults and carers under supported conditions. At observational effectiveness level (OCEBM Level 2b–3b, cohort and cross-sectional studies), studies such as Lyons et al. (2015) and Urwyler et al. (2017) provide longitudinal evidence of associations between sensor-detected behavioural changes and clinical outcomes, but causal inference is limited. At RCT level (OCEBM Level 1b, n = 2), evidence is emerging: Lu et al. (2025) demonstrate significant improvements in quality of life and activity outcomes, while Donelle et al. (2025) find no significant hospitalisation effect (HR = 0.7, 95% CI 0.3–1.4, $p = 0.30$). Crucially, no included study provides a full health-economic evaluation alongside clinical outcomes, representing a critical evidence gap that limits commissioning decisions. The two studies that address cost directly offer instructive but methodologically limited evidence that warrants careful interpretation. Cao et al. (2022), conducted in Singapore, found that older adults consistently prioritised perceived usefulness and security over cost when evaluating smart home sensors. However, this finding must be contextualised critically: participants received free subscriptions during the study, meaning long-term willingness to pay at the actual subscription rate (approximately SG$25/month, equivalent to around GB£14/month or US$17.50/month) remains untested and uncertain. Additional concerns raised by participants including electricity consumption and ongoing subscription fees indicate that cost sensitivity is present but may be suppressed when technology is provided without charge. Affordability in this study was also mediated by family financial support and government subsidy availability, limiting the generalisability of positive cost perceptions to unsupported or lower-income populations. Read et al. (2022) offer a complementary but distinct perspective, drawing on stakeholder (decision-maker) rather than end-user viewpoints. Internet access and subscription costs were identified as adoption barriers, particularly in rural areas where connectivity infrastructure is inadequate; a digital equity concern that compounds the technological adoption barriers identified in the qualitative literature. While decision-makers perceived major system-level cost savings through reduced institutionalisation and reduced workforce strain, these savings were projected and perceived rather than empirically quantified. No cost-effectiveness ratio, return-on-investment figure, or incremental cost per quality-adjusted life year (QALY) was reported in either study, meaning the claim that "benefits may outweigh costs" remains an inference rather than an evidence-based conclusion. Taken together, these two studies suggest that domestic sensor monitoring may be cost-beneficial at a system level, particularly through avoided institutionalisation, but this potential has not been empirically demonstrated. The absence of robust, prospective health-economic evaluations including full cost-utility analyses conducted alongside RCTs represents a major and continuing barrier to large-scale deployment, and NHS and comparable healthcare commissioning. Future trials must embed economic evaluation components from the outset, using standardised instruments (e.g., EQ-5D, ASCOT) to quantify cost per QALY and enable comparison with existing telehealth and care-home alternatives.

Adoption barriers and facilitators. Qualitative evidence (n = 11 studies) converges on a consistent typology of adoption barriers, each with distinct implications for smart environment design. Privacy and surveillance concerns are the most frequently cited barrier (reported in n = 9 studies), with older adults consistently describing discomfort with continuous passive observation and a perceived loss of autonomy (Bradford et al., 2017; Ghorayeb et al., 2021; Hargreaves et al., 2017). This has direct implications for sensor placement, data minimisation strategies, and the design of user control interfaces in smart homes. Digital literacy gaps and lack of perceived need (n = 6 studies) are particularly pronounced among the oldest-old and those living alone (Kavčič et al., 2022; Sames and Hutson, 2025), indicating that interface simplicity

and meaningful framing of benefits are essential design requirements. Technical reliability and alert fatigue (n = 5 studies): false alarms and system complexity create workflow resistance among care staff (Klemets et al., 2019), pointing to the need for AI-driven anomaly detection models that reduce noise and contextualise alerts. Conversely, the primary facilitator across studies is family reassurance (n = 8 studies): sensors are most accepted when framed as enabling independence and providing peace of mind to relatives, rather than as surveillance instruments. By integrating these adoption insights with effectiveness and maturity data, this review demonstrates that limited real-world adoption reflects not a technological deficit alone, but a misalignment between system design, user values, and health system readiness; a misalignment that ambient intelligence research is uniquely positioned to address. Finally, the cross-dimensional analysis above enables a more nuanced interpretation of the evidence than quality appraisal alone allows. Although methodological quality has improved over time, this and earlier reviews converge on a central limitation: the scarcity of large, high-quality quantitative studies with standardised outcome measures and economic evaluation components. The evidence base is densest at the feasibility tier (qualitative/pilot) and thinnest precisely where it matters most for commissioning decisions: the large-scale controlled trial and health-economic tier. As a result, despite significant smart environment technological progress, the empirical foundations for clinical and policy implementation remain underdeveloped. Addressing this requires not only more controlled trials, but trials designed with explicit sensor-type specifications, AI component descriptions, and application purpose definitions to enable the cross-dimensional comparisons that the field currently lacks.

Compared with foundational work by Brownsell et al. (2011), and subsequent reviews such as Abdi et al. (2019) and Kim et al. (2022), the present review demonstrates clear advancement in the field. Terminology has evolved from "lifestyle monitoring" to "domestic sensors", "smart homes", and "AI-enabled monitoring". Study sample sizes, follow-up durations, and methodological rigour have improved markedly: Lyons et al. (2015) tracked 480 homes over eight years, and Lu et al. (2025) conducted an RCT with 1086 participants showing statistically significant improvements in activity, sleep, and quality of life (all $p < 0.05$). The present review encompasses more sophisticated technologies, from basic PIR sensors to AI-enabled multi-sensor platforms with predictive machine-learning models, compared with the largely prototype-level systems described by Brownsell et al. (2011). Nonetheless, persistent gaps in evidence, economic evaluation, real-world implementation, and health and care service integration and commissioning confirm that concerns raised in earlier reviews remain relevant, underscoring the need for the structured future research agenda proposed here. Taken together, the cross-dimensional synthesis above provides a timely and analytically structured update to the literature. By organising the evidence across sensor type and technology generation, application purpose, evaluation outcome and implementation maturity, and adoption barriers and facilitators, this review moves beyond descriptive reporting to offer a framework for situating existing studies and designing future research. It demonstrates that the field has advanced from prototype PIR-only systems to AI-enabled smart environments, but that clinical validation, health-economic evidence, and system-design standards have not kept pace. Rigorous, long-term, and economically robust evaluations with explicit cross-dimensional design specifications are needed to close this gap, support large-scale adoption and healthcare commissioning in NHS and comparable healthcare systems.

Implications for policy and practice

Domestic sensor technologies have evolved beyond early prototypes (Brownsell et al., 2011) into interventions that show promise for improving quality of life, independence, and safety, though the strength of evidence varies across studies (Lu et al., 2025; Lyons et al., 2015). However, wider adoption requires stronger cost-effectiveness evidence and clear governance around privacy, consent, and data use. Policies should prioritise large-scale trials, explore interoperability with existing processes and systems, and be mindful of equitable access to prevent digital exclusion.

For healthcare practitioners. When relatively simple and well-integrated into daily routines, these technologies can enhance confidence, independence, and intervention adherence. Success depends on technical support, family involvement, and addressing ethical concerns. Practitioners should adopt co-design approaches, frame technologies as supporting independence, and ensure integration with primary and community care pathways. Specifically, clinicians should be involved in defining alert thresholds and response protocols before deployment, to ensure that sensor-generated data feeds meaningfully into care planning rather than creating "alert fatigue". Training in data interpretation will be essential. Practitioners should position these systems as complementary to, rather than replacements for, face-to-face care, and should advocate for co-design processes that include older adults, carers and other users from the earliest stages of deployment (Tiersen et al., 2021; Timon et al., 2024).

For families and carers. Domestic sensors show potential to enhance safety, support monitoring of medication routines, and enable ageing in place, while the evidence for improvement in medication adherence specifically remains limited.

However, acceptance depends on balancing safety with autonomy. Families should involve older relatives in decisions, ensure informed consent, and provide practical support, positioning technologies as empowering rather than controlling.

For health and care service commissioners. Although some studies suggest the potential to support independent living and dementia care, health and care service integration remains limited and the evidence for reduction of hospitalisation rates is mixed (Donelle et al., 2025). Key practical barriers include alignment with (possibly adapted) workflows and assigning responsibility for monitoring. Evidence shows modest short-term benefits in some contexts but heterogeneity in outcomes limits definitive conclusions, highlighting the need for standardised, long-term evaluations and better integration strategies. Meanwhile, the lack of robust evidence of cost-effectiveness will always hamper uptake by risk-averse and cash-strapped health services Commissioners should require economic evaluations as part of any future procurement, and interoperability with existing digital health infrastructure must be planned from the outset.

In summary, domestic sensors offer strong potential to support ageing in place but are not standalone solutions. Effective implementation requires alignment between technology, user needs, ethical considerations, and health system resources and readiness. Co-design, robust evidence, and policy support are essential for sustainable adoption.

Recommendations for future research

Future research should prioritise multi-site controlled trials, standardised outcome measures, and robust cost-effectiveness analyses. Greater focus is needed on underserved populations, health and care system interoperability, ethical governance, and measurable long-term outcomes such as hospitalisation and fall prevention to support scalable implementation. However, such robust studies are expensive in terms of time, money and resources, and so will require some commitment in terms of research funding bodies. To provide a structured agenda the following priorities are identified (listed here in no particular order): (1) Sensor and smart environment design: comparative studies of multi-sensor configurations (passive infrared, door/contact, environmental, acoustic) across diverse living contexts to identify optimal deployments. (2) AI and data analytics: development of explainable AI models for clinician-interpretable outputs, and privacy-preserving federated learning approaches for multi-site training. (3) Health and care integration: trials must explicitly test escalation protocols, alert threshold design, and clinician dashboard integration within real care pathways. (4) Equity and inclusion: co-design-led research specifically recruiting rural, low-income, and minority ethnic populations. (5) Longitudinal controlled trials: large-scale, multi-site trials with at least 12 months follow-up, incorporating full health economic evaluation from societal and health system perspectives. (6) Ethical governance: development of standardised frameworks for data consent, ownership, and algorithmic transparency in domestic sensor deployments.

Strengths and limitations

This scoping review offers several notable strengths. It is among the few reviews to focus specifically on domestic sensor-based activity monitoring technologies for older adults, with particular relevance to high-income country settings. By synthesising evidence across quantitative, qualitative, mixed-methods, and feasibility studies, the review provides a comprehensive overview of both effectiveness outcomes and user experiences. The inclusion of studies spanning different designs, countries, and contexts strengthens the breadth of insights, while the use of structured data extraction and narrative synthesis supports a transparent and systematic approach (Pollock et al., 2022). Furthermore, the review highlights important implications for policy and practice, particularly regarding feasibility within health and care systems, and the ethical challenges of large-scale implementation.

However, several limitations must be acknowledged. First, the review was conducted by a single primary reviewer, with only partial cross-checking by a second reviewer, which introduces the potential for selection bias during study screening, data extraction, and interpretation. Additionally, while the review focused on independent living, a small number of included studies were conducted in assisted living or continuing care retirement community settings (e.g., (Wild et al., 2020)); these were retained as participants were ambulant community-dwelling adults in analogous monitoring contexts, but this represents heterogeneity that should be acknowledged. The exclusion of non-English publications, studies prior to 2010, non-peer reviewed work and grey literature might well have excluded relevant evidence. Similarly, the exclusion of non-open access papers and other paywalled materials could also have excluded evidence. While it is inevitable that the evidence base that has been considered has been reduced and so is less comprehensive due to these restrictions, it is impossible to say whether this would have led to systematic bias in the data and what effect, if any, this would have on the conclusions drawn and recommendations made here. Another limitation relates to the methodological quality of included studies; many were qualitative studies, small-scale mixed-methods studies or feasibility trials with limited statistical power, and several reported only preliminary findings. This restricts the generalisability of conclusions. On the other hand, detailed participant characteristics such as age, gender, comorbidities, and baseline functional status were

not systematically analysed. Notwithstanding, the findings reported here are valuable for mapping current evidence and identifying gaps in that evidence.

Conclusion

This scoping review of 29 studies published in the period 2010–2025 shows that domestic sensor-based monitoring has advanced from early prototypes to more rigorous evidence demonstrating potential benefits in some studies, including improvements in quality of life, enhanced feelings of safety and independence, and early detection of functional or cognitive decline; however, evidence for reduced hospitalisations and improved medication adherence remains limited and inconsistent across included studies, and further rigorous research is required. However, effectiveness depends on acceptability, with barriers including privacy concerns, reduced autonomy, digital literacy gaps, and unequal access, while reassurance, safety, and family support facilitate uptake. However, work is still needed, at both research and practice levels, to expand the evidence base and deploy in such a way as to reliably realise the potential benefits.

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Ethical considerations

This scoping review used only secondary data. As such, formal ethics approval was not required.

Consent to participate

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Consent for publication

Not applicable.

Authors' contributions

AM: Data curation; formal analysis; investigation; methodology; visualization; writing – original draft; SP: Methodology; supervision; validation; writing – review & editing; MH: Conceptualization; methodology; writing – review & editing.

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Supplemental material

Supplemental material for this article is available online.

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