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DOI
10.1016/B978-0-323-85173-2.00007-2

Publication date
2022

Document Version
Final published version

Published in
Smart Home Technologies and Services for Geriatric Rehabilitation

CHAPTER

6

Smart home applications for cognitive health of older adults

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LEARNING OBJECTIVES

- To provide an overview of current smart home applications for cognitive health for older adults reported in the scientific literature.
- To define evidence-based recommendations for designing smart home applications for cognitive health of older adults.

6.1 Introduction

The world is aging and that is a good thing. It means that we have been successful in fighting disease and improving the overall quality of life. The average life expectancy has surpassed the age of 80, and by 2030, it is expected that people over 60 will outnumber children under 10 [1]. However, reaching old age is associated with some issues. As people live longer, they also accumulate more health conditions that affect their daily life. Presently chronic conditions are the leading cause of mortality, accounting for more than 70% of all deaths, and with numbers projected to keep growing [2].

The need for health support services will continue to increase as the aging population sees their physical, mental, and social capabilities decrease. In the early stages it is often family members who act as

Smart Home Technologies and Services for Geriatric Rehabilitation
DOI: https://doi.org/10.1016/B978-0-32-385173-2.00007-2

informal caregivers to try to meet the needs of an older loved one, but more often than not, their own resources are not enough. Professional services are provided in healthcare facilities and nursing homes but the constant battle from both old adults and their families to remain autonomous and stay in their own homes for as long as possible is ever present. However, the impact aging has on cognitive skills such as memory, attention, problem-solving, and processing speed severely affects the chances of us keeping our independence. Getting old may not always be fun.

Recent research suggests that technology-driven interventions, such as Smart watches, monitoring devices, or locator devices, can help home care delivery and support the informal caregivers [3]. It has been shown that technology can help maintain independence and improve quality of life. Some examples of how technology can support older adults in living independently are: cognitive problems detection [4], tracking systems for dementia patients [5,6], training cognitive functions such as short-term memory [7], or augmenting human memory [8]. The interdisciplinary field of designing technology and environments for independent living and social participation of older persons in good health, comfort, and safety is known as gerontechnology [9]. Among these technologies, Smart homes, that can be defined as "a residence equipped with computing and information technology, which anticipates and responds to the needs of the occupants, working to promote their comfort, convenience, security, and entertainment through the management of technology within the home and connections to the world beyond" [10], are particularly interesting. Smart home applications (SMAs) offer a solution to the complex needs of the elderly and their families, monitoring physiological and functional issues, as well as aiding in emergency detection and response.

In the following sections we will provide an overview of the current state of the art in relevant topics and summarize the main findings into key takeaway points in the shape of recommendations.

6.2 Relevant issues in SMAs for cognitive health of older adults

6.2.1 Usability, accessibility, and acceptability

Aging is associated with changes that may imply several physical, sensory, and/or cognitive impairments [11]. Sensory and cognitive impairments might affect individuals' ability to perceive information, sustain and direct attention, memorize information, communicate, orientate oneself, execute activities, think and reason in an abstract manner, or understand and manage numbers and time [12]. Those changes impact negatively on their autonomy in the daily living activities. SMAs can assist elderly to perform their daily activities, monitor changes in their behaviors and condition, and provide digital training to prevent cognitive decline. However, to be effective, those applications must be designed considering their special needs and capabilities. Designers and developers must put a special attention in issues such as accessibility and usability.

Usability is defined in the ISO 9241 as "the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use" [13]. Evaluation of the usability of a technological solution comprises several aspects as it is defined in Nielsen's heuristic: learnability, efficiency, memorability, errors, and satisfaction [14]. Accessibility is defined in the ISO 9421 as "extent to which products, systems, services, environments, and facilities can be used by people from a population with the widest range of user needs, characteristics, and capabilities to achieve identified goals in identified contexts of use" [15]. Regarding cognitive accessibility, several standards have been defined by international organizations to guide the design process of cognitive accessible products [16–19].

Recommendation 6.1

The design process of SMAs for cognitive health of older adults must follow the current design guides for cognitive accessible products.

Good practice in the development of digital applications identifies usability as a key component [20]. Also, usability is included as a relevant criterion for the assessment of digital health applications in several standards such as the National Health Service Digital Assessment Questionnaire [21], the guidance from the Medicines and Healthcare products Regulatory Agency [22], or the Mobile App Rating Scale [23]. Undetected usability or accessibility problems affect technology acceptance reducing product adoption and user adherence and engagement with technology. Ensuring high usability may even result in increased accessibility. There are several usability testing methods ranging from qualitative (interviews, focus groups, heuristic evaluation, etc.) to quantitative techniques (questionnaires, task completion, etc.) [24]. It is common to use a combination of these methods in the usability evaluation of digital health applications. Most of these methods require the participation of target users in the evaluation. Involving people with cognitive impairments in the usability studies requires the adaptation of the specific techniques to their abilities and conditions. Examples of usability evaluation studies of digital health applications involving older adults with cognitive impairments have been found in the scientific literature [25].

Recommendation 6.2

SMAs for cognitive health must be tested following robust usability methods adapted to target users' abilities.

Interacting with technology might be a great barrier for older adults, especially for those with cognitive impairments due to their reduced abilities. In such circumstances, the device-free approach, that is focused on freeing users to intervene as little as possible, is becoming very popular in SMAs [26]. Following this approach, despite requiring users to carry any devices, those devices are located in the environment and capture the required information.

The methodology followed to design the technological solution has been reported as another relevant factor affecting technology adoption and user engagement. Due to the wide range of impairments that older adults can suffer, it is important to engage them and/or their caregivers in the development process of SMAs for cognitive health. Involving them may make easy to identify all potential barriers that would prevent target users from being able to use the application.

Several participatory approaches, such as user-centered design (UCD), have shown reaching higher user acceptance and satisfaction and lower user errors [27]. UCD proposes placing the needs and characteristics of end users in the center of the technological solution design and development, involving target users from the early stages of the process [27]. Following UCD ensures that digital health solutions are more likely to meet end users' needs and expectations. In addition, UCD defines an iterative design process that comprises four stages: Understanding the context of use, specification of requirements, solution design, and evaluation (find critical feedback on the product developed). Usability and user experience are commonly tested in the evaluation stage. As the process defined in UCD is iterative, the evaluation is performed from early stage of the development process, which allows to detect usability and accessibility problems early, saving time and money and decreasing design changes late in the process [28]. UCD has been used in the development process of SMAs for elderly [29]. Additional contribution of the design reported in the scientific literature is an increased level of accessibility to technology and a higher level of autonomy that users can achieve.

Recommendation 6.3

A participatory approach should be followed in the design and development process of SMAs for cognitive health involving stakeholders in the process. Both accessibility and usability must be considered and tested from the early stages in the development process.

Besides usability and accessibility, there are other factors, such as people's motivation to use SMAs and their perceived usefulness, that affect the acceptance and adoption of these technologies [30]. Older adults are more prone to show an initial rejection attitude toward the introduction of new technologies, and therefore, it is critical to examine those factors to understand what the utmost relevant factors are to be considered in new SMAs.

Studies on usability and acceptance of new digital health solutions for older adults conducted in laboratory or real settings are common in the scientific literature. Liu et al. reviewed studies on Smart homes and home health-monitoring technologies for older adults with complex needs published between 2010 to October 2014 [31]. This review is not focused specifically on applications for cognitive health, only 6 of the 48 included studies were focused on cognitive decline and mental health. The usability and technology acceptance were assessed in 32 of the reviewed studies, including all of those focused on cognitive decline and mental health, showing the importance of these issues. Authors concluded that acceptability and usability of the proposed systems were high among older adults based on the reported outcomes. However, they highlighted that none of these studies was based on theories that helped to explain intention to use and usage behaviors of participants. Usability evaluation is also a common test of SMAs in recent studies [32].

To fill the reported gap regarding the lack of theoretical basis of acceptance evaluation, several well-known and widely spread acceptance models such as the Technology Acceptance Model (TAM) [30], the Unified Theory of Acceptance and Use of Technology (UTAUT) [33], and their adapted versions may be considered [34]. Those models have been used as a theoretical basis in the technology acceptance assessment of digital health solutions in the ambient assistive living (AAL) domain [35]. TAM is a behavioral model of end-user acceptance of new technologies based on the Theory of Reasoned Action which states that the use of a system or service is based on the user's attitude toward it. In this sense, TAM proposes that perceived usefulness and perceived ease of use of a technology predict the intention to use technology, and hence its actual use [30]. Several studies have reported the influence of users' personal characteristics such as age, gender, cognitive abilities, or personality traits in the technology acceptance [31]. Subsequent iterations of TAM have included some of them incorporating additional factors such as social norms, technology experience, habit, age, gender, etc. [34]. Particularly, the Senior TAM (STAM) was proposed by Renaud and van Biljon [36] that included gerontechnology self-efficacy and anxiety, facilitating health conditions, cognitive abilities, social relationships, attitude to life and satisfaction, and physical functioning as factors that influenced perceived usefulness, usage behavior, and perceived ease of use.

Despite their wide use in research, those models are generic and relevant aspects in SMAs such as contexts of use, usage situations, or specific target user group are not considered. Hence, those models must be extended and specifically tailored to the specific SMAs and its functions. Biermann et al. conducted a study using an acceptance questionnaire adapted to AAL and the proposed technology [35]. Heerik et al. addressed the limitation of TAM that has not been developed for systems that can be perceived as a social entity, such as a robot, and proposed an acceptance model for assistive robots [37].

Recommendation 6.4

Acceptability studies of SMAs for cognitive health of older adults must be based on theories specifically designed for those target users and technologies.

Several studies have analyzed factors influencing technology acceptance and adoption among older adults. Liu et al. found seven factors impacting the perceived value of Smart home and home health-monitoring technologies reported by older adults [31]:

1. Participants stated that they were reluctant to accept the Smart homes and home health-monitoring technologies, if these technologies did not allow them to remain in their own homes and to age in place (user's preferences, Recommendation 6.3).
2. Technology must improve their quality of life to be widely accepted (perceived benefits, Recommendation 6.3).
3. Data privacy is identified as a critical issue in technology acceptance of SMAs (see 6.2.2.3 Privacy and security).
4. Inappropriate designs such as buttons too small on the touch screen, incorrect feedback messages, or level of false alerts causing distress to users (usability issues, Recommendation 6.2).
5. It is common that technologies under test are in their initial development stages, and thus, several aspects relevant for older adults are not still considered. (Recommendation 6.5).

6. The users' success with technology under study was associated with users' personal characteristics, such as age, gender, cognitive abilities, and personality traits (Recommendation 6.4).
7. Older adults consider some technologies as obtrusive systems (user's preferences, Recommendation 6.3).

Recommendation 6.5

The maturity of SMAs must be clearly informed to participants in evaluation studies, especially in technology acceptance evaluation. Also, the level of technology readiness to be used in target settings by target users should be indicated in scientific publications reporting evaluation outcomes.

Peek et al. studied changes and stability in the use of technologies by independent-living seniors [38]. They found a core of six interrelated factors closely linked to the frequency of technology use:

1. *Emotional attachment*. Perceived usefulness, engagement and satisfaction with the technology directly affects user's emotional attachment (Recommendation 6.4).
2. *Need compatibility*. Whether user needs are met using the technology. As we mentioned before, selecting a good design methodology such as UCD help to identify users' needs and creating products that meet them (Recommendation 6.3).
3. *Cues to use*. Users experiment certain cues that lead him/her to using the technology. In general, participants' cues to use could entail specific situations, routines, and places (Recommendation 6.6).
4. *Proficiency to use*. User's self-efficacy to use the technology. Learnability (ease of learning how to use it) positively impacts user's proficiency. Internal reward such as feel proud of being able to use the technology or reach a goal using it may also impact on proficiency. Sensory impairments could make difficult to use the application reducing user's self-efficacy. Hence, the importance of considering usability and accessibility as crucial issues in the design and development process (Recommendation 6.3).
5. *Input of resources*. Availability of resources such as money to buy the system or time/effort to learn how to use it. Perceived benefits of the use of the technology could positively impact these investments. Developing a usable (easy to learn) solution reduces time and effort (Recommendation 6.3)
6. *Support*. Finding help from others when user needs (Recommendation 6.6).

Recommendation 6.6

SMAs designs should assist older adults in the integration of the use of the application in their daily life. Accessible and tailored materials supporting older adults in the use of the application should be provided. Adapted cues should be showed on the user interface. Advanced features such as context-aware reminders/triggers informing on how the use of the application could benefit to users might be considered.

As it is mentioned before, the user acceptance of SMAs is influenced by user's needs and preferences and those factors could vary over time. Additionally, changes in physical and/or cognitive conditions could reduce the user's ability to interact with the SMA. In such circumstances, monitoring changes in user's condition allows automatically to adapt and tailor the SMA functionalities to the new context maintaining a high acceptance level.

Recommendation 6.7

User's conditions, needs, and preferences could be monitored, and the application must be automatically adapted when changes are detected.

6.2.2 Functionalities

Abdelrahman et al. analyzed the opinions toward information technologies, especially those for brain health, in healthy older adults living in an independent elderly living community [39]. They identified seven relevant themes reported by participants: physical activity, cognitive health, social engagement, organizing information, desire to learn new technology, advancing technology, and privacy/security.

6.2.2.1 Physical activity and cognitive health

There is growing evidence demonstrating the potential beneficial impact of lifestyle changes and cognitive training for overall health, and particularly for cognitive health. Several studies have reported the positive effects of physical activity and exercise-related brain stimulation to maintain memory and learning. Due to this demonstrated positive relationship between physical activity and cognitive health, including personalized coaching features in SMAs to support and motivate older adults to be physically active is interesting. These features should be designed considering behavior change theories and implementing behavior change techniques for physical activity promotion such as those defined in the CALO-RE taxonomy [40]. Additionally, personalization of these features may impact user adoption, adherence, and engagement. Therefore, designs of SMAs should consider personalization models defined for physical activity features such as that defined by Op den Akker et al. [41].

Recommendation 6.8

Designers of SMAs should consider including personalized coaching features to support and motivate older adults to be physically active.

Regarding cognitive health, there are three key applications for Smart home to increase older adults' autonomy:

- Monitoring of cognitive conditions and detection of potential cognitive decline. Behavior and health status recognition and subsequent transmission of collected data for remote monitoring.
- Digital cognitive training. Several studies have reported slowing down of cognitive decline, maintenance, and even, improvements of cognitive functions using digital training.
- Assistive technology that supports older adults in their daily activities. Common assistive technology functionalities associated to cognitive health are: Information collection, organization, and presentation; communication; location, navigation, and orientation; support in activities execution; and time management.

6.2.2.2 Social engagement

Social inclusion is a crucial factor in aging, especially when individuals suffer from cognitive impairments. Social isolation is seen as a public health issue for older adults that can affect negatively their physical, cognitive, and mental health. Technological solutions enabling maintenance of social relationships or improving social connections are more likely to be successfully adopted by older adults. In this sense, current studies reported that older adults use technology to socialize with their family members [39]. Also, these communication technologies enable an adapted alternative facilitating older adults and healthcare professional relationships. Not only communication, but also Smart home technologies enable remote monitoring that allows to detect critical events requiring healthcare professional interventions. Additionally, promoting social engagements facilitating social participation of older adults in community events reduces their loneliness feelings impacting positively their mental wellbeing. However, older adults are often less familiar with technologies and more prone to show an initial rejection toward its use. Some studies have reported mixed older adults' opinions regarding social features that highlight the need of individual customization, especially in people with complex conditions. Some facilitators for Smart home social technology adoption reported in the scientific literature are: ease to use and learn, training on technology use, and social features including customization.

Recommendation 6.9

SMAs should include optional and customizable social features adapted to user's communication ability and preferences.

6.2.2.3 Privacy and security

SMAs collect user information to monitor their conditions or behaviors and/or automatically adapt the system to their preferences and/or conditions. Therefore, privacy, data integrity, safety, and security are all strong requirements of these systems given their ability to collect and process sensitive information and make decisions based on this information. Hence, these issues must be considered in the development process of SMAs ensuring products and services are compliant with current regulations. In this sense, designers and manufacturers of SMAs should follow the privacy by default approach. As it is mentioned previously, privacy and security have been reported as relevant factors in technology acceptance by older adults. In some studies, older adults expressed feeling anxious due to loss of privacy, especially when cameras are used, and confidentiality concerns based on the risk of unauthorized access of their information. Due to concerns about this privacy invasion, and how end users would react to Smart home monitoring, some studies state that there is great variability in what factors about their life people would want to track, and that what people wish to track will change over time. Their interest will be based upon their age, life circumstances, interactions with friends and family, health status, and general curiosity.

Recommendation 6.10

Privacy and security issues must be considered from early stages of the development process of SMAs following privacy by default approach. Designers of SMAs should consider including personalization about the parameters to track and share. Including a clear and understandable privacy policy compliant with current regulations is mandatory when user data are collected, treated, or shared.

6.3 SMAs for cognitive health: study cases

6.3.1 Smart home architecture

A SMA generally consists of three layers: the *acquisition layer* that monitors the individual's context using a set of devices, sensors, and actuators (sensor platform); the *service layer* that processes, and analyses data collected to recognize the context of inhabitant and environment; the *application layer* that activates and deactivates services and helps make "visible" the Smart spaces to users [42]. Data collected by the acquisition layer are shared among devices, sensors, and actuator elements of the sensor platform and sent to the service layer using wired and/or wireless communication protocols.

The acquisition layer benefits from recent advances in embedded computing that have enabled the development of a huge variety of sensor and actuator devices that can be used in increasingly complex applications. These devices could be classified as: physiological sensors (heart rate, blood pressure, oxygen saturation, etc.), activity trackers, environmental sensors (thermostat, presence control, etc.), Smart objects (Smart fridge, air quality control devices, etc.), and advanced user interfaces devices (Smart glasses, social robots, etc.). Earliest Smart homes were composed of relatively simple nodes collecting information and transmitting it to centralized systems (perhaps in the cloud) for processing. The current trend is toward an Internet of Things model of powerful interconnected nodes (through wireless connections such as WiFi, 5G, or Bluetooth Low Energy) running sophisticated local processing (including advanced artificial intelligence) and sending this processed information (event data, alarms, recommendations, etc.) to central nodes, or even directly to the user.

The service layer includes advanced techniques to automatically recognize individual's cognitive condition, behaviors, and daily life activities performed. Artificial intelligence–based techniques to identify environmental elements that older adults can interact with are also included in this layer. SMAs use detected changes in user's condition to automatically adapt themselves to the new condition being responsive to users' needs and routines by predicting them instead of having to entirely rely on programmed routines. Additionally, healthcare professionals must be informed about these changes in conditions for early detection of potential mild cognitive impairments and events requiring intervention.

There are three key applications of Smart home for cognitive health that increase older adults' autonomy: Smart home cognitive health monitoring, digital cognitive training, and assistive Smart home technology. In this section, we present study cases representing some of SMAs for cognitive health published in the scientific literature.

6.3.2 Smart home cognitive health monitoring

Lussier et al. published in 2019 a systematic review of Smart home sensors technologies for early detection of mild cognitive impairments through the monitoring of everyday life activities [43]. They found 17 studies: 13 were conducted in real-life settings and 4 in a living laboratory. Studies conducted in real-life settings analyzed activities including mobility (walking frequency, walking speed, level of general activities, movements during nighttime), leisure time (computer usage), and self-care (medication uptake) while those conducted in lab measured time of completion, quality of activity completion, number of errors, amount of assistance needed, and task-irrelevant behaviors. Other systematic review, performed by Piau et al., analyzed the evidence for real-life home-based use of technologies for the early detection and follow-up of mild cognitive impairments or dementia [44]. Sensors used in the included studies were grouped into four groups based on technology (Table 6.1).

TABLE 6.1 Groups of sensors based on technology used to collect data.

Group	Sensor
Data from dedicated embedded or passive sensors	Infrared motion sensors Magnetic contact door sensors Radiofrequency identification Temperature sensors Driving sensor (passive sensing device plugged into participants' vehicle data port)
Data from dedicated wearable sensors	Sleep monitoring sensor GPS Inertial sensors
Data from dedicated or purposive technological solutions	Interactive voice response Personal digital assistant Touch screen system Online questionnaire/survey Augmented reality Nintendo Wii balance board
Data derived from use of nondedicated technological solutions	Electronic pill box Computer usage Mouse pointer movements

In a more recently published paper, Rawtaer et al. evaluated the feasibility and acceptability of utilizing in-home sensors to detect changes in behaviors of older adults as indicators of mild cognitive impairments [39]. Authors used a network of multimodal sensors delivered in participants' home that comprised passive infrared motion sensors, proximity beacon tags, a sensor-equipped medication box, a bed sensor (fiberoptic technology for sleep behavior monitoring), and a wearable (pedometer and heart rate).

6.3.3 SMAs for cognitive training

Traditional cognitive interventions are usually designed as group-based or face-to-face programs that require qualified therapists, appropriate facilities, and adequate locations for accessibility. The provision of these traditional cognitive interventions may be challenging due to the increase of aging population. Therefore, there is a need for innovative alternatives enabling cost-effective interventions. In-home digital cognitive training has been evaluated in the scientific literature reporting promising outcomes. Particularly, services robots can interact with humans offering appropriate services to provide home-based cognitive interventions. As an example, Lee et al. developed five programs for home-based cognitive intervention using a personal robot for people with mild cognitive impairments [45]. Authors used a robot named Bomy (Robocare, Seongnam, Republic of Korea) that provides five cognitive training programs focused on specific domains such as memory, language, visuospatial function, calculation, and frontal executive function.

6.3.4 Assistive Smart home technologies

In this study case, Microsoft HoloLens are used to enable users to interact with a Smart home in a project named HoloHome [46]. HoloHome creates virtual home appliances that are presented on the same position and scale alignment of the corresponding real-world objects. Each time the user moves his/her head and looks at a specific device through the HoloLens, additional information (images, animations, etc.) appears on that object to help using it. Examples may include a simplified control panel of the washing machine or hints to find ingredients in the refrigerator. The system is designed as an assistive tool for people with mild cognitive impairments suffering from memory and/or executive function deficits, improving their ability to perform daily activities in a more independent way.

6.4 Conclusions

We are only starting to realize what opportunities technologies such as Smart homes unlock for the care of old adults. Our modest success in extending our lifespan should act as encouragement for taking bolder steps to improve how well we live our life in the later stages. The world is aging, let us spend our golden years better with the help of gerontechnologies. We have presented an overview of current applications reported in the scientific literature. SMAs for cognitive health must take all listed recommendations into account, especially in the application layer design. The true challenge is to evolve from prototype implementations to fully useful, commercial solutions. Application development is probably the weakest part of current SMAs for cognitive health, and new approaches are needed that incorporate interdisciplinarity, personalization, participatory design, as well as standardization through technology-neutral abstractions of the lower layers.

Acknowledgment

Enrique Dorronzoro-Zubiete is supported by the "V Plan Propio de Investigación" of the Universidad de Sevilla. The present study is funded by the Fondo Europeo de Desarrollo Regional (FEDER) and the Andalusian Government from Spain (US-1263715) grant for the "Understanding Daily Multiple Sclerosis Related Fatigue: A Participatory Health Informatics Approach" (MSF-PHIA) project,

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