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Exploring AI Smart Home Aging-in-Place: Use Cases to Empower Individuals With MCI and Their Carepartners

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ABSTRACT

Mild Cognitive Impairment (MCI) presents a critical juncture between normal cognitive aging and dementia, necessitating tailored interventions for individuals and their informal caregivers (carepartners). Individuals with Mild Cognitive Impairment (MCI) often require greater assistance at home to complete everyday tasks and increased support from their carepartners through prompts and shifting of task responsibility. This evolving dynamic often leads to a heightened burden on caregivers. In order to understand these challenges in the home environment and how they may be addressed with technology, we employed an AI-powered smart home system and app as a technology probe in n = 13 homes of individuals with MCI. We used a mixed-methods, user-centered approach to collect qualitative and quantitative feedback from dyads of individuals with MCI and their carepartners on their experience with the system and desires from the system. Results indicated nuanced patterns of app usage based on factors such as caregiver proximity in relation to living arrangements, extent of MCI progression, and individual tech proficiency. This paper describes use cases underscoring the potential of AI-driven smart home technologies to address the unique challenges faced by individuals with MCI and their carepartners in order to foster independence and enable safe aging-in-place. This research contributes to the field by offering future considerations for AI-based interventions, including: unique user needs necessitating greater personalization, dyad living arrangements, and seamless integration with existing technologies.

Keywords: MCI, Mild cognitive impairment, Artificial intelligence, Smart home, Interventions, Aging-in-place, Activity monitoring, Home safety, Technology probe

INTRODUCTION

Mild Cognitive Impairment (MCI) is a clinical syndrome involving subtle changes in cognitive function that are beyond normal aging, but not yet dementia. (Winblad, 2004). MCI is characterized by a decline in cognitive functions, such as: "memory, attention, language, visuospatial skill, perceptual speed and executive functioning" (Winblad, 2004), which affect Instrumental Activities of Daily Living (IADLs), including: managing finances and medication, keeping appointments, finding items, using technology, preparing meals, and performing household chores. (Ahn, 2009). Individuals with early MCI can perform most home-related tasks without issue, but the effects of their cognitive decline may result in less awareness, slower performance, and engagement in unsafe tasks (Vogel, 2004). To ensure the safety of the individual with MCI (iwMCI) as cognitive status declines, informal caregivers (carepartners), such as a spouse, adult child, or other family member, often take over more responsibilities and provide increased oversight and prompting of the iwMCI. In turn, both carepartner and iwMCI may experience decline in mental, social, and physical health, as well as relationship challenges (Carlozzi, 2018; Paradise, 2015, Lu, 2009).

Past studies involving technology solutions intended to address the needs of carepartners and iwMCI at home have focused on monitoring one or more of the iwMCI's activities, such as hygiene, toileting, eating, medication adherence, social interaction, and technology use to detect changes in patterns using multimodal sensing (wearables, smarthome sensing, cameras, etc) and to intervene in some way based on that information. In some studies, insights from monitoring are shared with carepartners to inform when intervention may be necessary, while in other studies, the insights drive a technology intervention. Examples include: conversational assistant medication reminders (Mathur, 2022), intelligent pillboxes, lost object finding, handwashing hygiene reminders, smart stove alerts and control, and holistic health monitoring (Demris 2008, Thapliyal, 2017).

With a goal of identifying additional opportunities for tech to assist iwMCI and carepartners at home, this research explores the home support needs of 13 dyads, each consisting of an older adult with MCI and their carepartner, using an AI-powered smart home solution and app as a probe (Hutchinson, 2003). This paper presents multiple use cases underscoring the potential of AI smart home technologies to address the unique challenges faced by iwMCI and their carepartners and offer future considerations for AI-based interventions, including: unique user needs necessitating greater personalization, dyad living arrangements, and seamless integration with existing technologies.

METHODOLOGY

Smart Home System

For this study, commercially available smarthome devices monitored by an AI-powered Software-as-a-Service (SAAS) and smartphone apps developed by People Power Co. dba Care Daily (referred to as AISmartHome) was deployed in 13 homes. The Care Daily platform with app was selected due to its ability to provide insights valuable for older adults and carepartners, along with its flexibility in deployment and remote adjustments. The integrated app was designed to deliver essential insights to users, offering information such as medication adherence reminders and notifications for daily activities, to enhance caregiving support and promote independence for the iwMCI. Such insights were supported by the placement of sensors and cables within the home (see Table 1). The application functioned as a technology probe, providing insights into potential use cases for similar systems and the considerations necessary for developing future systems.

Table 1. Set of sensors available to be deployed in homes.

Sensor	Placement in Home	Supported Inferences
Motion Sensor	Kitchen, master bedroom & bathroom, entrance areas, commonly used spaces (living rooms, informal dining, gym, office)	Sleep, activity levels, occupant presence and whereabouts
Temperature & Humidity Sensors	Kitchen (above stove/rangehood), showers used by iwMCI, central room in home, bedroom	Showering
Vibration Sensors	Inside toilet tank, medication boxes	Toileting, medication adherence
Entry Sensors	Perimeter doors (front, back, garage, etc.), fridge & freezer doors, microwave door	Entry door opened/left open, wandering, meal-time activities
Smart Cables	TV, lamps, microwave, convection ovens	Electronics use, energy consumption, meal-time activities

Beyond the base system, some homes were selected for additional feature tests, such as pet care monitoring, or lighting control with a wireless button or voice control using Google Home or Alexa. The decision to install in these homes was based on feedback from the dyads and discussions on potential usefulness. Due to the diversity of homes, some sensors were not possible to install. For example, smart cables would shut off with some microwave models and stove venting system designs hindered placement of temperature and humidity sensors.

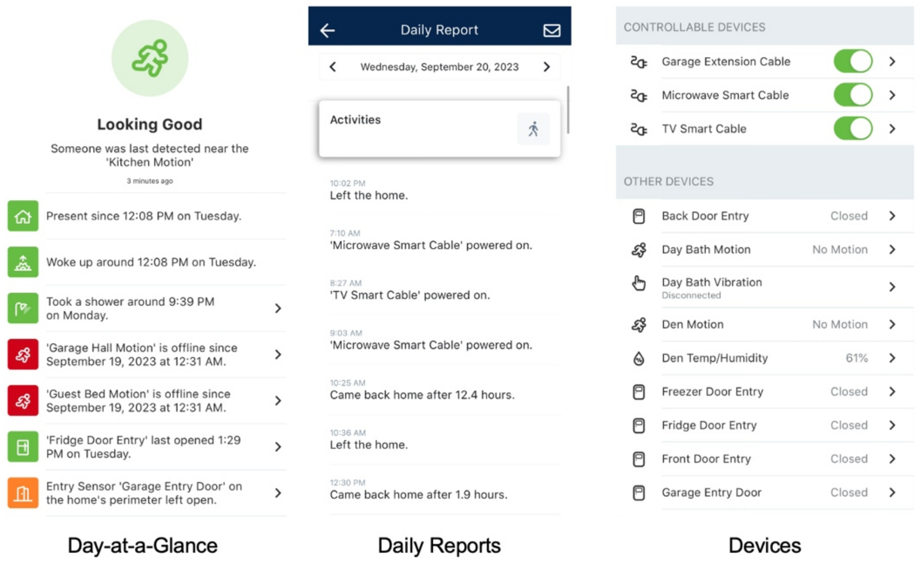

Figure 1: Smart home application key features.

The application allowed participants to view sensor insights through 3 main features referred to as: Day-at-a-Glance, Daily Reports, and Devices (see Figure 1) as well as Notifications. With Day-at-a-Glance, users could view a summary of recent activities within the home, highlighting any areas of concern, including offline sensors or doors left open. If information of interest was not shown in Day-at-a-Glance, users could use Daily Reports to view a full breakdown of all activity within the home. Daily Reports divided information by day and by activity type (e.g. Meals, Medication, Bathroom), enabling users to scroll through previous days. With the Devices page, users could remotely control lights and view the real-time status of sensors, checking for open doors and offline sensors.

The application provided updates to users primarily through customizable notifications. Users could opt into app or SMS alerts based on their individual needs, for example, enabling alerts for wandering, medication adherence, or late-night activity.

Participants

Thirteen dyads (n = 13), consisting of an older adult diagnosed with MCI (iwMCI) and their carepartner, were introduced to the app. Carepartner relationship varied per dyad, presenting as spouses, siblings, or adult children with different caregiving arrangements in relation to the iwMCI (i.e. cohabitating, adjacent living, remote). All carepartners were given access to the application, while iwMCI were given the option to use the app (either full app access, or SMS notifications only). Table 2 details participant information.

Table 2. Dyad information.

Dyad	Who Had App	Carepartner Relation	Living Arrangement
D01	CP	Spouse	Cohabitating
D02	CP	Spouse	Cohabitating
D03	CP	Spouse	Cohabitating
D04	CP & iwMCI	Adult child	Remote
D05	CP & iwMCI (notifications only)	Adult child	Adjacent
D06	CP	Spouse	Cohabitating
D07	CP & iwMCI	Adult child	Adjacent
D08	CP	Spouse	Cohabitating
D09	CP	Spouse	Cohabitating
D10	CP	Spouse	Cohabitating
D11	CP & iwMCI	Spouse	Cohabitating
D12	CP (notifications only) & iwMCI	Partner	Mix of Co/Remote
D13	CP	Adult child	Remote

Procedure

Smarthome sensing technologies were installed in participants' homes during the first in-person visit. This installation process was guided by information from initial phone interviews to optimize sensor quantity and placement for enhanced system efficiency. Sensors were installed at least a month before the app introduction to allow the system to learn patterns and behaviors within the home. The app introduction involved a walkthrough of key features including Day-at-Glance, Daily Reports, Devices, and Notifications. Users were encouraged to explore additional features as desired.

The feedback protocol employed a mixed-methods, user-centered approach, combining qualitative and quantitative feedback through System Usability Scale (SUS) scores, Likert scales, and open-ended questions. Interviews, conducted at least twice for most dyads, were scheduled at least a month apart. The first feedback interview served a dual purpose: collecting feedback and reintroducing the app's functions, prompting user engagement and value discovery. Questions focused on app usage, perceived usefulness, and challenges related to MCI goals.

Researchers fostered relationships with dyads to encourage honest feedback through established rapport. Semi-structured interviews conducted with lead researchers captured information around dyad living situations, observed progression, and unique challenges. Insights were gathered through built relationships and observations during home visits, providing a unique contextualization of interview feedback.

FINDINGS

Results highlighted a range of use cases for AI-powered smart home systems in supporting aging-in-place for iwMCI and their carepartners. However, they also pointed to limitations in the current system. Findings obtained from a thematic analysis of feedback sessions are summarized below.

Use Cases for Carepartners

Use cases of the system for carepartners of iwMCI were categorized across several themes (see Table 3).

Security (Door Status): AISmartHome was most frequently used by dyads to monitor door status, with 11 out of 13 homes utilizing the app for this purpose. Door opening alerts proved beneficial for both remote and in-person carepartners, aiding in tracking the movements of the iwMCI and preventing wandering. Two homes specifically employed the app for wandering prevention. The immediate door opening alerts, especially when not in the same room as the iwMCI, prompted these carepartners to take action in ensuring the safety of the iwMCI. In eight homes, concerns around entry doors being left open were addressed through customized alerts, notifying carepartners when doors remained open for a self-selected duration.

Daily Routine Check: AISmartHome aided carepartners in ensuring daily routine adherence, addressing activities such as medication intake, mealtime adherence, showering, sleep, and pet care. The application was utilized by carepartners to verify the completion of specific daily tasks based on dyad concerns. 5 out of 13 carepartners used the app for tracking morning and evening medication. Additionally, 3 out of 13 homes employed the application to monitor fridge openings and microwave usage as potential indicators of mealtime adherence. However, one home noted the limitations of using such activities as evidence of actual meal consumption.

Daily Routine Analysis: AISmartHome provided carepartners with both reminders and the ability to analyze daily tasks. Cohabitating carepartners utilized motion sensor data to track the whereabouts and activities of the iwMCI in the home, while remote carepartners monitored their presence at home. Two carepartners found the app useful for non-intrusive safety checks. Sleep quality and duration were also concerns, particularly for remote carepartners, with three reporting it as a use case. AISmartHome facilitated the assessment of night-time activity, allowing one carepartner to identify instances of night-time confusion.

General Household Maintenance: Through smart cables, humidity sensors, and door sensors attached to appliances and devices, AISmartHome facilitated remote household management for carepartners. In three households, the app ensured fridge and freezer doors were closed. An app alert also prompted one carepartner to remind the iwMCI to retrieve food left in the microwave, contributing to meal-time adherence.

Table 3. Use cases of smart home systems for care partners (CPs) and iwMCI.

Theme	Use Case	# of Users (CPs)	# of Users (iwMCI)
Security	Entry Door Left Open	9	
	Entry Door Opened	6	1
	Security Alarm Armed	1	1
Daily Routine Check *(Did iwMCI or I do x task today?)*	Medication Taken	5	3
	Ate (Fridge/Microwave Opened)	3	2
	Showered	2	
	Oven Used	1	
	Napped	1	
	Pet Fed	1	
	Complete Task List		1
Daily Routine Analysis *(When did I or iwMCI do x task? What are the details of x task?)*	Details Around Movements *(Is iwMCI home? Where in home?)*	7	
	Open Fridge/Microwave	4	
	Quality of Sleep	3	
	Sleep & Wakeup Times	3	2
	Bathroom Visits Monitoring	3	
	Activity Level Monitoring		1
General Household Maintenance	Microwave/Fridge Left Open	3	
	Food Left in Microwave	1	1
	Turn Lights On/Off	2	2
	Monitor Humidity Levels	2	
Detect out of the Norm Activity	Understand MCI Progress through Changes in Living Patterns	5	
	Identify Problem Spots/Events	2	
	Fall Detection	1	
Social	Prompt Check-in with iwMCI	3	
	Provide Topics of Conversation	1	

Detect out of the Norm Activity: AISmartHome facilitated the establishment of a baseline of normal activity for iwMCI through the Daily Reports. Carepartners compared activities across multiple days, identifying changes in living patterns that may signify further progression of MCI. One carepartner noted that the app prompted adjustments to these changes and enabled sharing insights with their doctor when concerned.

Social: AISmartHome sends social alerts as reminders for users to reach out to the iwMCI. In three dyads with remote carepartners, these social alerts prompted check-ins with the individual. Furthermore, one iwMCI noted the app's information facilitated conversations with family members with access, prompting questions about daily activities.

Use Cases for iwMCI

Use cases for iwMCI with app or SMS notification access centered around specific daily activities of concern including security, daily routine check, daily routine analysis, and general household maintenance (see Table 3).

Daily Routine Check: For iwMCI, AISmartHome served as a reminder for daily events, allowing them to answer the question, "Did I complete this task today?". Of the five iwMCI with app or notification access, three found the app beneficial for medication adherence. One participant, who often forgets medication while in the garden, was successfully reminded through AISmartHome. Another participant appreciated the ability to verify medication adherence, eliminating the need to check with their carepartner.

Daily Routine Analysis: AISmartHome enabled iwMCI to collect additional, detailed information about their daily activities, fostering a sense of independence and control. Two participants used the app for analyzing sleep quality, considering sleep length and nighttime wakeups. The app also sent SMS alerts for low activity levels, encouraging occupants to be active, which one participant found useful.

General Household Maintenance: AISmartHome enhanced awareness of the household environment and deviations from the norm for iwMCI. For example, one iwMCI, who also served as caregiver for their spouse, appreciated the app for providing greater home awareness, ensuring closed fridge and entry doors. Reminders of food left in the microwave also facilitated mealtime adherence.

Factors Influencing Use

Analysis of the AISmartHome system pointed to nuanced patterns of usage influenced by three variables: carepartner proximity, MCI progression, and tech proficiency of the user. Figure 2 demonstrates how two of these factors - MCI progression and carepartner proximity - impact use cases.

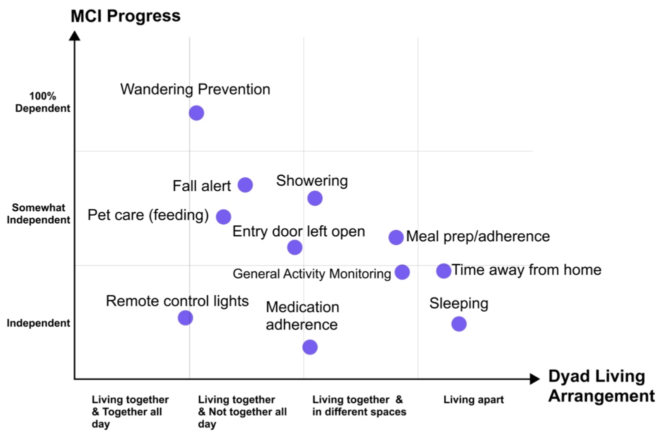

Figure 2: AISmartHome use cases based on caregiver proximity and MCI progression.

In four homes, cohabitating carepartners who were with the iwMCI for most of the day found app information redundant, as they were already aware of most activities, while six homes stated the level of monitoring was unnecessary for the iwMCI's current condition. Despite fewer observed use cases in situations where caregivers and iwMCI cohabitated, entry door sensors remained valuable for addressing wandering and enhancing general security. In these homes, the app was also often useful for managing daily chores and tasks such as medication adherence, showering, and pet care, particularly when the iwMCI had higher independence.

For iwMCI under remote caregiving arrangements, a relatively higher level of independence was observed. However, concerns arose with remote caregivers around quality of sleep, night-time activity, and medication adherence. Medication adherence also emerged as a concern when cohabitating iwMCI and their carepartners were not in close proximity throughout the day. In instances of more pronounced decline, cohabitating carepartners often assumed the responsibility of managing medications, making app use unnecessary for this purpose.

Technology proficiency was another factor that was consistently seen as an influence on dyad app use for both iwMCI and their carepartners. Carepartners and iwMCI with lower proficiency were more likely to face frustrations and discouragement in using the app due to system inaccuracies and limitations.

Usability & Usefulness

The System Usability Scale (SUS) was administered during each round of feedback sessions to gather a quantitative understanding of AISmartHome's usability. The average SUS score for both the first round (16 responses SUS = 70.47) and subsequent sessions (13 responses, SUS = 76.54) was 73.19 out of 100, indicating "good" usability on Bangor's adjective rating scale. This increase in score may be attributed to the inherent reintroduction of features during the first session.

During feedback sessions, participants systematically evaluated the usefulness of each application feature, providing ratings on a scale ranging from "not at all useful" (1) to "very useful" (4) based on their usage experience. The participants' assessments of the key app features are synthesized in Table 4. All participants engaged with app notifications, assigning an average usefulness rating of 3.21. This highlights the perceived efficacy of these notifications in the context of participants' interactions with the application.

Table 4. Usefulness of key AISmartHome features (1 = not at all useful, 4= very useful).

App Feature	Usefulness	# of Responses
Day at a Glance	3.09	23
Daily Report	2.88	16
Devices	3.08	15
Notifications	3.21	29

System Limitations

While the findings highlight promising use cases of smart home interventions, it is imperative to acknowledge the limitations of the system.

One notable limitation pertains to the system's inability to distinguish between occupants of the home and pets. Wearables were considered, but not implemented, thus activity inferences (e.g. sleep, meal prep, door openings) were for the home, not the iwMCI alone.

Challenges from sensing failures due to sensors falling, varying signal strength, water intrusion (toilet tank), or just incompatibility with appliances resulted in frustratingly inaccurate alerts, such as closed garage doors appearing left open (3 homes) or falsely reporting food left in the microwave (4 homes). A carepartner also noted the AI inferred the home was empty when the iwMCI was napping and the carepartner went out, but noted that a notification indicated when the iwMCI awoke. Six homes reported receiving notifications that exceeded the level of information needed for the iwMCI's current condition, raising concerns about the relevance of the information provided.

The system's inability to accurately distinguish between occupants, coupled with issues of information overload and sensor or AI inaccuracies, underscores the need for further refinement in the development and deployment of AI-based interventions for this population.

DESIGN IMPLICATIONS

Drawing from dyad feedback and described challenges with the app, several design implications for future AI-based interventions were identified to enhance the effectiveness of smart home systems in supporting iwMCI and their carepartners.

Customization and Personalization: Dyads emphasized the need for greater customization across the app, particularly in addressing unique information needs dependent on MCI progress. The ability to tailor the frequency and types of notifications and highlight information of interest within the application is essential in enhancing the relevance of the system in daily caregiving routines.

Detailed Information around the Kitchen: Dyads expressed the need for real-time detailed monitoring of kitchen activities and enhanced safety features, lacking in the current system, to address potential hazards (e.g. stove left on or something left on stove) effectively. Providing detailed information about kitchen events would enable carepartners to respond promptly to safety concerns and mitigate risks associated with meal-prep.

Greater Precision: Dyads requested greater precision in monitoring activities and events within the home that would, for example, allow them to distinguish medication taking from filling the med box or patterns of meal prep versus just opening the fridge. Enhancing precision in activity detection, distinguishing occupants, and reporting presence in and away from the home would provide dyads with more accurate insights into daily routines and enable better decision-making regarding caregiving tasks and safety measures.

Integration with Existing Technologies: Dyads suggested integrating the smart home system with wearables like Apple Watch and voice assistants like Google Home to precisely track behaviours such as wandering and provide timely reminders for tasks like meal-time or medication adherence, offering expanded capabilities and support for users. In this study, only a few homes received integrated voice assistants.

CONCLUSION

This case study underscores the diversity of use cases of smart home systems for individuals with MCI and their carepartners. System use is influenced by factors such as the progression of MCI, technological proficiency, and carepartner proximity. Medication management and door activity monitoring emerged as common use cases across dyads, with medication reminders being particularly helpful among iwMCI with app access. The findings emphasize the need for future smart home systems to accommodate varying needs and preferences of dyads, allowing for a level of customization that can adapt to their specific challenges. By incorporating such flexibility, these systems can better support individuals with MCI and their carepartners in managing daily tasks and maintaining independence in their living environments.

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