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Gerontechnologies for home support

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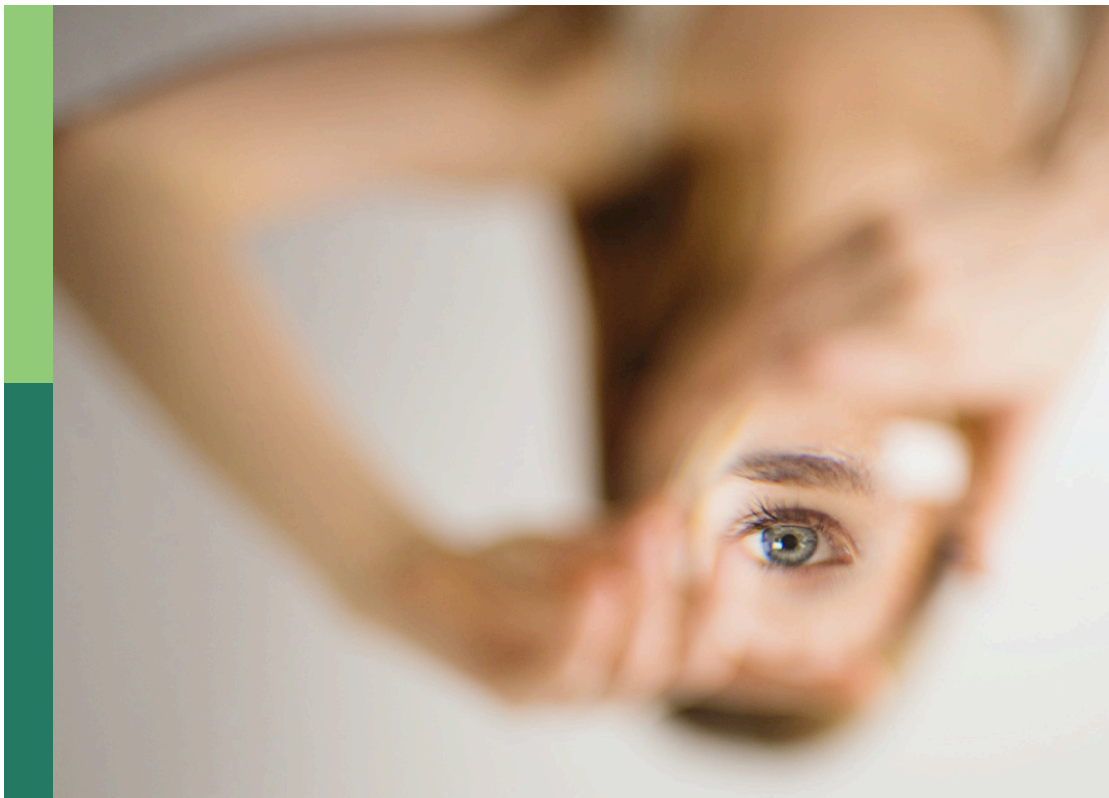

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Gerontechnologies for home support

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Editorial: Gerontechnologies for home support

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Editorial on the Research Topic
Gerontechnologies for home support

According to the United Nations Department of Economic and Social Affairs (2023), estimates indicate that by 2050, one in six people globally will be aged 65 or older. As the cost of institutional care for older adults continues to rise, it is likely to become increasingly unaffordable for middle- and lower-class families. Also, there is an imbalance between the number of professional caregivers and the number of older adults requiring healthcare. This trajectory seems unsustainable underscoring the need to expand home care options, reserving institutional care for older adults with moderate to severe care needs. Gerontechnology is a relatively young transdisciplinary field established in 1991 to conduct research and development of technological products and services, based on the knowledge of aging processes and to provide innovative tools to contribute to independent living environments, support healthcare and family caregivers, and increase social participation of older adults to promote health, comfort, and safety. Gerontechnology offers promising solutions to support "Aging in place" complementing traditional care models. Many community-dwelling older adults with and without cognitive impairment along with their family caregivers are already using technology to address challenges related to activities of daily living, often without conclusive evidence of its efficacy.

In recent years, a variety of digital and non-digital gerontechnology applications have been developed to support aging in place. These include tools for medication administration (e.g., reminders and alarms), to environmental monitoring (e.g., air quality sensors and cameras), to fall detection systems, and health and activity monitoring (e.g., smartwatches). Most of these promising solutions are either in development or already available in the marketplace. Additionally, the COVID-19 pandemic has further accelerated the development and adoption of technological solutions supporting remote care and communication (e.g., videocalls), and home service delivery (e.g., meals and groceries). This trend has proven to be particularly significant as reducing institutionalization of older adults has become a key objective for governments and caring families around the world. Gerontechnologies, therefore, offer a potential and promising avenue to help older adults maintain autonomy, independence, and social connections

while aging in place. Gerontechnology is also expected to ease the burden on family and professional caregivers.

This Research Topic provides a set of papers describing studies that have explored the development, effectiveness, and adoption of gerontechnologies—innovative technologies designed to support older adults—over the past decade. The focus is on research that not only introduces new technologies but also evaluates their real-world application and impact. Specifically, this Research Topic highlights studies that offer evidence-based insights, shedding light on the various stages of technology development and the factors influencing their adoption.

The research spans several key dimensions:

1. **Feasibility:** investigating whether the proposed gerontechnologies can be effectively developed and integrated into everyday life. This includes examining the technological requirements, potential drivers and barriers, and the practicality of implementing these technologies in the homes of older adults.
2. **Usability:** evaluating how user-friendly these technologies are for older adults and their family or professional caregivers. Usability studies often focus on the interface design, the ease of learning to use the technology, and the overall experience of the user.
3. **Acceptability:** assessing the willingness of older adults and their family or professional caregivers to use these technologies. This includes exploring cultural, social, and psychological factors that influence the acceptance of technology in aging populations.
4. **Efficacy:** determining the effectiveness of gerontechnologies in achieving their intended outcomes. For example, studies might measure whether a particular technology improves health outcomes, enhances quality of life, or reduces the burden on family or professional caregivers.
5. **Satisfaction:** gauging the gratification levels of older adults and their family or professional caregivers with the technology. This often involves assessing how well the technology meets user expectations and whether it adds value to their lives.
6. **Early adoption:** exploring the factors that contribute to the early adoption of gerontechnologies by older adults and their family or professional caregivers. Research in this area might examine how early adopters are identified, what motivates them to try new technologies, and the challenges they face in doing so.
7. **Accessibility:** ensuring that gerontechnologies are available to all older adults, regardless of physical, sensory, or cognitive abilities. This involves designing technologies that can be used by individuals with disabilities or impairments or less tech-savvy older adults, and making sure that these technologies are available in different languages, formats, settings, and even forms. Accessibility also includes addressing the economic aspects, ensuring that these technologies are affordable and available to a wide range of older adults.

This Research Topic is particularly interested in studies that employ cross-sectional methodologies, using qualitative, quantitative, or mixed methods approaches. Cross-sectional studies are valuable because they provide a snapshot of the population at a specific point in time, offering insights into the current state of technology adoption and use among older adults and their family or professional caregivers.

The focus is on gerontechnologies that have been tested in real-world settings, particularly within the homes of older adults. This includes studies involving family caregivers, older adults, or both, and covers a broad spectrum of aging experiences—from normal aging processes to more complex conditions like dementia.

Additionally, this Research Topic encompasses various aspects of the technology development continuum:

- **Recruitment:** examining how older adults and family or professional caregivers are recruited for studies on gerontechnologies, which can provide insights into the demographics of early adopters and the generalizability of the findings.
- **Technology development:** focusing on the design and creation of gerontechnologies, including how they are tailored and personalized to meet the needs of older adults and their family or professional caregivers.
- **Early adoption and implementation:** studying the initial rollout and integration of these technologies into everyday life, including the strategies used to encourage adoption and overcome barriers, and learning about the challenges, obstacles, drivers, as well as successes.
- **Public policy:** investigating the role of public policy in supporting or hindering the development and adoption of gerontechnologies. This might include policies related to funding, regulation, and the promotion of technology in aging populations.

Overall, this Research Topic aims to contribute to a deeper understanding of how gerontechnologies can be effectively developed, adopted, and used to improve the lives of older adults and their family or professional caregivers, while also informing future research, development, and policy efforts in this field.

The content can be read following the order suggested here, or be appraised depending on the readers' specific interest in different aspects of gerontechnology. The articles provide empirical data on different challenges and opportunities in gerontechnology research and development.

The first article of this Research Topic addresses recruitment for gerontechnolgy studies and the lessons learned from the pandemic challenges to research. Williams et al. focus on the problem of recruitment of user-caregiver dyads for gerontechnology research in the context of older adults living with dementia. They use COVID-19 as an example of one of the most challenging periods to recruit older adults living with dementia to participate in research using sensors to monitor activities of daily living. With community-based strategies such as the distribution of flyers alongside home-delivered meals, they implemented the least expensive and most effective strategy to recruit their participants. This strategy was possible in collaboration with home-delivered meal programs who are trusted service providers. Also, "Word of mouth" emerged as the second-highest source of dyad enrollment, being a low-cost, relatively low-effort recruitment method. Researchers can benefit from these strategies as older adults are more likely to respond to surveys provided by someone trusted and known to them rather than cold surveys received in the mail or e-mail.

Gerontechnology research is not only challenging in terms of recruitment; the quality of gerontechnology research is also a concern. Moreno et al. provide a 5-year systematic review of the literature of gerontechnologies tested among community-dwelling older adults with unimpaired cognition and their family caregivers to support aging in place. Surprisingly, only 13 gerontechnologies met the study criteria and were classified into four categories: monitoring technologies, communication technologies, daily life assistance technologies, and health information technologies. The results highlighted the benefits and challenges of each gerontechnology. The study also provided recommendations for technology development, implementation, research, and public policy. Considering a global perspective of aging, the study encouraged the early introduction of these technologies before the onset of cognitive decline including personalization based on dyads' needs and easy-to-use co-created solutions respecting their privacy.

The content also includes a remarkable example of multi-country initiatives to develop gerontechnologies for home support and the cultural and technical challenges of international collaborations. Nap et al. conducted a study with an international team to test a co-created Decision Support System connected to multiple assistive technologies for home support among older adults living with dementia, their family and professional caregivers in the Netherlands, Italy, and Taiwan (e.g., sensors, a fall detection device, GPS tracker, medication dispenser, among others). Their technology integrates data of physical activity, eating and sleeping patterns, cognitive functioning, social contacts, and medication intake using a dashboard. Data come from assistive technologies that are selected based on the profile of the individuals with dementia to respond to individual care and support needs. After a 1-to-6-month test period, participants reported perceived added value in their use, which provided a better insight on the status of people living with dementia at home in three different cultural contexts.

The content also features the use of voice assistants that have shown increasing interest and popularity among gerontechnology scientists. Cao et al. studied the factors influencing older adults' acceptance of voice assistants. The qualitative results among older adults suggested that their acceptance depends on both product characteristics (e.g., perceived usefulness, perceived privacy and security risks, perceived enjoyment, perceived benefits for supporting independent living) and personal characteristics (e.g., technological self-efficacy and dispositional resistance to change). Using partial least squares structural equation modeling, they demonstrated that perceived usefulness, perceived enjoyment, and technological self-efficacy positively influenced older adults' behavioral intention to use voice assistants. When older adults see the benefits of voice assistants, when they perceive enjoyment through their interactions, and especially when they trust their capabilities to use them, they will probably accept them.

On the same line of research, pioneer research conducted by Astell and Clayton offer the first study testing gerontechnologies in the oldest old to combat social isolation with voice assistants. In their community case study, the researchers tested the use of smart speakers by older adults of 90 years of age or older living in supported accommodation. Participants reported a sense of presence having a positive impact on their experience of loneliness and social isolation. Interestingly, using voice control and hearing a voice gave them "agency" creating a sense of connection with the device. They discuss their findings in terms of "Digital Prescribing" to tackle well-being outcomes.

Early adoption has been another challenge in gerontechnology research over the years. Profiling early adopters and the characterization of their needs has implications for public policies. Teles et al. address the early adoption of an eHealth platform developed by the World Health Organization to help dyads of individuals living with dementia and their family caregivers in the Portuguese context. This platform provides a freely accessible and self-guided program delivering caregiver education about dementia, caregiving responsibilities, and strategies for coping with common problems in dementia care. Early adopters of this technology were mostly highly educated women in their early fifties taking care of their parents living with dementia. The use of this platform allowed them to obtain a profile based on the psychosocial needs of Portuguese family caregivers of older adults living with dementia, which is essential for planning the organization of healthcare services.

Another challenge in gerontechnology research corresponds to the characteristics of interfaces designed for older adults to facilitate accessibility. Zhou et al. use the example of human-computer interaction interfaces in smart homes to provide insights into the importance of designing technologies adapted to older adults. These products may use interfaces not allowing users to clearly identify the content, with too much information, leading to cognitive load and a negative experience for older adults. Age friendly interfaces for smart homes have to be easy to understand and facilitate the interaction process. Convenience, simplicity, and warmth can reduce unnecessary operations. For instance, the 18 mm function buttons, the up-and-down sliding layout, and the minimalist style received the best subjective evaluation from older adults. As such, personalization, operation guidance, warm reminders, and touch voice are among the characteristics to make them simple, easy to use, and attractive for end users.

Implementation is another major challenge in gerontechnology research. Jutai et al. discussed the process of the implementation of digital health technologies in home care and long-term care for older adults. The results of their scoping review uncovered 10 thematic Research Topics in peer-reviewed research about technologies for assisted living for older adults (e.g., communication, design, economic analysis, ethical considerations, among others). Based on their findings, they recommend a framework to improve the quality of research in this area so that implementation is planned and executed before the design of a technology has been completed.

The last major challenge addressed in this Research Topic of articles corresponds to public policies in gerontechnology research. Genge et al. propose five key messages for policymakers and funders of gerontechnologies inspired by observations from the Canadian AgeTech context. In their opinion, a life course perspective of aging is necessary to address the heterogeneity and evolving needs of older adults. As such, gerontechnologies must respond to older adults' real problems and be integrated as a complement to existing health and social services. In addition, end-user engagement requires the

recognition of older adults as experts with lived experiences participating in co-designing gerontechnologies. Consequently, they stress the importance of finding a more flexible approach to developing and testing gerontechnologies. They recommend that policymakers and funding agencies structure their calls to encourage the participation of older adults with diverse life course perspectives, either as project partners, members of an advisory board, or reviewers of funding applications. Also, financial allowance for family caregivers participating in gerontechnology research can reduce barriers to participation (e.g., to cover the cost of respite care). They stress the importance of policymakers and funders promoting Equity, Diversity and Inclusion (EDI) and Gender-Based Analysis Plus (GBA Plus) plans to ensure that research teams and participants are fully representative of the perspectives of diverse individuals throughout the innovation process.

We hope that readers will find the articles in this Research Topic both useful and enlightening. We believe the content will inspire the readers to be aware of the challenges and opportunities in this exciting transdisciplinary field. In conclusion, as institutional care becomes increasingly unsustainable, it is crucial to continuously update our knowledge on evidence-based technologies for home support tested with both older adults and their family caregivers. Healthcare professionals and families are often disadvantaged by lack of clear information on the utility and cost effectiveness of these technologies. Having reliable, evidence-based data on both emerging and existing gerontechnologies is essential for making informed decisions about their recommendation or purchase. Older adults need proof upon which to make an informed decision to invest in a specific technology when needed. Family caregivers need this information to improve their judgment when trying to choose, purchase, and adopt a technology aiming to solve a specific problem at home and have peace of mind when these technologies are used to support their loved ones. Clinicians, health insurance companies, and governments need a pool of evidence-based technological tools that could be recommended to families facing the loss of autonomy and independence of older adults. Researchers and scholars need a base of knowledge for future applied research in gerontechnology. Finally, policymakers and governments need this information to create legislation aiming to protect the public and the end users of these technologies. As a society, we must act quickly and wisely to make sure that the gerontechnologies that we develop and disseminate have a positive and lasting impact on the lives of older adults and their family caregivers. This is a mission that can be accepted by new generations of highly motivated transdisciplinary scientists and trainees inspired by former generations of visionaries. We are all building innovative possibilities with gerontechnologies to help improve the quality of life of our older adults with new opportunities to continue to live fulfilling lives. At the same time, we are creating new possibilities when we face our own aging to contribute to a society where older adults' wellbeing is a priority.

Author contributions

AM: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. HN: Conceptualization, Writing – review & editing. SH: Conceptualization, Validation, Writing – review & editing. GG: Conceptualization, Supervision, Validation, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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An empirical study on the collaborative usability of age-appropriate smart home interface design

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Introduction: The smart home has become a popular product, but with the development of the aging population, the differentiated characteristics of the elderly smart home products in terms of demand and use are becoming more and more significant. The existing smart products are complicated to operate and cumbersome to interact with, which increases the cognitive load of the elderly group and hinders the daily use and user experience feeling of the elderly. The purpose of this paper is to study the interface data information and interface visual design starting from hardware and software, interface interaction, to explore the better interface data information and interface visual design, and to output, a new prototype of the operating interface of smart home system for the elderly, so that the smart products can be better used by the elderly.

Methods: Thirty-two participants aged 55–75 were invited to conduct the test, and subjective evaluation was conducted at the end of the test. Through the tests, the operability of the prototype structure for smart furniture systems for the elderly was demonstrated.

Results: In terms of functionality a new task based on a combination of icons and text is proposed. In the control of devices, the switching status of devices, etc., needs to be clearly distinguished visually, eye-protective bright colors are used, paired with low saturation to highlight the focus, and high bright colors with gray to distinguish the device status. In terms of the density of the content, an appropriate proportion of images and text were used to make the information less dense. In the arrangement of web content, information content relevant to users was placed first as much as possible.

Discussion: Based on this, a secondary optimal design was carried out to improve the interactive design of the smart home for the elderly and output it as a prototype interactive interface. Thus, the operability, rationality, and aesthetic comfort of the prototype design of smart home interaction in an age-friendly scenario are improved, allowing the elderly to have a better experience when using the smart home.

KEYWORDS

smart home, interactive interface, age-friendly design, optimal design, ease of use

1. Introduction

With the rapid growth and popularity of the Internet of Things (IoT), the term "intelligence" has become an umbrella term for innovative technologies with a degree of artificial intelligence as the technology and environment continue to evolve. An important feature of smart technology is to perceive and respond accordingly to external information

acquisition (Chan et al., 2008; Balta-Ozkan et al., 2014). Since the long-term purpose of smart technology is to benefit humanity, it has become the backbone of innovative ideas such as the "smart home" (Alam et al., 2011; Dawid et al., 2017; Han et al., 2022). The shift in products and services has led to an increase in the operability of devices, which has driven an increase in the number of smart home technology transactions worldwide (Khedekar et al., 2017). As a result, the smart home is becoming a popular product, that is, the use of IoT technologies in the daily life of the home. It plays an important role in providing users with convenience, efficiency, and quality of life (Marikyan et al., 2019). Smart homes can control and monitor environmental changes in people's homes (Pan et al., 2022), determine user behavior, detect anomalies (Fahad and Tahir, 2021), and contribute to better family-to-family control (Bissoli et al., 2019). In addition, the study showed a significant correlation between the use of smart home services and wellbeing (Sesto et al., 2012). Many studies have demonstrated the benefits of smart homes, but the current research revolves around the technical characteristics of smart homes, i.e., the lack of a user perspective, especially in the elderly user group (Marikyan et al., 2019).

The increasing pressure of survival in modern society, the expanding proportion of older people, and the gradual increase in the age of childbirth have made the problem of aging increasingly serious. Globally, the population of older adults is growing rapidly, and it is estimated that by 2050, the number of older adults over 60 will double from 12 to 22% of the population, with 80% of these older adults expected to live in low- and middle-income countries (Yu et al., 2022a). In this context, the physical, emotional, behavioral, and cognitive aspects of older adults will undergo significant changes, and it is particularly important to explore the real needs of older adults (Yang et al., 2018). As older adults have more free time, their physical and psychological problems are magnified in this context (Xiong et al., 2018). In terms of physiology, it has been shown that more than half of the elderly over 65 have visual impairment, one third have hearing impairment, and two fifths have motor impairment, and that their physical condition deteriorates with age (Nebeker et al., 2021). This means that care design for the elderly population needs to take full account of their physical functioning problems, taking into account their visual and hearing difficulties (Chang and Östlund, 2019; Lindström and Ståhl, 2019). In response to the psychological and physical needs of the elderly, assistive devices or caregivers are needed to take care of their daily lives and spiritual-based humanistic care (Andrews et al., 2019). However, most elderly people, cannot afford long-term in-home care. The emergence of smart homes is a great way to do this (Fox and Connolly, 2018). Smart homes can not only make life easier and safer for the elderly but also provide a sustainable solution for long-term in-home care (Rashidi and Mihailidis, 2013; Sharma and Wong, 2020). Smart homes can help older adults live independently, especially those who suffer from motor control disorders (Chen et al., 2022). Past studies have shown that older adults are receptive to life changes and benefits such as emergency assistance, fall prevention and screening, and medication alerts from smart home devices (Crespo et al., 2006; Chen et al., 2013; Hu and Ning, 2016). Therefore, the design of smart homes is considered a key factor in improving the quality of life and protecting the health and safety of the elderly.

The supply of smart homes and other healthy senior products suitable for the older population is increasing in demand as health needs grow (Lee et al., 2006). However, studies addressing the current state of communication among older adults have found lower usage of smart devices (e.g., cell phones) compared to younger adults due to uncontrollable factors such as the decline in perceptual and cognitive abilities over time. Smart devices continue to be upgraded, and communication and communication when used by older adults has become a significant problem (Majumder et al., 2017; Eiguren Munitis et al., 2021). Lack of experience in independent use and difficulties in product operation have become major barriers for older adults to use products (Axisa et al., 2005; Kim et al., 2010). With the increase of smart home functions and complexity, the communication and control of smart devices become more and more inconvenient for the elderly, who are unfamiliar with digital technology and whose physiological and cognitive learning levels are constantly in decline as they age. They experience difficulties in correctly operating digital systems not only because of their vision and physical strength, but also because they forget the operation process and steps due to their intelligence and memory, as well as lack the ability to communicate and understand (Kim et al., 2010; Cho and Kim, 2014; Po-Chan, 2019; Cheng et al., 2022). Studies show that more than 50% of seniors encounter problems related to product design every day in their daily lives. Only 53% of them are well-trained to use quality products for their own needs (Wang et al., 2020). Therefore, to effectively address these issues, attention and focus on smart home product design are needed, and along with technological advances, it is crucial to develop user-friendly device interfaces. How the elderly can be more simple and easy to understand in the interaction process of operating smart homes has become an important research topic, and being able to truly allow the elderly to use and enjoy smart homes has become a key goal in solving this problem. In this regard, although smart homes can provide a certain convenience for the elderly, the user experience and interaction of the elderly in this process is an issue worthy of attention (Yang et al., 2016). In the field of smart home, with the continuous development of home automation, Internet of Things and other technologies, users will interact with smart home more and more. Therefore, from the interaction mode, the user experience design concept is applied to the interactive operation interface design of smart home to benefit the elderly.

Current solutions for the age-appropriate use of smart homes focus on research related to the use of sensors in smart solutions, research related to the implementation of remote access functions in smart home systems to monitor the elderly and operate devices through mobile devices rather than fixed devices, smart home operational benefits and smart scenario output and whether smart home design solutions have the potential for direct application and the cost of smart home value. Scholars' research has focused on studies on user-centered factors of smart home affordability (Cho and Choi, 2020) or personalized user interface frameworks based on Eclipse Smart Home and Universal Remote Console to enhance the user experience when using smart homes (Smirek et al., 2016) among others. In the controlled experiments with the older and younger groups, objective experimental data and subjective ratings then showed that: (1) Elderly preferred figurative icons compared

to the younger group (Backhaus et al., 2018; Chen et al., 2020). (2) The younger group had better user performance for button sizes of 15 mm and above, while the older group had better performance for button sizes around 20 mm. (3) Participants in the younger group had better user performance for graphics vs. text ratios of 1:1 and 1:3, while the user performance of the older group participants was better at 1:3 (Yu et al., 2022b). In terms of user experience, existing research demonstrates that augmented reality and affective computing at the edge enable social robots to be better companions for older adults (Anjum et al., 2021). The emergence of smart environments and social robots proves that environment-based smart homes can provide integrated care services suitable for the elderly (Anghel et al., 2020). The current research results of ICT (Information and Communications Technology) with intelligence, personalization, and adaptivity as the core can actively, healthily, and effectively respond to aging and improve the operability of smart home interfaces (Giakoumis et al., 2019). In summary, most of the current international research on a smart home is centered on smart home-related technologies, which are very extensive and have high depth and relevance, while China's research in this field is still in its initial stage. Especially for smart homes for the elderly, related research is still weak, and domestic smart home research is still mostly focused on technological innovation of smart home systems, lacking analysis of user preferences and ease of use of operating interfaces (Colle and Hiszem, 2004; Cheng et al., 2019). Few studies have also used systematic methods and evaluation metrics to study the interaction and subjective experiences of older adults in using smart homes. Touch screen control, video control, and voice control are the three most common human-computer interaction methods in smart homes, and because the declining physical functions of the elderly have an impact on human-computer interaction, mobile application interfaces need to be designed to match the behavioral abilities of the elderly. The touch interface, on the other hand, allows natural and convenient human-computer interaction (Geva et al., 2013; Fahad and Tahir, 2021), making it easier and more convenient for inexperienced users (Marikyan et al., 2019), and therefore, it was chosen as the display carrier for smart homes in this study. In the touch screen, the comfortable and easy-to-understand operation interface helps to develop a user-centered smart home and is more likely to propose solutions to the problems of lack of independent use and difficulties in product operation among the elderly (Mittelstädt et al., 2014).

Therefore, the focus of this paper is on the study of human-computer interaction interfaces in smart homes for the elderly-adapted population, especially touch-screen interfaces aimed at supporting the usability and user experience of the elderly. The research in this paper is as follows: (1) Taking the factors of the self-care elderly, spatial scene, interaction behavior, behavior object, and experience demand in the smart home age-friendly scenario as the research basis, the smart scene panel is used as the design carrier of the age-friendly smart home interaction system, and the prototype design of the age-friendly smart home interaction interface is carried out with the themes of convenience, simplicity, and warmth, while two special functions, i.e., scene opening and scene presetting. This can reduce unnecessary operations for the elderly when setting up devices in different scenes, which usually do not exist in smart home interactive systems. The prototype contains the functions of scene opening and closing with one click, personalization, operation guidance, warm reminder, and touch voice. (2) In terms of details of operational data and information, functional buttons are important components for users to interact with smart home devices, and the size, style, and operation mode of functional buttons may affect user experience. This paper identifies four operational problems in the operation prototype and optimizes them through experiments, and studies several operations such as new tasks, information modules, and control devices. (3) This study also pays much attention to the subjective preferences of the elderly in terms of visual interface aesthetic performance. In terms of interface aesthetics, firstly, the findings of the prototype design study by Demiris and Hensel (2008), Zhou et al. (2022a), and Zhou et al. (2022b) were combined with the questionnaire. The prototype interface was designed to verify the conclusion that the 18 mm functional buttons, up and down sliding method and simple style in the interactive interface of the age-friendly smart home are better subjectively evaluated through satisfaction testing, followed by the design points such as interface theme color, key color setting points, information density layout and content priority on the page. The aesthetic design of the interface can be more in line with the aesthetics of the elderly and enhance their sense of user experience. (4) Through the deepening test of the experiment, the original interface was re-optimized and experimented again to ensure that the output intelligent interface system can be better facilitated for the elderly to use, studied, and optimized from both functional and visual perspectives, solved the pain points of the elderly, reduced the cognitive and usage burden of the elderly group, enhanced its ease of use, and output a set of interaction prototypes. On the one hand, this study facilitates the life of the elderly and strengthens digital technology communication with the outside world; on the other hand, it provides smart home services for the elderly, which can reduce the consumption of human resources and ease the burden of aging on families and society; it helps elderly users improve their independence in life and enhance their psychological self-recognition and live happier. Finally, the research on the interactive prototype of smart home systems deepens the development and direction of interface design and user experience. In addition to the construction and enhancement of technology, economy, and ecology, this paper provides new ideas to improve the user experience of a smart home.

2. User requirements elements disassembled and built

2.1. Demand disassembly

This user study of age-friendly smart homes was conducted using a questionnaire distributed to a healthy and self-sufficient elderly group between the ages of 55 and 75, all with normal communication comprehension and textual understanding. It contained demographic questions (age, gender, income, education level, etc.), habit and opinion questions, specifically divided into single sections on smart home usage, user physiology, lifestyle

habits, and basic user profile. A total of 155 were collected. The Ethics Committee of the Science and Technology Division of Nanjing Forestry University approved the study protocol (Jiangsu Province, China), which was read and signed by all participants before participation.

In the questionnaire, the respondents were asked to select the level of importance of different aspects of the smart home interaction system according to their needs, which were classified into five levels: very unimportant, unimportant, indifferent, important, and very important (Park et al., 2020). This survey was an attitude scale, and the quantitative information collected in the questionnaire was examined, especially the reliability and accuracy of the attitude scale questions were studied with the help of reliability analysis. The Cronbach reliability analysis of the Smart Home Interactive Function and Experience Needs Scale is shown in Table 1, and it can be found that the value of the reliability alpha coefficient is 0.777, which is greater than 0.7, indicating that the quality of the reliability of the research data is good. According to the column of "alpha coefficient of deleted items", we can see that there is no increase in reliability after deleting any item, so each item can be used and should not be deleted.

The validity of the design of this question was checked using validity analysis: with a KMO value of 0.829 and a KMO value greater than 0.8, the study data were well-suited to extract information and responded with good validity. The *p*-value was met by Bartlett's test. However, it can be seen from Table 2 below: for the common degree, a total of 3 items involving prominent information, comprehensive function, and personalized customization interface, their corresponding common degree values are less than 0.4, which indicates that the information of the research items cannot be expressed effectively. Therefore, after deleting these 3 items and analyzing them, the validity analysis of the smart home interaction function and experience requirements scale is shown in Table 2.

The 5 levels of very unimportant, unimportant, indifferent, important, and very important are scored, respectively −2, −1, 0, 1, and 2. According to the average score, users think that the aesthetics of the operation interface is the most important when they use the interface, followed by clear and easy-to-operate information, and the importance score of the remaining items is between important and indifferent. To summarize the interactive experience needs and priority order of smart home: beautiful operation interface >clear information not easy to operate wrongly >simple operation with few steps. Smart home interaction function and experience demand scale scores are shown in Table 3. Finally, the questionnaire also investigates the user's life troubles and speculates the smart home functions that users may need. The survey results show that the most prominent distress of users is vision loss, and 100% of the elderly group over 65 years old chose this item. Therefore, we should focus on the visual design of the interface when designing the interactive interface of the age-friendly home, which needs to be simple and clear, with not too many elements and not too small text and icon sizes. Therefore, in the subsequent development of the interface, we chose a 1:3 graphic ratio, with black font and white background. At the same time, we noticed that elderly people prefer to read figurative icons rather than text, and considering the overall aesthetics of the interface, we set the font size to 18 mm to highlight the icon display. In addition, nearly one in seven users chose the item of poor memory, so the functions of schedule reminders and medication reminders should be considered in the development of a smart home operating system.

After the quantitative user study of the questionnaire research, a qualitative study of user interviews was conducted to understand how the age-friendly smart home should adapt to users' living habits and how users would use the product when, where, and for what reasons, aided by the user observation method. A total of six users, all aged 60 and above, were screened through the questionnaire as suitable for further user interviews. The interviewees had experience in using smart home products and services, as well as those who had no experience in using smart home but had experience in using other smart devices and were potential users who were willing to try using smart home products or services. The interviews started from three types of oriented questions, such as goal, system and process, and recorded the users' rating rate, problem, feeling and expectation of using smart home. The results show that users will generally go out every day and need to see the time and weather conditions before going out, and most users have a relatively regular life. In terms of equipment, most users use smart home function is relatively single, and many smart products are eventually used as ordinary products, the reason is still that the interaction experience is poor, and the operation process is complicated and will not operate. Second, most users believe that the linkage between devices is insufficient. In terms of user preferences, typing and search functions are generally difficult or time-consuming for users, who prefer light-colored interfaces and do not like interfaces with too many information content elements. Therefore, in the subsequent interface development, light color is adopted as the theme color of the page, the overall style is simple, the home page needs to reflect the time, weather, and other situations in a large area, and the operation simplifies the process as much as possible, and develops one-key open and close functions according to different scenarios. User research was conducted through questionnaire research and user interviews to obtain user characteristics, lifestyles, and needs from a macro perspective (Joshi et al., 2015), which guided the interface design and operational functions of the subsequent system development. The specific results are shown in Figure 1.

2.2. User objective disassembly

The three levels of cognitive and affective processing correspond to the three types of user goals, namely experience goals, final goals and life goals (Al-Maskari and Sanderson, 2011). User goals are a part of the main manifestation of the persona model, and user goals drive users to produce different behaviors.For example, users open the window every morning to ventilate and get fresh air, and the reason for ventilating is derived from the pursuit of healthy life. Based on the questionnaire and user interview results discussed above, two types of user models are constructed, namely, A users who pursue simple and convenient life and B users who pursue a beautiful interface and high-quality life.

TABLE 1 Cronbach's reliability analysis of the smart home interaction function and experience requirements scale.

Item	Correction term total correlation(CITC) of the deleted item	The alpha coefficient of the deleted item	Cronbach alpha coefficient
Beautiful operation interface	0.493	0.753	
Large text and prominent	0.448	0.760	
Simple operation and few steps	0.555	0.753	
Clear information	0.551	0.753	0.777
All functions are included in the	0.456	0.753	
Personalized interface	0.493	0.467	
Personalized features	0.493	0.538	

Through the reliability analysis, the design requirement points with excellent reliability were retained for screening.

TABLE 2 Validity analysis of the smart home interaction function and experience requirements scale.

Object	Factor loading factor	Commonality (common factor variance)
Beautiful operation interface	0.649	0.421
Large text and prominent information	0.598	0.358
Simple operation and few steps	0.706	0.498
Clear information	0.698	0.488
All functions are included in the interface	0.609	0.371
Personalized interface	0.628	0.394
Personalized features	0.694	0.482
KMO value	0.829	-
P-value	0.000	-

The design requirement points with excellent validity were retained for screening by validity analysis, $p < 0.05$.

TABLE 3 Smart home interaction function and experience demand scale scores.

Item	Score	Average score
Beautiful operation interface	168	1.135
Clear information, not easy to operate error	79	0.534
Simple operation and few steps	61	0.412
Personalized features	6	0.041

The analysis found that users consider interface aesthetics to be the most important, followed by clear information and easy operation, and finally personalization and customization.

Class A users who pursue simplicity and convenience are the entry-level experience of smart home for aging. To ensure that the system is easy to learn and to reduce the cognitive load and learning cost of the system, it is necessary to have a strong readability of the interface content, smooth interaction process, simple operation, clear functional instructions, reasonable layout of interface elements, uniform interaction form, so that users are willing to accept and learn, and have a good emotional experience (Han et al., 2022).

B users who go for a beautiful interface and high quality of life have more experience in using smart products, have higher requirements for smart home interaction experience, need to set and control devices according to preferences, have more diversified requirements for interaction forms, need to be reasonably concise in functions, clear interaction logic, strengthen the scene mode multi-device linkage, and have deeper requirements for interface beauty and layout (Pan et al., 2022).

The goal analysis of the two categories of target users constructed in this paper then draws on the three levels of cognitive and emotional processing in product design proposed by Donald Norman: instinct, behavior, and reflection (Rose and Levinson, 2004). The goal disassembly is shown in Figure 2. The goal disassembly of the two types of target users guides the subsequent prototyping, requiring us to focus on more advanced features and interface aesthetics based on satisfying the needs of the former type of users. Therefore, our prototype design starts from both functional and formal aspects to ensure the beautiful and simple interface and smooth and fluent operation. Strengthen the important aspects and weaken the unimportant details. At the same time, we also needed to increase the variety of interaction forms. Therefore, multi-device linkage, voice interaction and other functions were added to the development.

Through quantitative and qualitative analysis, the user pain points were derived and the user needs were refined, and the goals of two different types of users were dismantled, thus summarizing the design direction of this age-friendly smart home system as follows: (1) Interface and visual level. The interface needs to be clear and easy to understand while maintaining aesthetics. In the development, we chose a 1:3 graphic ratio, an 18 mm button size, a light color as the theme color of the page, a black content expression on a white background, and an overall simple style. To clarify the interface design details need to conduct experiments to further explore the interface factors that meet the user's operating habits. (2) System level. Relying on scene mode and room mode to achieve smart home multi-device linkage, the user experience of using smart home is enhanced and the difficulty of using it is reduced by reducing the user's operation steps on the devices in the fixed scenes of daily life. (3) Interaction mode level. The main interaction mode is touch, which is simpler than other interaction modes and can give elderly users enough space to think and react; voice interaction is

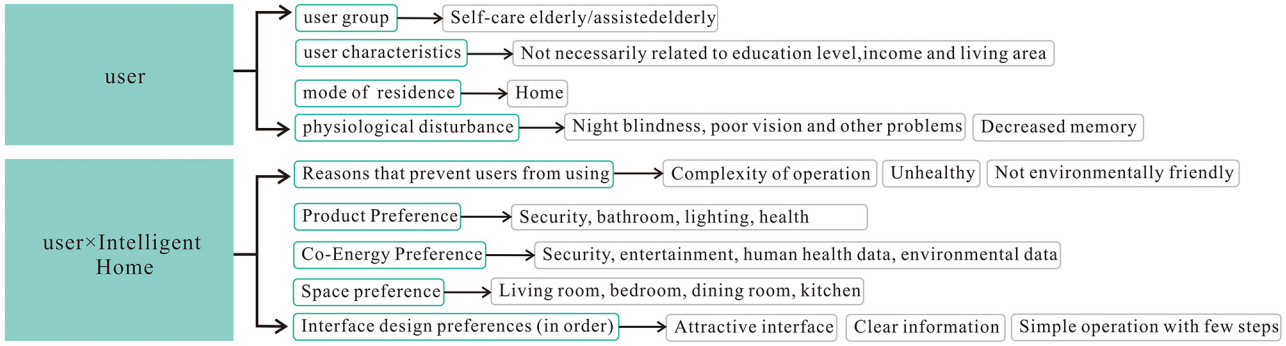

FIGURE 1
Summary of questionnaire research results. The different colors in this figure indicate the different layers of the hierarchy. The button with blue background is the first level, indicating a summary from the user and the user with the smart home; the basket box button is the second level; and the button with white background is the third level. It serves as the main basis for the subsequent user goal disassembly.

	User Goals	What is it	How to get	Importance	Examples
Reflection	Life Goals	Users' personal expectations, what they want to be, their long-term desires, their self-image.	Class A users: need to clarify the product concept, the designer will turn their life goals into practical and operable functions, focusing on convenience and practicality. Class B users: designers need to translate their life goals into high-level system functions, which can be achieved by using special scenario function design.	are deep-seated drivers and motivators that explain why these two types of users need to achieve certain end goals.	Category A users. -Living a healthy life -Living a convenient and easy life Category B users. -Become a valuable person -Living an interesting and diverse life
Behavior	Ultimate Goals	The user's motivation to use the product or a feature of the product.	Class A users: Designers need to achieve the goal of simplicity, speed, and convenience through good interaction design. Class B users: Designers need to achieve experiential information architecture through the design of product behaviors, tasks and scenarios.	Behavior affects the instinctive and reflective processes of both types of users, and the achievement of a good end goal is one of the significant factors in obtaining a good sense of experience.	Class A users. -Play my favorite music -Find the information I need quickly Users in category B. -Pull back the curtains on the whole family -Customize my life
Instinct	Experience Goals	The user's desired feeling when using the product.	Class A users: visual characteristics of the interface (clarity, ease of finding, aesthetics) Class B users: auditory features of the system, details of the interaction process (button clickability, touch response, animation effects, etc.)	If the product makes these two groups of users feel powerless, clumsy, or confused, it may make them unhappy or give up using it, even if the product is highly functional.	Class A users. -feel pleasant and convenient -Feeling easy to control Category B users. -Feels trendy and relaxed -feel very meaningful

FIGURE 2
Target analysis of target users. This figure illustrates the three levels of cognitive and affective processing in product design proposed by Donald Norman for each of the two different types of users mentioned above, starting from instinct, behavior, and reflection, and analyzing them in different aspects.

used as an auxiliary to touch so that users can use voice interaction when it is inconvenient to touch or when they need to operate more conveniently and quickly. (4) Functional requirements. Easy access to daily information, warm prompts according to the scene, operation guidance, clear meaning of icons, one-click control of multiple devices in the scene mode, detection of the environment, and feedback data.

2.3. Description of user interaction behavior

The scenarios of users using smart homes in different situations are classified. To explore the development of the scenario mode function of controlling multiple devices with one click, the interaction task flow structure words required for user requirements are expressed with the help of a flowchart, and the user's operation history is visualized with the help of the preliminary design of the prototype page, and the specific scenarios are designed as follows.

Under the scenario of starting scenario mode, users can switch to the scenario panel by clicking the item button in the bottom sidebar, turn on or off the scenario by clicking the corresponding scenario in the scenario panel, double-click or long-press the scenario to enter the editing page of the scenario module, ordinary users can turn on the scenario with one click in the "Scenario" page, and users with more needs can personalize the scenario by clicking the home button in the bottom sidebar. Users with more needs can personalize the scenario, and click the Home button in the bottom sidebar to go back to the home page.

In the case of a room or a device that you want to turn on in a room, you can click the "Room" button in the middle of the upper area of the page to enter the room page, where you can turn on or off all the devices in a room with one click. If you want to view the details of the room or view the equipment in the room and make

settings for the equipment, you can double-click or long-press the room to see the details of the room, click the equipment on this page to turn it on or off, double-click or long-press the equipment to make adjustments.

Under the scenario of voice interaction, the user can enter the page of voice interaction by clicking the voice button hovering at the bottom right corner of the page, and depending on the page where the user is before clicking the voice button, the guidance words on the pop-up voice page will be different. When the user turns on voice interaction on the home page or the scene page, the instruction will be biased to instruct the user how to give voice instruction to turn on a scene mode, how to record a schedule, how to play music review, etc. When the user turns on voice interaction on the room and device pages, the instructions will guide the user on how to issue voice commands to search and find a room or device or how to schedule a single device. The operation flow and page flow under the scenarios of starting scenarios, turning on devices, and voice interaction, as shown in Figure 3.

2.4. Interface prototype construction

Through the research and analysis of user needs and objectives and the construction of activity scenarios, combined with the results of the prototype design study conducted by Zhou et al. (2022b). It was concluded that the design points of this prototype for its age-appropriateness were as follows: (1) A simple style with lines was adopted, and the information was conveyed in black characters on a white background. (2) The size of the graphic ratio was 1:3, and 18 mm was chosen for the functional buttons. (3) In the layout features of the homepage, a simple and intuitive multi-column layout or card layout is used, combined with a bottom navigation bar type of main navigation. (4) In the selection of the main color, a light monochrome with low saturation is used as the main color to highlight key information with a saturated tone (Lindberg and Näsänen, 2003; Norman et al., 2003; Smith, 2009). Its age-appropriateness was continuously confirmed and optimized in subsequent experiments, and finally, a set of operational interaction fidelity prototypes were produced as follows.

1) First-level page

The first-level page is mainly the home page and the project panel, as shown in Figure 4. The home page is a daily information display page made to match the age-friendly scenario, mainly with a time module, environment module, and warm reminder module. The time module is a dynamic time, showing the year, month, day of the week, and time. The environment module focuses on weather information, outdoor temperature, air humidity, and air quality information display. The time module is one of the indispensable daily information that aging users need to get, and it takes up a large space in the home page for the problem of declining eyesight of the elderly. Click the second button "Project" in the bottom bar to enter the smart home function opening mode, and recommend users to use the scene mode. Under the "Scene" selection on the project page, users can perform the preset scene mode one-click opening operation, and the switch in the upper right corner of each preset scene module shows the running status of the scene. At the same time, for the sake of aesthetic user needs for personalization, double-click or long press the scene module to enter the corresponding scene editing page.

2) Scene opening and setting page

There are three main pages involving scenes, namely the scene page, the scene details page, and the device details page. Ordinary users, they can turn on or off the scene with one click on the scene page. Users with more advanced needs can add more device behaviors to the mode on the scene details page, or turn on or off the preset device behaviors, as in Figure 5.

3) Rooms and settings page

In addition to the scene module also designed for the user room module, the user can turn on the equipment in the room with one click, or through the room details page to view the room information, energy consumption, the user can also use the room module to view what devices are in the room and operate the device, the design logic is the user usually turn on a device will go to the room where the device to operate the device or to find its remote control behavior habits, such subconscious. The design logic is that users usually go to the room where a device is located to operate it or to find its remote control. This kind of subconscious design helps the user to perceive and smooth the operation process, as shown in Figure 6.

4) Voice and voice feedback page

The hearing and memory of elderly decrease with age, and single-channel speech interaction may increase the cognitive burden of users. In voice interaction, speech is the language-based means of interaction, aided by visualization of visual information, thus improving the interaction experience of voice users and improving the multichannel perception of voice interaction for the elderly (Rose and Levinson, 2004). By adding voice interaction, the opening of scenes, control of devices, and access to information can be completed conveniently and quickly.

Finally, to verify the suitability of this interface design for the elderly, the interface of the general-purpose smart home system of H brand (China) was first extracted, and the two interfaces of "Home" and "Scenes" were processed with low fidelity, and then compared with the interface of this design. The four aspects of the home page content layout, bottom navigation module, voice, and prompt function, and graphic ratio and button size all prove that the design direction of the age-friendly smart home system summarized above is well-responded to in this interface design, and it is more suitable for the elderly compared with the general-purpose interface. The analysis process is shown in Figure 7.

3. Interface prototype testing

3.1. Experiment and materials

3.1.1. Experimental stimulus materials

Axure (Axure Software Solution, San Diego, CA, USA) and MockingBot (Beijing Modaokeshi Technology Co., Ltd., Beijing, China) were used for the prototype of this experiment. as the support for the interface design. To check the usability and satisfaction of the prototype, four different operation tasks were set, namely "View daily information board", "Scene opening board", and "Voice interaction board". "Voice interaction board"

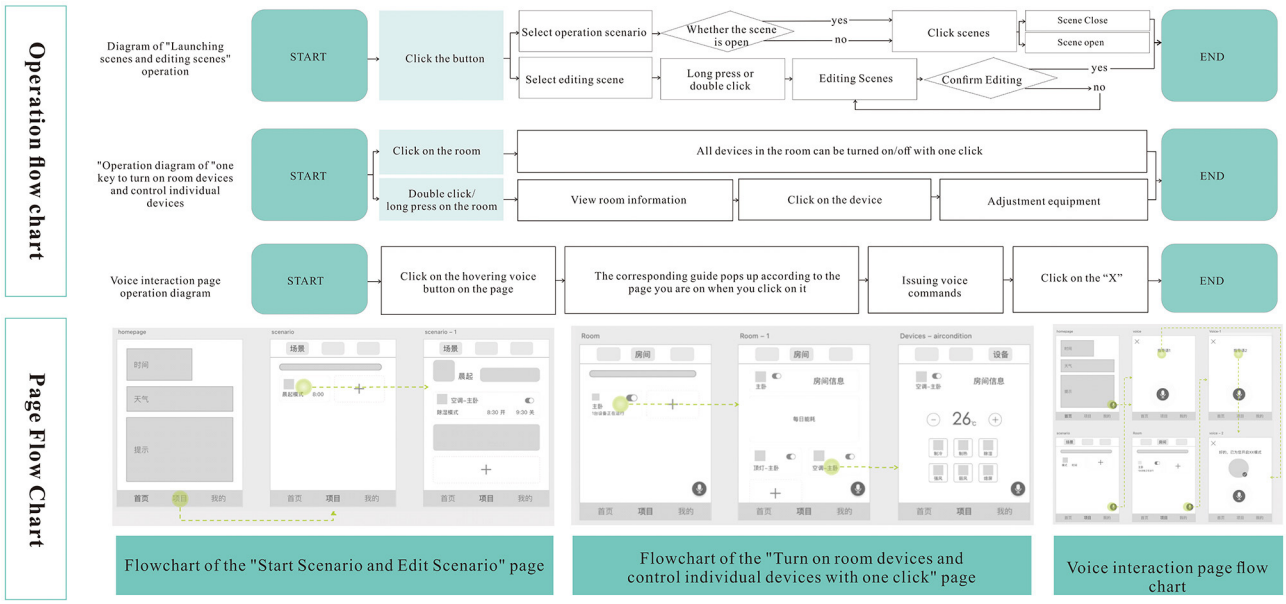

FIGURE 3
Operation flow chart and page flow chart. It includes scenarios such as starting scenes, editing scenes, opening room devices and regulating individual devices with one click, and voice interaction.

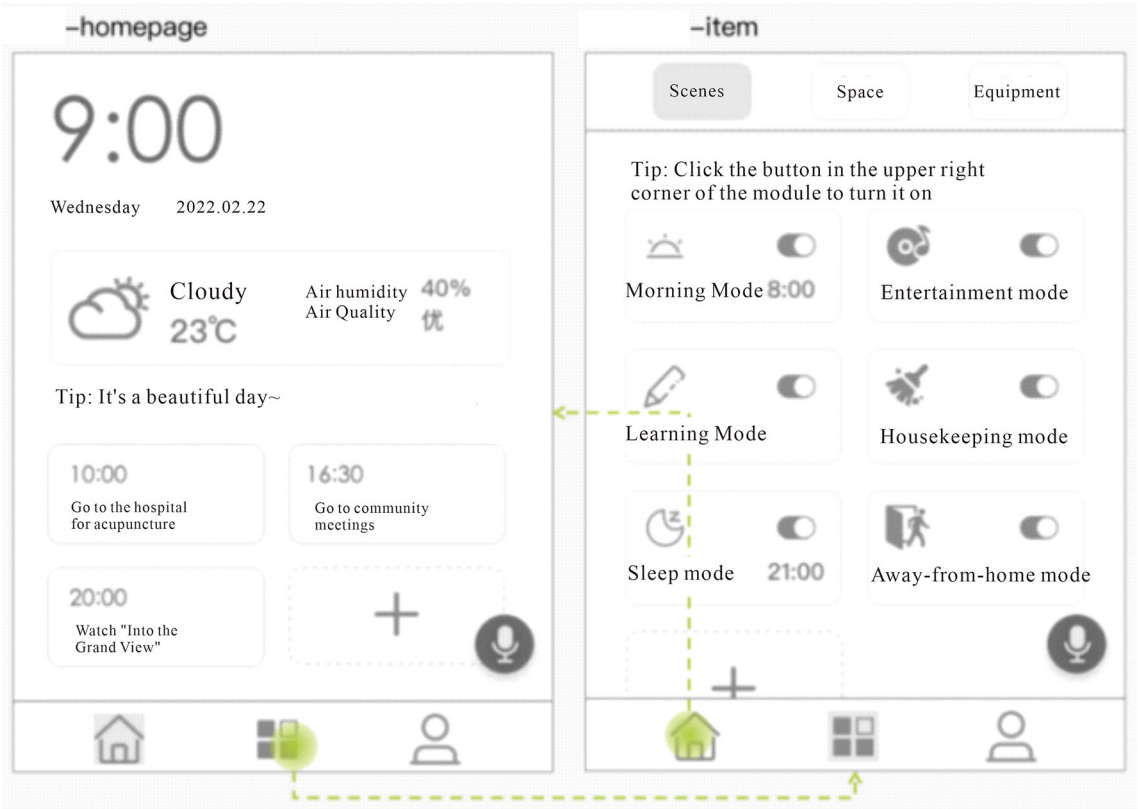

FIGURE 4
Age-friendly smart home panel level 1 page. Including home panel and project panel.

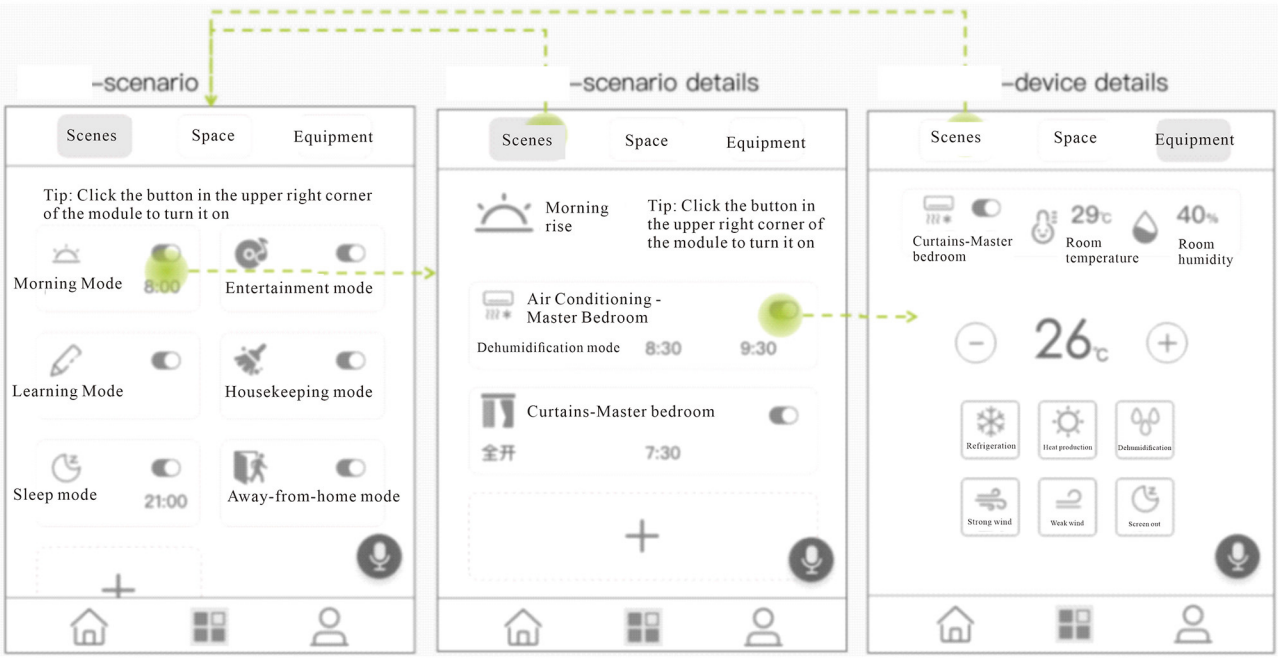

FIGURE 5
Age-friendly smart home panel scene mode related pages. Including scene page, scene detail page, and device detail page.

and "Device control board", the difficulty varies, and need to operate separately.

3.1.2. Experimental equipment

The experiments were conducted in a controlled environment, controlled illumination, and a sound reduction chamber. The framework of the experiment was deployed on a 10.5 in iPad air with a 12-megapixel rear wide-angle camera and horizontal stereo dual speakers. Participants were invited to sit on an adjustable chair in front of the flat screen. Participants' operation time and a number of jams were recorded and analyzed, and during the operation test, which operated the predetermined four tasks, subjects were asked to ensure a minimum distance of approximately 60 cm from the display during the experiment. The height of the webcam and the respondents' eye height were kept at the same level to ensure that the experiment would not have a large time error due to the tricky angle. A questionnaire on the aesthetic assessment of the interface was also filled out upon completion.

3.1.3. Experimental subjects

This experiment was conducted in the laboratory of the School of Home and Industrial Design at Nanjing Forestry University. A total of 32 healthy, independent elderly people, aged 55–75, were recruited, 17 of whom were female (159–173 cm) and 15 male (166–180 cm). To ensure the accuracy and validity of the sample, the 32 subjects were asked to be free of eye swelling, eyelid ptosis, eye disease, or eye surgery within 6 months, and to wear glasses with natural or corrected visual acuity over 1.0 for myopia or presbyopia; in addition, subjects were asked to be free of physical or cognitive impairment, with the usual hand being the right hand. All study subjects were retired teachers or residents living on campus.

The ethics committee of the Science and Technology Division of Nanjing Forestry University approved the study protocol (Jiangsu Province, China). All subjects will read and sign the trial before participating in the trial and will be compensated for the trial upon completion.

3.1.4. Experimental procedure

(1) Experimental purpose

The reason for conducting prototype testing is to discover the functional and experiential problems of the age-friendly smart home interactive prototype, evaluate its age-appropriateness, and verify the suitability of the designed prototype for designing an age-friendly smart home system. The test scenarios are constructed by using storyboarding to create scenarios for the subjects and make them complete the test tasks to obtain more realistic user experience feedback.

(2) Functional testing

Construct test scenarios against already designed interaction prototypes. When building test scenarios, virtual scenarios built using interactable prototypes, described in the form of stories or scenarios, are used to test tasks in key activity scenarios of users. The specific functional test scenarios contain four main types of tasks as follows.

1) In the view daily information section, task one is to get information such as time, weather, and outdoor environment. It is suitable for going out grocery shopping, going out, and other scenarios. Through the smart panel to check whether it is suitable

FIGURE 6
Age-friendly smart home panel room and settings page. The picture shows the one-touch to turn on the control devices in the room.

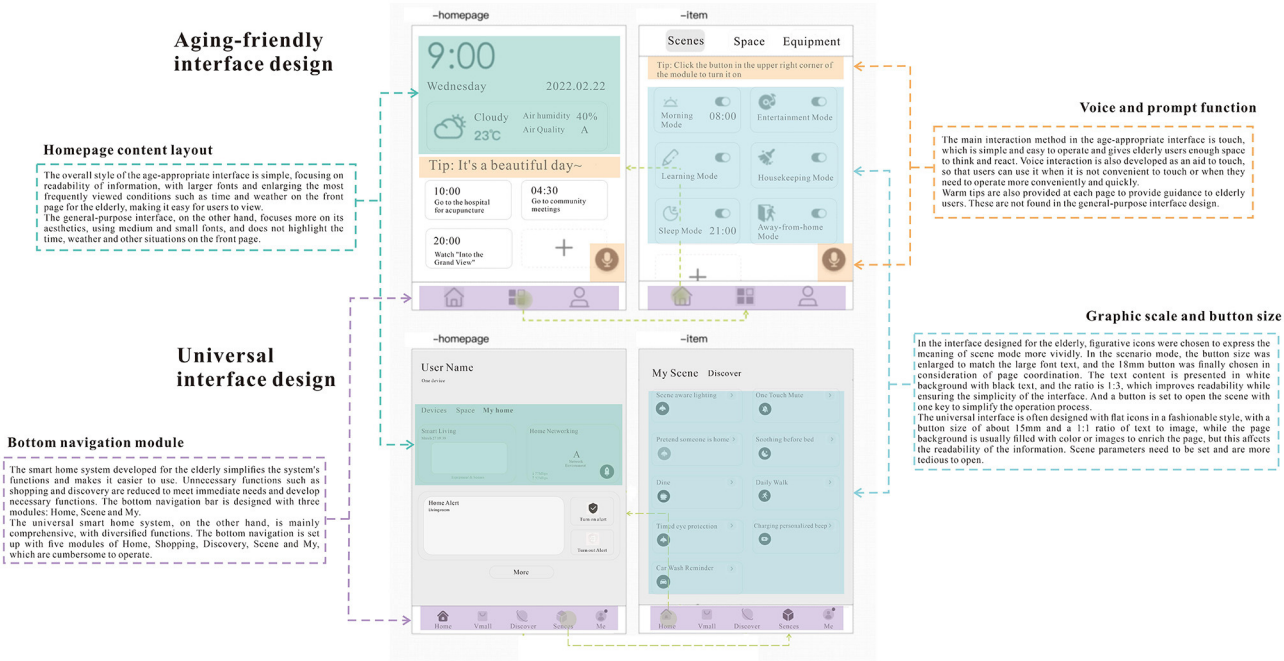

FIGURE 7
Comparison of the age-friendly prototype and the generic prototype. The H brand was compared with the "Home" and "Scenes" sections of the interface design. The top is the age-friendly prototype designed for this study, and the bottom is the generic prototype of H brand. The green part is the comparison of the content layout of the home page, the purple part is the comparison of the bottom navigation module, the blue part is the comparison of text and icons, and the yellow part is the comparison of voice and prompt functions.

to go out, whether it is necessary to add clothes, etc., you need to ask the user to check the panel and say the result.

2) In the scene opening section, task two finds the scene page and opens the scene with one click. It is suitable for scenes such as buying groceries and starting to cook, listening to music while cooking after turning on cooking mode, etc. Users are required to find scenes and turn them on.

3) In the voice interaction panel, task three is to find the voice button and issue a command to open the leisure mode, after dinner in the living room watching TV, using the smart panel to issue a voice command to open the leisure mode scene, the user needs to use the voice function to open the leisure mode.

4) In the device control panel, task four is to find the device list and the master bedroom air conditioner and adjust the temperature of the master bedroom air conditioner. Suitable for scenarios such as hot weather and adjusting the air conditioning temperature of the master bedroom alone, users can also use the voice function to find them. The experiment was conducted for 15-20 min, with a 5 min break after completing the first two tasks to ensure the subjects' eye comfort, and the subjects were randomly selected and completed the tasks as required, and the entire experiment was recorded.

(3) Interface evaluation

After the interface use test, the subjects were asked to complete a questionnaire to evaluate the interface design of the prototype, to study this chapter on the age-ability of the intelligent home interaction design interface, to verify the validity of the research methods and strategies in this study for realizing the interaction interface visually responding to the ageability scenario, to discover the problems in the prototype design and to make improvements from the interface design. The Likert Scale was used to rate the satisfaction level of the interactive interface of the age-friendly smart home system, and the satisfaction was classified and scored, and the evaluation was divided into very satisfied (5 points), satisfied (4 points), average (3 points), dissatisfied (2 points), and very dissatisfied (1 point). The evaluation results were obtained by counting the satisfaction rating questionnaires filled by the subjects and calculating the mean value to further deepen the aesthetics of the prototype.

3.2. Data statistics and analysis

3.2.1. Analysis of operational data

Using the Kano model to study the relationship situation between functional requirements and satisfaction, the same function was first asked from both positive and negative questions, and then the cross summaries between the options of positive and negative questions were obtained for a total of 6 attributes. The cross-tabulation of the Kano model evaluation results is shown in Figure 8.

As shown in Table 4, F represents a function, A represents a charming attribute, O represents desired attribute, M represents an essential attribute, I represents an undifferentiated attribute, R represents a reverse attribute, Q represents a suspicious attribute, and CR represents classification result B represents better W represents worse. The functions are 1 for daily information as a display, 2 for warm tips, 3 for operation guidance, 4 for scene presetting, 5 for voice feedback, and 6 for voice touch combination (Sharif Ullah and Tamaki, 2011). After the analysis of the results, it can be seen that in the 6 functions according a certain attribute accounted for the most as the division boundary, and finally in the 6 functions with the necessary attributes there is one, for the daily information display. There are two charming attributes, namely, warm tips and scene preset. There is one desired attribute, which is operation guidance. The combination of voice feedback and voice touch is an undifferentiated attribute. This result can better reflect the previous research and design direction and is analyzed as follows.

(1) Because the elderly have difficulties in giving specific and standardized voice commands, voice interaction is used as an auxiliary means of interaction when defining product features. Voice interaction as an auxiliary function does not have a great impact on satisfaction, but according to the charm attribute study, its undifferentiated attributes and essential attributes have the same score, so the combination of voice interaction and touch control of the two control methods will not improve user satisfaction, but without voice, interaction may be a slight decline in user experience.

(2) The analysis results show that "Daily Information Display" is a necessary attribute, time and weather are the information users need to get in their daily life, daily information display is not a special feature and will not significantly improve user satisfaction, but the absence of this feature will affect the user experience.

(3) The "Warm Reminder" and "Scene Preset" functions are charming attributes, without which user satisfaction will not drop significantly, which can explain why there are few such functions in the existing domestic smart home systems. However, for the elderly user group, the scene preset can simplify the operation steps and improve efficiency, which is in line with the research results in Chapter 3. The warm reminder function addresses the pain point of memory loss of the elderly and brings emotional care to the elderly, thus enhancing user satisfaction.

(4) "Operation Guidance" is the desired attribute, without which user satisfaction decreases and with which user satisfaction increases. The analysis of the questionnaire results shows that without this feature, user satisfaction decreases because users need to think about how to do the operation or make trial and error to complete the task during the operation.

In summary, the order of importance of the function development of the age-friendly smart home should be "Daily Information Display" >"Operation Guidance" >"Scene Preset" >"Warm Tips" >"Voice Touch Combined Interaction", which is basically in line with the previous research results and can provide a reference for development priority in the subsequent system iteration and upgrade process.

3.2.2. Visual data analysis

The content of the questionnaire is about the interface design, including the overall look and feel, layout and icon style and size, text size satisfaction issues. Specifically, it includes: Whether, the overall appearance of the interface is good. Whether, the layout of the interface elements is reasonable. Whether, the size of the text in the interface makes you feel clear and readable. Whether, the size of the icons in the interface makes you feel satisfied. Whether, the sparsity of the interface layout makes you feel satisfied. Whether, the style of the icons in the interface makes you feel satisfied, etc.

The evaluation results were obtained by counting the mean values of the satisfaction rating questionnaires filled by the subjects. The overall mean score of the interface design of the age-friendly

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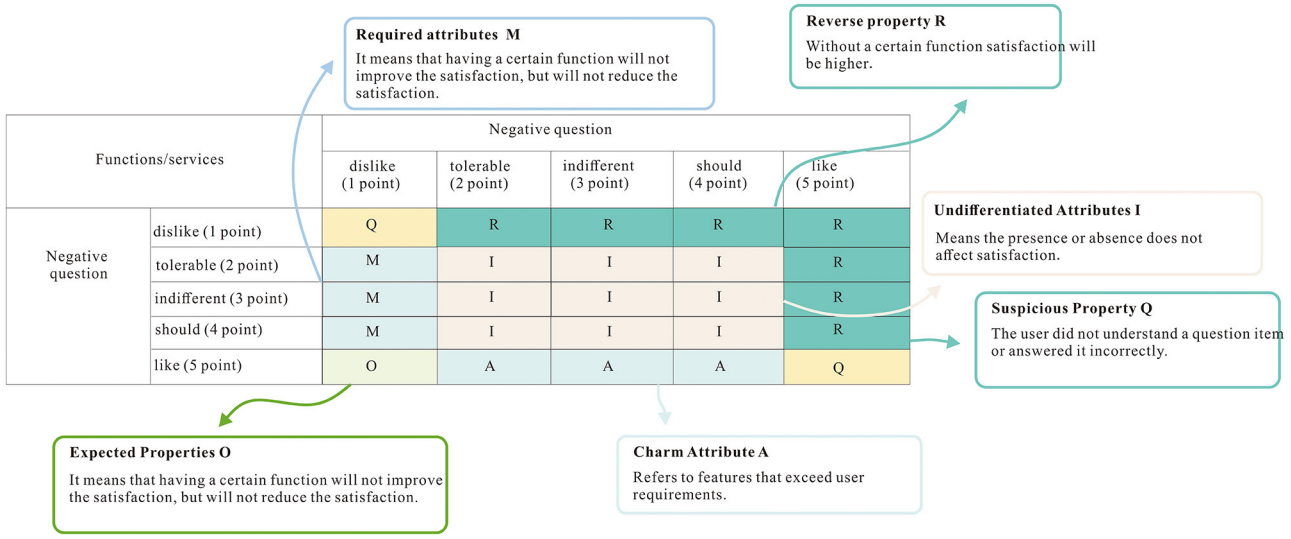

Functions/services	Negative question	dislike (1 point)	tolerable (2 point)	indifferent (3 point)	should (4 point)	like (5 point)
Negative question	dislike (1 point)	Q	R	R	R	R
	tolerable (2 point)	M	I	I	I	R
	indifferent (3 point)	M	I	I	I	R
	should (4 point)	M	I	I	I	R
	like (5 point)	O	A	A	A	Q

FIGURE 8
Cross-tabulation of Kano model evaluation results. The same function was asked separately from both positive and negative questions, and then the cross-tabulations between the options of positive and negative questions were summarized.

TABLE 4 Charisma attribute study. Charisma attribute analysis was performed for 6 functions.

F	A (%)	O (%)	M (%)	I (%)	R (%)	O (%)	CR	B (%)	W (%)
1	0.00	25.00	41.67	33.33	0.00	0.00	M	25.00	−66.67
2	41.67	25.00	8.33	25.00	0.00	0.00	A	66.67	−33.33
3	16.67	58.33	16.67	8.33	0.00	0.00	O	75.00	−75.00
4	50.00	25.00	0.00	25.00	0.00	0.00	A	75.00	−25.00
5	0.00	0.00	41.67	58.33	0.00	0.00	I	0.00	−41.67
6	8.33	8.33	41.67	41.67	0.00	0.00	I	16.67	−50.00

smart home interactive system is 5.53, and the users are most satisfied with the text size and icon size, which are 6.5 and 6.08, respectively. It means that users are satisfied with the interface design in general, the icon size is the highest, and the satisfaction with the interface layout is the lowest, only 4.42, which needs to be improved. Users were asked in detail about the layout of the interface and found that the reason for the low score was that they thought the main function "Scene Preset" should be placed on the home page or in a position that is easier to find, and that the current design did not allow them to complete their tasks faster.

After the test is completed, the data is organized and analyzed. (1) In the view schedule information task, users do not understand the meaning of the plus sign in the schedule area, and the icon for a new schedule is changed to "+" and the text "New Schedule". In the scene opening task, the meaning of the icon in the bottom sidebar is not indicated, so users cannot understand it accurately. (2) Users think the step of clicking the "Project" button in the middle of the bottom sidebar and then opening the scene is not simple enough. We need to add text labels to the icons in the bottom sidebar, adjust the scene mode to the home page, and adjust the display position of the schedule. (3) In the device control task, there are too many elements in the device information column, which increases the user's cognitive cost and the uncertainty of whether the device is turned on or not on the device control page. It is necessary to change the main information in the information module from the upper part to the lower part and concentrate it in the hot zone of the thumb, to reduce the crowding of elements and enhance the convenience of operation, as well as to distinguish the page status when the device is switched on or off. (4) In the device control task, it is not sure whether the device is on or not on the device control page, and it is necessary to add a page state that distinguishes when the device is switched on or off. The improvement scheme is shown in Figure 9.

The first improvement is the interface improvement. Before the improvement, the schedule reminder was placed in the lower part of the home page, after the improvement, the main function "Scene Preset One-click On" was adjusted to the lower part of the home page and concentrated in the thumb hot zone, reducing the interaction steps for users to use the scene function.

The second improvement is the interface improvement for the device control page. Before the improvement, the switch status of the device is not obvious, but after the improvement, the low saturated gray color is used to imply that it cannot be clicked and the visual color difference with the main color green is used to

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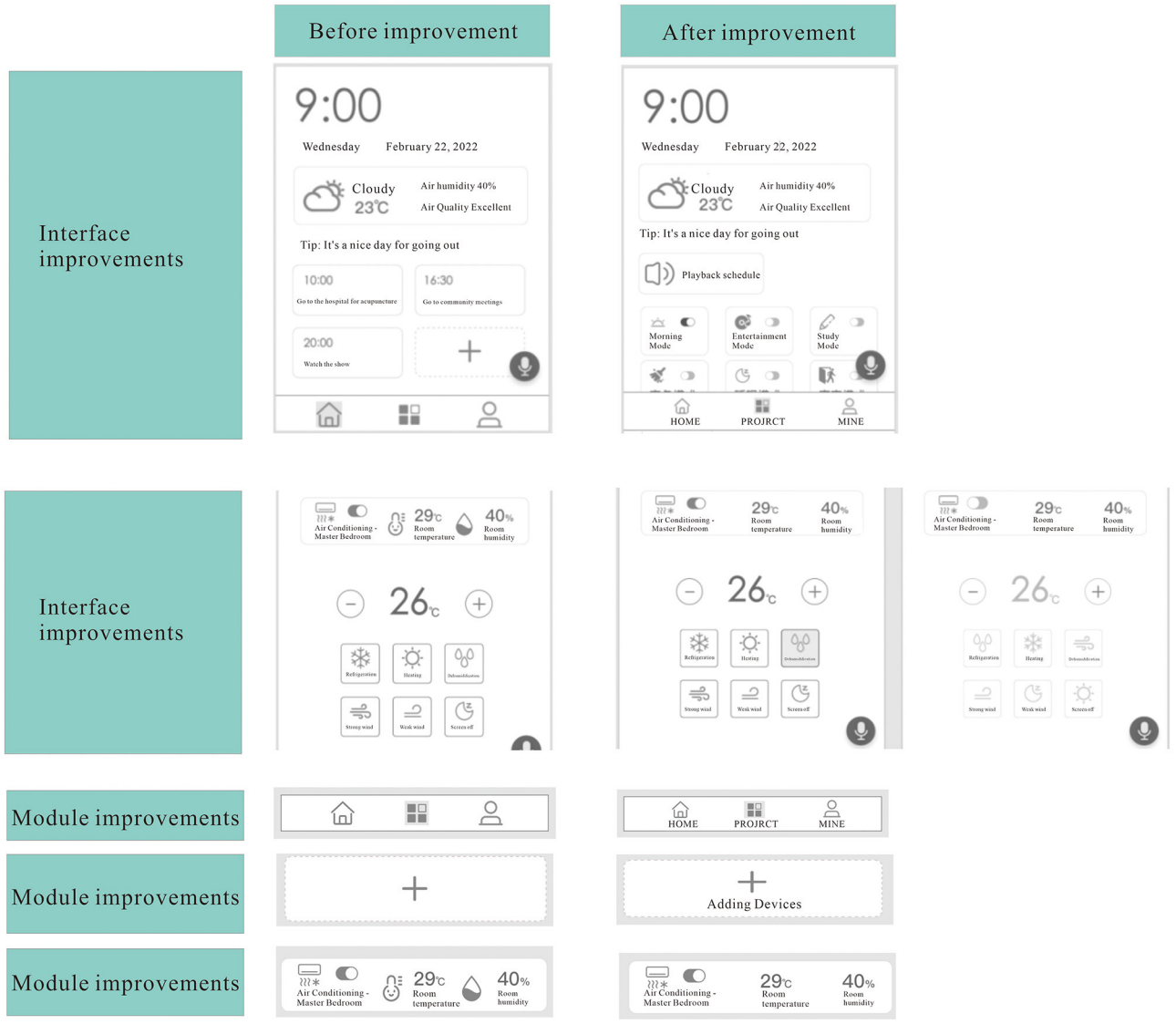

FIGURE 9
Operation scheme improvement. Before and after the improvement of the interface is listed, the optimization of the icon meaning, new task, device control, information density.

convey the signal of refusing to click this button. The gray device control icon is used to indicate that the device is turned off on the current page, while the green color indicates that the device is clickable or not yet turned on. The color and the on/off button function are used to indicate the on/off status of the device.

The third improvement to the module is the improvement to the bottom navigation bar. Before the improvement, the three buttons in the navigation bar were not marked, which made it difficult for users to understand the meaning of the buttons, after the improvement, the 3 buttons are marked with text, which makes the meaning more clear and reduces the cognitive load of users.

The fourth improvement is the improvement of the module, which is the improvement of the design of the new or added button. Before the improvement, the button only had a plus icon, and the user could not understand its meaning at first, but the improvement is the combination of the plus icon and the text mark to help the user understand and find the function.

The fifth improvement is the improvement of the module, which is the improvement of the device information column. Before the improvement, there were too many elements, which affected the efficiency of the user's information acquisition, after the improvement, the necessary information was left to improve the user's cognitive efficiency.

3.3. Visual optimization

The visual optimization stage mainly includes the specification design of visual elements of the age-friendly smart home interaction interface and the high-fidelity design of the interaction interface.

The experiment proved through subjective evaluation that users accept and like the 18 mm function buttons, the up and down sliding method, and the minimalist style in the existing conclusion. It was also found that different usage scenarios required the application of different colors. The theme color is green, as green usually contains the semantics of "Pass" and "Success", and is also very eye-friendly and senior-friendly, used to indicate "Task Success", "The Device is Running", etc. and to highlight and guide older people to click. The color of the icons is divided into two categories: green indicates that the corresponding function button is highlighted, indicating that the scene, room, or device is on or running, and the green bottom bar icon indicates that the current page is under that category. The gray icon indicates that the scene, room or device is not yet on. In terms of the information density of the page arrangement, a moderate proportion of graphics is used, and the information density is low. In terms of the arrangement of the page content, priority needs to be given to the information content with high user relevance. In terms of the information density of the page arrangement, a moderate proportion of the text is used with a low information density to facilitate the view of the elderly group. In the arrangement of the page content, information content with high relevance should be highlighted as the focus.

Finally, the functional and visual problems found in the prototype test were optimized and landed, and the design scheme was deepened and improved, which finally improved the interaction design practice of the age-friendly smart home system and output the prototype of the high-fidelity interaction interface of the age-friendly smart home system. Finally, according to the experimental results, the problems of functionality and visibility that appeared in the prototype verification were optimized, and the design was deepened and improved, to realize the human-computer interaction design of the smart home for the elderly and form a set of human-computer interaction interface with high fidelity. The design of color and font specification, buttons, icons, and interactable modules are shown in Figure 10. Finally, invited 32 subjects (all of whom had participated in Experiment 1) to test the optimized output interaction interface, and the testers were satisfied with the overall satisfaction of this optimized design, as well as with the optimized five operation optimization and visual optimization.

4. Discussion

Smart homes are rapidly gaining popularity and more and more consumers are using smart home systems. To make more people accept and use smart homes, especially the elderly, it is necessary to make the interface of smart home simple and easy to use. This study focuses on the pain points of the elderly group, which can effectively help designers identify the design features of smart home interfaces in terms of form and function, to better improve the ease of use and achieve a better user experience. A combination of literature research, quantitative analysis of questionnaires, and qualitative analysis of interviews was used to identify users' needs and goals and refine the focus in specific usage scenarios. The experiments in this study aim to optimize the prototype of the interaction interface designed in the first round and to examine whether the use of the prototype is easy and beautiful for users in terms of both operational experiments and visual evaluation. The interface design was optimized in terms of color, font size, icon size, etc. and the final design results were output. The interface design was optimized through satisfaction experiments, such as reducing the interaction steps of the user using the scenario function and developing a one-click opening function. The buttons were switched between low-saturated gray and highlighted green to signal whether the device was on or not. The text was added to the bottom navigation bar buttons, and the labeling used a combination of icons plus text to create new tasks. When arranging the web content, informative content with a high degree of relevance to the user was placed first whenever possible, etc. Finally, the existing findings of the research on button design, module design, and icon design in the age-friendly smart home interaction interface were also verified.

4.1. Operating functions

The existing smart products are complicated to operate and cumbersome to interact with, which increases the cognitive and usage burden of the elderly and hinders their daily use and user experience. This paper designs an interface prototype of an age-friendly smart home system based on previous research results and questionnaire analysis, and experimental testing proves that the overall usage process of the age-friendly smart home prototype designed in this paper is smooth and consistent with previous research results. However, there are shortcomings in the operation details, such as users do not understand the meaning of the plus sign in the schedule area in the task of viewing schedule information, users think that the step of opening scenes by clicking the "Project" button in the middle of the bottom bar is too complicated, and there are too many elements in the device information bar, etc. Further improvements can be made through experimental analysis to include the main function. The main function of "One Click to Open Scene Preset" is adjusted to the lower part of the home page to reduce the interaction steps for users to use the scene function, use color and switch button function to indicate the switching status of the device, add text labels for the 3 buttons to make the meaning clearer and reduce the cognitive load of users, use plus icon and text labels to help users understand and find, etc.

4.2. Interface form

Interface design is increasingly focused on the subjective preferences of users, but this is largely ignored in smart interface design guidelines. User selection of products is largely based on subjective preferences. Therefore, it is necessary to focus on user perceptions and preferences. The subjective questionnaire analysis proved the existing findings of the studies on button design, module design, and icon design in age-appropriate smart home interaction interfaces noted in the previous studies. In terms of interface aesthetics, the interface was optimized and improved in details, such as using green as the theme color to indicate "Task Successful", "Device Running", etc. and to highlight the icons to guide the elderly to click on them, and the icons can be divided into two categories according to the color: highlighted In terms of

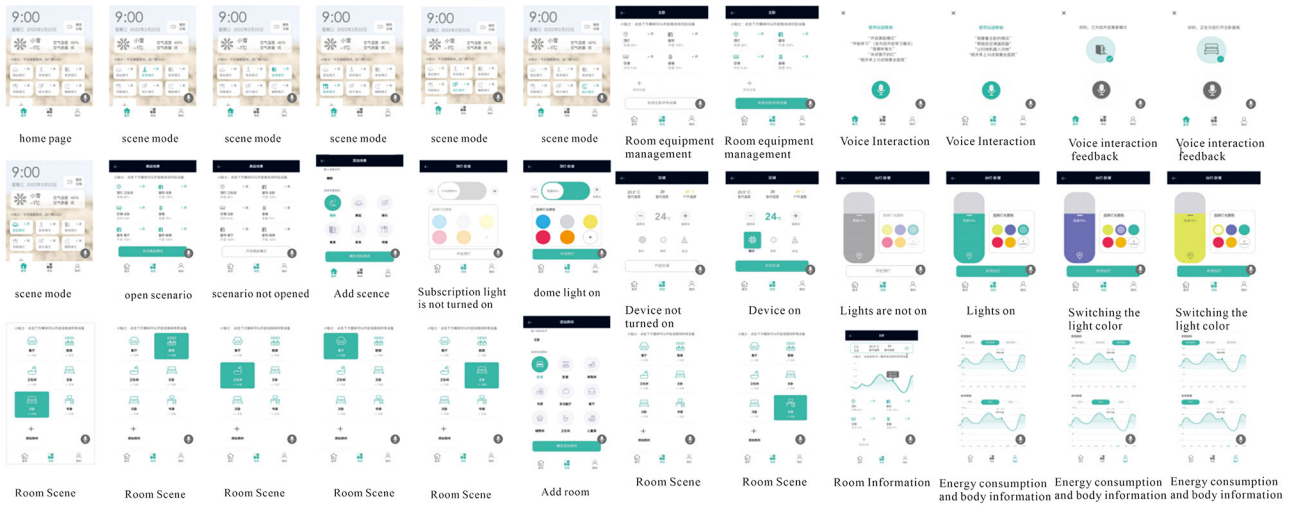

FIGURE 10
Output the final high-fidelity prototype design interface. Used 1:3 graphics in page layout, larger text ratio, 18 mm icon size, and color split between green and gray. The information density is low, and the information content with high user relevance is amplified. The function contains three sections: Home, Scene, and My, and developed special functions such as one-key opening scene and voice interaction.

the information density of the page layout, it adopts a moderate proportion of graphics and text with low information density. Tn the arrangement of the page content, it gives priority to the information content with high relevance to users. It not only improves the operability of the prototype design of smart home interaction in the age-friendly scenario, but also improves the beauty and comfort of the prototype design, so that the elderly can have a better experience when using the smart home.

4.3. Limitations

In this study, only middle-aged and elderly people with good vision were selected as experimental subjects. It is not clear whether different postures and usage environments will have an effect on the users' behavior compared to those related to elderly vision, eye diseases, and sensory disorders. When users manipulate the smart home device interface, they are not necessarily in a sitting position. They are likely to stand, lie down, or walk, and the effects of the above factors on the experimental results need to be further explored. Second, the volume of the voice control interface can affect the test results, especially when the subjects heard voice commands to perform the task. In subjects with good hearing, they will move faster and easier, and vice versa. The third reason is that the task in the experiment was relatively homogeneous, allowing the subjects to complete the task easily and satisfactorily. However, in reality, when users wish to operate in the smart home device interface, they are expected to complete a series of searches and constant clicks. This difference will have an impact on the results of the study. Fourth, the test method and the final analysis of the experiment were mainly derived from the subjective evaluation of the subjects, and the process did not combine with the subjective evaluation, although some objective data such as the number of blockages and the frequency of clicks were recorded, which is the deficiency and shortcoming of this experiment at this stage, and is the direction and research topic to continue our experiment subsequently. Furthermore, the illustrations included in this research proposal are limited to conceptual diagrams and images related to the study product, which we will expand on in subsequent studies. We will also focus more on disability in the target group, which is often the case, and this aspect of the study is meaningful and important and points to our future research goals. Finally, although the timeout of using smart home products in the home may cause certain safety hazards, it can be more harmful to the elderly group of users if it is not operated properly. This study combines safety, ease of use, and satisfaction with subjective assessments to examine user behavior. Elderly will respond more slowly; therefore, the validity of the task completion time indicator should be explored in depth. Future work should focus on a combined subjective and objective evaluation system, further research on system construction and technology, and a multifaceted evaluation system. Although some of the above factors are reflected in this paper, there is still much to explore, and we hope that future research will focus on these aspects.

5. Conclusion

In this paper, we developed a design framework to improve the usability of smart home systems for ageing and exported an interaction prototype. A user study test with 32 participants verified the key points of interaction prototype ease of use design and optimization: operational flow test and interface evaluation test. The accuracy of set target values, task completion times, and participant preferences were recorded for comparison.

The experimental results show that the overall usage process of the age-friendly smart home prototype designed in this paper is smooth for the elderly in the operation test, which is basically consistent with the results of previous studies. However, there

are shortcomings in the operation details. It is recommended to adjust the main function bar to the lower part of the home page, reduce the interaction steps for users to use the scene functions, use color and switch button function to indicate the switching status of the device, add text labels for the buttons, use plus icons and text logos, etc.. It makes the meaning clearer, reduces the user's cognitive load, and helps the user understand and find. It shows that the 18 mm function buttons, the up-and-down sliding layout and the minimalist style received the best subjective evaluation from seniors. In terms of color, green is recommended as the theme color, with highlighted green and gray highlighting to guide seniors to perform correct tapping operations.

The results of these studies improve the operability and aesthetic comfort of smart home interaction prototyping in age-friendly scenarios, both functionally and visually, and enhance the ease of use of the interface to provide a better experience for the elderly when using smart homes.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by Nanjing Forestry University. The patients/participants provided their written informed consent to participate in this study.

Author contributions

CZ contributed framework ideas, experimental design, and analysis methods. WZ conducted the experimental manipulations, collection, and analysis of primary data, and plotted the graphs. TH and HZ assisted in acquiring and analyzing the data for the work and assisted in graphing the figures. JK guided the refinement of the language, analyzed the data, critically revised important intellectual content and the layout of the article, and ensured that issues related to the accuracy or completeness of any portion of the work were properly investigated and resolved. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Recruitment of older adult-caregiver dyads during the COVID-19 pandemic: an example from a study to evaluate a novel activities of daily living (ADL) sensor system

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Under ideal circumstances, recruitment of older adult-caregiver dyads to dementia research is challenging. The COVID-19 pandemic introduced additional barriers to recruitment, necessitating swift adjustments to pre-pandemic recruitment strategies and schedules. This brief research report describes the challenges, yield, and cost of recruiting older adult-caregiver dyads to an 18-month observational research study during COVID-19. The study aimed to evaluate the effectiveness of a novel in-home sensor system at identifying cognitive change in older adults with Alzheimer's disease and related dementias (ADRD) through background monitoring of activities of daily living (ADL). Recruitment methods included flyers distributed alongside home-delivered meals, direct mailings, publicly available brochures, community presentations, periodical advertisements, and various other strategies. Of 510 inquiries, 117 older adult-caregiver dyads were enrolled at a total cost of ~$368,000, yielding an average per dyad recruiting cost of $3,148. Distributing flyers alongside home-delivered meals produced the most dyads (n = 46, 39%) and the least non-labor costs ($24.33) per enrolled dyad. Recruitment during the pandemic exceeded the pre-COVID-19 budget, but enrollment goals were nevertheless achieved through community-based methods. Our experience illustrates the challenge of recruiting older adult-caregiver dyads to dementia research and the value of trusted community partners in recruiting this population. Our strategies and recommendations may benefit researchers who plan to recruit community-based older adults and their caregivers for future dementia research.

KEYWORDS

recruitment, Alzheimer's disease, dementia, COVID-19, caregiver, dyad, cost, community-based

1. Introduction

Recruitment for any research study is a complex endeavor that can prove challenging, but recruitment of persons with dementia is notably difficult (Grill and Galvin, 2014; Watson et al., 2014; Fargo et al., 2016; Nuño et al., 2017; Bartlett et al., 2019). Recruitment of older adult-caregiver dyads adds another layer of difficulty because

both parties must be eligible and consent to participate (Nahm et al., 2012; Field et al., 2019). The COVID-19 pandemic only amplified existing recruitment challenges and introduced novel obstacles to enrolling a representative sample. Lockdowns, social distancing measures, and heightened health concerns disrupted many carefully laid pre-pandemic recruitment plans. With COVID-19 having drastically reshaped the recruitment landscape, understanding which recruitment methods proved successful for recruiting persons with dementia and their caregivers during the pandemic offers insight into the planning and execution of future human-subjects research.

This brief research report presents our experience with recruiting older adult-caregiver dyads to an Alzheimer's disease and related dementias (ADRD) observational research study to validate a novel in-home sensor technology amid the COVID-19 pandemic. The nature of the study as it concerned ADRD, dyads, and technology meant that recruitment was expected to be demanding, but COVID-19 only intensified the demand by necessitating a complete overhaul of the original recruitment strategy. In this paper, we aim to (1) describe the revised community-based recruitment plan, (2) examine the effectiveness of each community-based recruitment method based on cost and participant yield, (3) evaluate the overall impact of COVID-19 on recruitment, and (4) provide lessons learned regarding the recruitment of older adult-caregiver dyads for future ADRD research.

2. Method

2.1. Study overview

In April 2020, Birkeland Current, along with Baylor Scott & White Health, the Georgia Institute of Technology, and the Texas A&M Center for Population Health and Aging were awarded the Small Business Innovative Research (SBIR) Phase II program R44AG065118 for *Improved AD/ADRD Assessment Sensitivities Using a Novel In-Situ Sensor System*. The purpose of the study was to validate a new activities of daily living (ADL) monitoring system to assess cognitive decline in ADRD adults ages 65 and over. Using radio frequency identification (RFID) technology, the system continuously tracks device usage and real-time location to identify behavioral patterns (e.g., ADL) and objective changes to those patterns associated with physical or cognitive decline. System-derived ADL scores were compared to scores recorded from monthly telephone surveys with caregiver informants using the Alzheimer's Disease Cooperative Study—Activities of Daily Living (ADCS-ADL) Scale (Galasko et al., 1997). The recruitment goal included 108 older adult-caregiver dyads in home settings (i.e., single-family homes, apartments, independent living communities) and 32 dyads from assisted living facilities. The sensor system was to be installed in the residences of older adult participants for an intended 18 months. Eligibility requirements for older adults—henceforth referred to as care recipients (CRs)—and caregivers (CGs) can be found in the Supplementary material. A full overview of the ADL monitoring system is available at sovrinti.com. All elements of the original and updated study protocols were managed and approved under the Texas A&M University institutional review board (IRB) process.

2.2. Original recruitment approach and budget

The pre-COVID-19 recruitment plan relied upon commitment letters from nine assisted living, home care, and home health companies representing a total client base of over 3,000 older adults. These care companies committed to recruiting study participants using materials and training provided by the researchers. From discussions with these strategic partners, approximately 900 clients were expected to meet the study's inclusion criteria for CRs and included the expectation that the majority of CG participants would be professional CGs employed by the various companies. CRs and CGs were each to be paid $75 per month as a participation incentive which was classified separately from the recruitment budget. $212,503 was budgeted for direct recruitment costs, including $300 for materials, $6,602 for travel (i.e., mileage reimbursement), and $205,601 for labor not including indirect costs or fringe benefits. The travel recruitment budget was intended to cover two trips to participants' homes—one consent appointment and a subsequent visit to install the sensor system. While the care companies were to perform the bulk of educating and recruiting participants, the labor budget was to cover two research staff members' presence at consent appointments and subsequent sensor system installation appointments. The recruitment plan anticipated a 4-month consent and sensor installation schedule, with an additional 4-month available margin. Based on care company partner populations, recruitment efforts were expected to be concentrated within a narrow geographic area surrounding the Birkeland Current facilities in Waco, Texas. An average of 60 miles round trip per CR household was used to estimate labor and mileage calculations for recruitment. Informed by the demographics of Central Texas, the resulting CR sample was projected to be 67% female, 33% male, 80% white, 20% Black or African American, 70% not Hispanic or Latino, and 30% Hispanic or Latino. The CG sample was projected to be 85% female, 15% male, 70% white, 30% Black or African American, 76% not Hispanic or Latino, and 24% Hispanic or Latino.

2.3. COVID-19 impacts and revised recruitment approach

On April 15, 2020, the NIA approved the Phase II program to begin recruitment starting May 1, 2020. On April 30, 2020, Texas A&M halted all human subjects research under their purview until appropriate protocols for accomplishing research during COVID-19 could be established. Birkeland Current worked with the Texas A&M Office of Sponsored Research to establish additional screening and safety protocols to allow the research to proceed beginning in August 2020. Between April and August 2020, all nine care partner companies formally or informally suspended their support for the study. Reasons cited by the companies for suspension included: (1) policy changes restricting non-essential personnel's access to CR's residences; (2) dramatic reductions in client bases due to COVID-19 fears, lockdown policies, or family-imposed restrictions; (3) significantly elevated CG turnover and

reductions; and (4) a need to focus on existential business concerns that did not include research support.

The COVID-induced withdrawal of the nine companies' support necessitated a complete overhaul of the original recruitment plan and protocols. In the absence of care company partners to act as intermediaries between the research team and potential participants, all recruitment efforts shifted to the recruitment team at Birkeland Current. Recruitment pivoted to a community-based approach that included the following: flyers distributed alongside home-delivered meal programs (e.g., Meals on Wheels), direct mailings, publicly available brochures, community presentations (both in person and remote), event booths (both in person and remote), Facebook advertisements, magazine advertisements, newsletter articles, new partnerships with assisted living facilities (ALFs), newspaper advertisements and articles, press releases, radio public service announcements, referrals from medical professionals, website postings, and word of mouth. These updated recruitment methods and documents received IRB approval in September 2020.

To facilitate the distribution of IRB-approved flyers alongside home-delivered meals, recruitment staff emailed and called approximately 26 home-delivered meal programs administered by groups such as Meals on Wheels, local senior centers, and other non-profit organizations. Recruitment staff educated meal program administrators on the research study and requested a one-time distribution of study flyers alongside home-delivered meals. Seventeen of the 26 programs agreed to deliver flyers to their client bases. Direct mailings included an IRB-approved postcard sent to potentially viable research candidates. Mailing lists were purchased to target different populations: zip codes within 150 miles of Waco, Texas, adults ages 65 and older, and adult children (ages 45 to 65) that might be acting as CGs to aging relatives. Publicly available or displayed brochures included those delivered to senior centers, senior apartments, medical offices, churches, pharmacies, and community recreation centers. Recruitment staff contacted representatives from these sites and requested to provide brochures for patrons to take. A full overview of recruitment methods can be found in Table 1.

TABLE 1 Recruitment methods.

Recruitment methods	Description
Direct mailings	Staff purchased targeted mailing lists and sent postcards to potentially viable research participants
Publicly available brochures	Staff contacted senior centers, senior apartments, medical offices, churches, and community recreation centers to request that study brochures be made available in common areas for patrons to take
Community presentations	Staff made presentations both in person and virtually at CG support groups, senior centers, retirement communities, CG agency lunch and learns, and social clubs. Presentation attendees were shown a video describing the study and given informational brochures to keep and distribute to other potentially eligible individuals
Event booths	Staff offered study recruitment materials at an Alzheimer's Association Walk to End Alzheimer's, a local farmer's market, and a regional medical center lobby
Facebook advertisements	Facebook advertisements featuring a video introducing the study targeted adult children that might be caring for aging parents
Magazine advertisements	One advertisement was placed in the official magazine of a 55+ community with over 15,000 residents
Newsletter articles	Announcements about the study were placed in electronic newsletters disseminated by aging resource agencies, caregiving agencies, adult day care centers, and churches
New partnerships with assisted living facilities (ALFs)	Staff emailed and called ALFs to solicit new partnerships whereby the sensor system would be installed in the entire facility. Staff educated ALFs on the study before subsequently making presentations to residents at the facilities that agreed to serve as facility partners
Newspaper advertisements and articles	2-3-week study advertisements were placed in primarily rural newspapers. Staff also contacted rural newspapers and explained the research. If newspaper staff were receptive, the recruitment team subsequently submitted a 300-word article about the study for printing
Press releases	Press releases were submitted to professional board listings
Radio public service announcements (PSAs)	Staff contacted the local radio station and requested they run PSAs regarding the study
Referrals from medical professionals	General practitioners, neurologists, and gerontologists were recruited to disseminate information and flyers regarding the study
Website postings	Information about the study was available on ClinicalTrials.gov and Alzheimers.gov
Word of mouth	The research team encouraged prospective and enrolled participants to share about the study with family and friends. Enrolled participants were given additional study flyers/brochures to share with others

2.4. Recruitment flow

From September 2020 to December 2021, CR-CG dyads were recruited to the study via the above methods. Recruitment utilized a two-step screening process whereby interested dyads were first screened over the phone or in person using a brief script. If the dyad met the initial eligibility criteria, an in-home consent meeting was scheduled. At the consent appointment, two researchers educated dyads on the study and administered the Mini-Mental State Exam (MMSE) (Folstein et al., 1975) to potential CRs to assess cognitive function. The MMSE was also administered to CGs over 75 years old. CRs with MMSE scores of 11–25 and CGs with scores of 25 and above were deemed eligible for study participation. Eligible dyads could then consent to the study or decline to participate. At the consent meeting, researchers also measured the layout of CRs' homes to prepare for the sensor system's installation. An appointment was then scheduled where researchers returned to the CR's home and installed the ADL sensor system.

Recruitment data were captured using an SQL-based, internally developed Customer Relationship Management (CRM) system. This system was fully encrypted for the protection of personal identifiable information (PII). Persons inquiring about the study

were classified as either potential Care Recipients, Caregivers, Family Members, or Household Members. The following information was collected from individuals who completed the initial screening process: name, name of potential dyad partner, referral source (i.e., how they heard about the study), date of birth, education level, physical address, phone number, email address, estimated time spent with dyad partner per week, willingness to carry an RFID tag for at least 50% of waking hours, COVID-19 screening questions and vaccination status for individuals screened after February 2021. The following information specific to CRs was also recorded: living situation (i.e., lives alone or with others), mobility status (e.g., mobile, mobile with cane), number of people in the household, number of prescription medications taken, and presence of hospice care. CR-CG dyads that passed the initial screen and participated in consent meetings were asked to complete demographics questionnaires which included additional data regarding race, ethnicity, and gender which was then recorded in the CRM.

3. Results

3.1. Yield per recruitment method

Table 2 shows the number of inquiries and subsequently enrolled CR-CG dyads resulting from each recruitment method. Between September 2020 and December 2021, recruitment staff received approximately 510 inquiries regarding the study through the various recruitment methods. Flyers distributed alongside home-delivered meals produced the most inquiries and enrollees. Seventeen agencies delivered ~5,863 flyers to clients across 32 counties of Central and Southeast Texas. From these 5,863 flyers, 239 individuals inquired about the study, resulting in the enrollment of 46 dyads. This recruitment method yielded 39% (n = 46/117) of dyad participants. Direct mailing produced the second-highest number of inquiries and the third-highest number of enrollees. Of 16,801 mailings, 62 individuals inquired about the study, resulting in 11 dyads enrolled. Direct mailings accounted for 9% (n = 11/117) of participating dyads. Word of mouth yielded the second-highest number of enrolled dyads (n = 15), accounting for 12.8% of participants.

3.2. Total cost and cost by recruitment method

The total expense for recruitment was $368,315.82, for an average cost of $3,148 per enrolled dyad. Of the total, labor accounted for $322,208.83, travel expenses (i.e., mileage reimbursement, gas, meals) accounted for $26,236, and materials accounted for $19,870.99. Based on non-labor costs, direct mailings were the most expensive recruitment method, costing $9,476 and yielding 11 dyads for an average cost of $861.45 per dyad (Table 2). Similarly, from a non-labor cost perspective, flyers distributed alongside home-delivered meals proved the most cost-effective, costing $1,119, representing an average cost of $24.33 per enrolled dyad. Event booths were the least cost-effective, costing $6,000 and yielding no enrollees. Personnel hours associated with individual recruitment methods were not recorded.

3.3. Recruitment flow and resulting sample demographics

Of the 510 inquiries yielded by all recruitment methods, 117 CR-CG dyads were fully enrolled (i.e., consented and installed) into the study, with 107 dyads representing CRs living at home and 10 representing CRs living in ALFs. Figure 1 presents a flowchart depicting the outcome of the two-step eligibility screening for the study. Of the initial 510 inquiries, 316 (62%) individuals were excluded during the initial screening step. The primary reason for exclusion was that the individual declined to participate (n = 133). Subsequent consent meetings were scheduled with 194 dyads, with 70 dyads being deemed ineligible for the study. The primary reason for ineligibility was that the CR scored too high on the MMSE to qualify (n = 45). Of 124 dyads accepted into the study, 7 withdrew consent before the installation of the sensor system into the CR's residence, resulting in the installation of 117 dyads. The average distance traveled per CR home installed was 168 miles roundtrip for 2 in-home visits including the consent meeting and the subsequent installation of the sensor system.

Table 3 shows the demographic characteristics of CRs and CGs fully enrolled in the study through all recruitment methods. As CG turnover was allowed during the study, the demographic data reflects all CGs enrolled from the start of recruitment until study completion (n = 123). The majority of CRs were female (n = 65; 56%), White (n = 81; 69%), and had at least some college education (n = 79; 68%). The mean CR age was 79.4 (SD =8.3) years. The majority of CGs were female (n = 94; 76%), White (n = 87; 71%), and had a mean age of 60.6 (SD=15.3). Spouses accounted for the largest portion of CGs (n = 41; 33%) followed by professional CGs (n = 39; 31%) and adult children (n = 25; 20%).

4. Discussion

This paper presents a narrative of COVID-19's impact on the recruitment of CR-CG dyads for an observational ADRD study and the outcomes of community-based recruiting. COVID-19 drastically shaped this study's recruitment process. Due to COVID-related concerns, the nine care companies that were to serve as recruitment associates suspended their partnership. This necessitated a swift pivot to a community-based recruitment approach where all recruitment responsibilities (i.e., outreach, initial screen, cognitive evaluation/MMSE, and consent) shifted to the Birkeland Current research team, leading to greater labor, travel, and materials costs as well as a different sample composition than anticipated. Despite the challenges introduced by COVID, the original recruitment goal was largely met through various community recruitment methods, providing insights for future researchers regarding the effectiveness and costs of strategies.

In our experience, home-delivered meal programs' willingness to distribute flyers proved invaluable to recruiting CR-CG dyads for an ADRD study during COVID. Unlike many medical

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TABLE 2 Participant yield and cost per recruitment method.

Recruitment method	Number	Inquiries	Enrolled dyads	Percentage of enrolled dyads ($n = 117$)*	Cost of materials	Cost per dyad
Flyers alongside home-delivered meals	5,863	239	46	39.3%	$1,119.00	$24.33
Word of mouth	NA	42	15	12.8%	$0.00	$0.00
Direct mailings (i.e., postcards)	16,801	62	11	9.4%	$9,476.00	$861.45
Community presentations	20	53	10	8.5%	$0.00	$0.00
Newspaper advertisements/ articles	10	22	10	8.5%	$751.00	$75.10
Partner ALFs	2	12	10	8.5%	$0.00	$0.00
Publicly available brochures	5,600	17	8	6.8%	$2,120.00	$265.00
Newsletter articles	5	6	3	2.6%	$0.00	$0.00
Referrals from medical professionals	NA	2	2	1.7%	$0.00	$0.00
Website listings (clinicaltrials.gov; alzheimers.gov)	2	4	2	1.7%	$0.00	$0.00
Event booths	4	7	0	-	$6,000.00	-
Facebook advertisements	5	1	0	-	$104.99	-
Magazine advertisement	1	0	0	-	$300.00	-
Press releases	3	0	0	-	$0.00	-
Radio public service announcements	2	0	0	-	$0.00	-
Unknown/Not reported	NA	43	0	-	-	-
Total		510	117	-	$19,870.99	$169.84

*Percentages do not total 100 due to rounding.

practices, care companies, and social service agencies, home-delivered meal programs largely retained access to their clients during COVID, providing meals to a population that became isolated to an even greater extent during the pandemic (Lebrasseur et al., 2021). As a trusted service provider with access to a sizeable, diverse population, home-delivered meal programs were well-positioned to disseminate study flyers alongside meals even during a pandemic. Once they understood the research and the meaningful impact of their assistance, most leaders in these organizations graciously offered their support. The research team also received feedback from organizations that including study flyers with meals did not add an undue burden to their operations. Reasons cited by home-delivered meal programs for not distributing flyers included: (1) present operations too strained by COVID; (2) currently prioritizing information about COVID-relief resources; (3) already working with other researchers to disseminate recruitment materials and do not want to inundate clients; (4) privacy concerns related to in-home sensor technology.

Flyers distributed alongside home-delivered meals ultimately generated the most inquiries and the highest number of enrolled dyads for the least cost among recruitment methods with associated expenses for materials. The better response rate obtained via flyers disseminated by home-delivered meal programs (4.1%) compared to the response rate of direct mailings (.4%) is consistent with the finding that older adults are more likely to respond to surveys provided by someone known to them than surveys sent in the mail (Edelman et al., 2013). Results suggest that distributing flyers alongside home-delivered meals represents a promising recruitment strategy for recruiting CR-CG dyads for ADRD research.

Newspaper advertisements and articles proved to be another relatively efficient and cost-effective recruitment strategy, with 10 ads/articles yielding 10 dyads representing an average cost of $75.10 per dyad based on materials. Submitting ads and articles to newspapers required less time compared to other labor-intensive methods like presentations and soliciting new partnerships with ALFs.

Word of mouth emerging as the second-highest source of dyad enrollment came as a surprise to the research team. While researchers had encouraged prospective and enrolled participants to share about the study with family and friends, word of mouth was seen as a secondary recruitment method involving a less systematic, concerted effort such as might be done in snowball sampling. As a low-cost, relatively low-effort recruitment method, word of mouth proved to be a valuable component of our community-based recruitment effort. These results suggest the efficacy of word-of-mouth in recruiting participants to ADRD research which is in keeping with historical uses of snowball sampling to recruit hard-to-reach populations (Heckathorn, 2011).

In contrast to flyers, newspaper ads/articles, and word of mouth, targeted mailings, event booths, and social media proved inefficient in our experience. While direct mailings yielded 9% of enrolled dyads, it was the costliest method in terms of materials (including contact list costs and postage) and resulted in the highest average non-labor cost per dyad. Event booths were also expensive while yielding no enrollees. Although relatively low-cost, Facebook ads generated only one inquiry and no dyads.

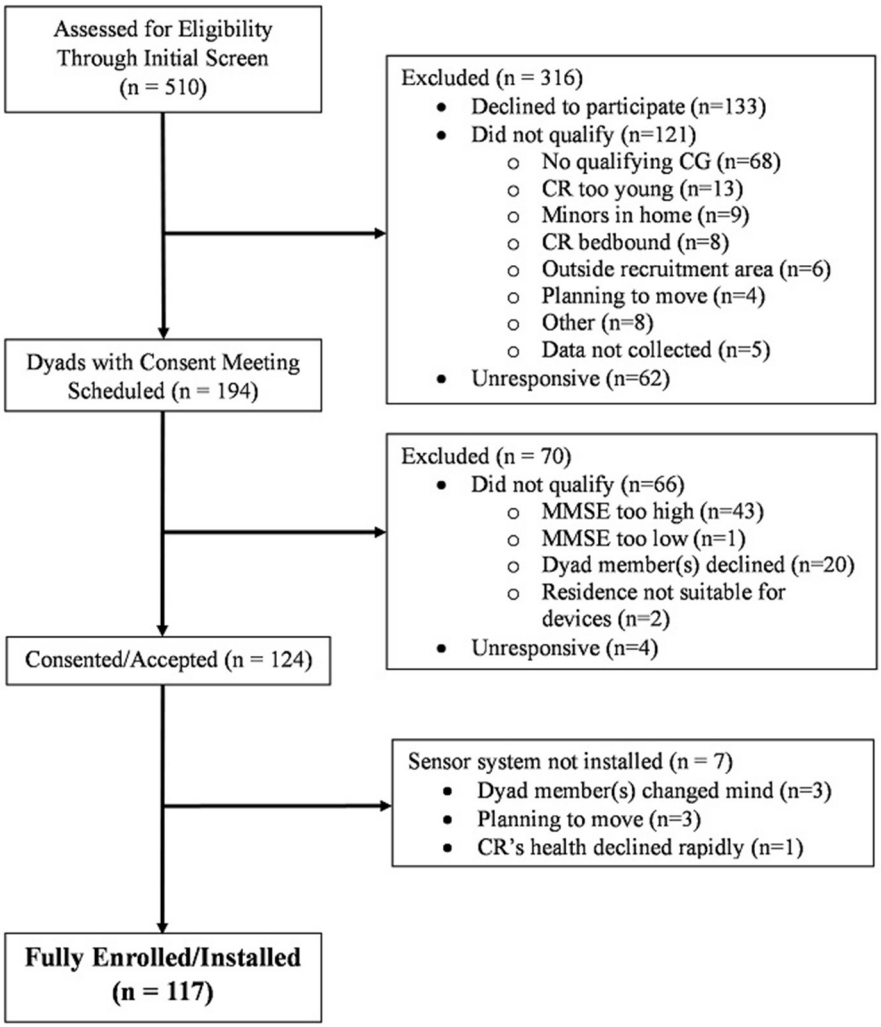

FIGURE 1
Flow diagram of dyad recruitment.

Overall, community-based recruitment cost considerably more than what was originally budgeted based on the pre-COVID-19 care company partnership approach. Labor costs exceed the original budget by 64% as recruitment tasks shifted to the research team and necessitated additional staff (i.e., four paid interns). That community-based recruitment took longer than the care company partnership was expected to take also contributed to the higher recruitment cost. While care company partners would have recruited from their existing client bases that mostly met initial eligibility criteria surrounding age and availability of a CG partner, community-based recruiting involved the additional step of having to first identify potential participants who met these inclusion criteria and subsequently determine if they qualified for the study. This added step in recruitment led to a longer recruitment process which impacted labor costs. Similarly, travel constituted a greater expense due to having to recruit participants from beyond the originally targeted geographic zone to meet recruitment goals. The recruitment zone was expanded to include Dallas, Austin, and Houston, each situated at distances ~200 miles, 340 miles, and 200 miles roundtrip from the research offices in Waco, respectively. While the original recruitment plan anticipated that participants would be clustered in geographic areas served by the nine care company partners, the sample resulting from community-based recruitment was more dispersed. Consequently, the distance traveled to the 117 CR households exceeded original projections by 180%, averaging 168 miles per household compared to the estimated 60 miles per household. Additionally, materials cost 6,524% more than originally budgeted. This is because the planned recruitment approach only necessitated flyers and brochures for the nine care company partners to distribute. The COVID-induced pivot to community-based recruitment methods required substantially more materials, leading to a significantly higher cost.

In addition to its impact on cost, the COVID-induced shift in recruitment approach also yielded a different sample than anticipated. While community-based methods yielded nearly the desired number of CRs living at home (107 CRs compared to the targeted 108), we did not meet the recruitment goal for

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TABLE 3 Participant demographic information ($N = 240$).

Characteristic	Care recipients ($N = 117$)	Caregivers ($N = 123$)
Age in years, mean (SD)	79.3 (8.3)	60.6 (15.3)
MMSE, mean (SD)	22.6 (2.7)	27.8 (1.5)*
Gender, *n* (%)		
Female	65 (55.6)	94 (76.4)
Male	50 (42.7)	27 (22)
Other	0 (0)	1 (0.8)
Not reported	2 (1.7)	1 (0.8)
Race, *n* (%)		
American Indian	1 (0.9)	0 (0)
Asian	0 (0)	1 (0.8)
Black or African American	23 (19.7)	25 (20.3)
White	81 (69.2)	87 (70.7)
Other	6 (5.1)	4 (3.3)
Prefer not to answer	4 (3.4)	5 (4.1)
Not reported	2 (1.7)	1 (0.8)
Ethnicity, *n* (%)		
Hispanic/Latino	6 (5.1)	11 (8.9)
Not Hispanic/Latino	94 (80.3)	99 (80.5)
Prefer not to answer	14 (12)	10 (8.1)
Not reported	3 (2.6)	3 (2.4)
Education, *n* (%)		
Less than a high school degree	16 (13.7)	5 (4.1)
High school degree	18 (15.4)	33 (26.8)
Some college	29 (24.8)	34 (27.6)
Associate degree	9 (7.7)	13 (10.6)
Bachelor's degree	25 (21.4)	26 (21.1)
Master's degree	13 (11.1)	10 (8.1)
Professional degree	3 (2.6)	2 (1.6)
Prefer not to answer	1 (0.9)	0 (0)
No answer	3 (2.6)	0 (0)
Care recipient living alone, *n* (%)		
Yes	38 (32.5)	
No	79 (67.5)	
Caregiver relationship to care recipient, *n* (%)		
Adult child		25 (20.3)
Hired (i.e., formal) caregiver		39 (31.7)
Spouse		41 (33.3)
Other Family		8 (6.5)
Other (i.e., roommate, friend, volunteer, etc.)		10 (8.1)

*N = 28 CGs aged 75 years and over with whom an MMSE was completed.

CRs in ALFs, enrolling only 10 CRs in ALFs compared to the desired 32. This outcome was unsurprising given the withdrawal of the original ALF strategic partners and the difficulty of forging new partnerships with ALFs during COVID-19 when even family members were often not allowed access to facilities. The original recruitment plan also assumed the majority of CG participants would be formal CGs employed by the nine care company partners. In contrast, community-based recruitment resulted in informal CGs (i.e., spouse, adult child, other family, friend, etc.) constituting 68% of CG participants. Based on initial screen reports, this majority informal CG population spent more time with CRs per week (35 h on average) than the formal CGs (24 h on average), with 77% of informal CGs living with their CR dyad partner. With CGs serving as the primary informants of CR ADL performance via monthly surveys, we expect this unanticipated majority informal, live-in CG sample to shape future data analyses and interpretation of CG survey results.

Compared to original projections, the enrolled CR sample consisted of more men than anticipated. While we met the target of enrolling a CR sample that was at least 20% Black/African American, we fell below the anticipated percentage of Hispanic/Latino participants, recruiting a sample only 5% Hispanic/Latino compared to the expected 30%. We similarly yielded fewer Black/African American and Hispanic/Latino CGs than estimated. These outcomes are consistent with literature noting the underrepresentation of racial and ethnic minority populations in ADRD research (Olin et al., 2002; Areán et al., 2003; Gilmore-Bykovskyi et al., 2019). Also, study inclusion criteria required participants to be English speakers, which potentially created a barrier to recruitment. Similarly, recruitment methods targeting minority populations were not employed, which may have contributed to a less diverse sample.

4.1. Insights

Based on our experience of recruiting CR-CG dyads for an ADRD research study during the COVID-19 pandemic, we offer several preliminary insights and recommendations for future researchers. First, the response to flyers distributed alongside home-delivered meals highlights the encouraging prospects of employing this cost-effective method for recruiting CR-CG dyads for ADRD research. We encourage researchers to engage with home-delivered meal programs and other trusted community organizations to aid in recruitment. While many organizations may not have the margins to actively recruit or refer research participants, distributing flyers to clients represents a less labor-intensive alternative. Secondly, the resulting sample of majority informal CGs illustrates the impact that recruitment methods have on sample demographics. We anticipated recruiting more formal CGs via care company partners, but the pivot to community-based methods yielded a majority informal CG sample. If researchers seek a majority formal CG population, community-based recruitment methods may not be most effective. Thirdly, the shift in recruitment approach dictated by COVID-19 and the resulting costs showcase the need for researchers to be flexible and mindful of the time and expense needed to recruit CR-CG dyads for ADRD research. Community-based recruitment required more concerted effort than expected, which necessitated staffing and budgetary adjustments. While COVID-related complications could not have been predicted, we might have anticipated potentially needing alternative recruitment strategies to supplement the originally planned care company partnership approach.

4.2. Limitations

There are limitations in obtaining and applying insights based on this recruitment narrative. First, CR eligibility was based on unadjusted MMSE scores, resulting in more CRs being accepted than if eligibility required an official ADRD diagnosis or was based on MMSE scores adjusted for age and education. Second, the monthly CG surveys were only conducted in English, resulting in a less linguistically and ethnically diverse CG sample. Third, participants were compensated for their involvement in the study, which may have inclined them to participate. Fourth, we did not record the time and associated labor costs associated with individual recruitment methods, which would need to be explored to fully assess the cost-effectiveness of different recruitment strategies. Fifth, the recruitment source was unknown for 8% (n = 43) of inquiries. These represent inquiries that could not be followed up on as well as people who declined to participate before information about the recruitment source could be collected. Had the information been collected, it may have impacted which recruitment methods were considered most successful and cost-effective. Lastly, we cannot ascertain whether individuals who inquired based on one recruitment method would have inquired in response to another strategy.

4.3. Summary

Despite the multi-layered challenges associated with recruiting CR-CG dyads for an ADRD research study involving in-home sensor technology during the COVID-19 pandemic, our results demonstrate the feasibility of using community-based recruitment methods—specifically flyers distributed alongside home-delivered meals—to enroll participants. We anticipate that our transparency regarding recruitment challenges and costs will aid future researchers in planning for the successful recruitment of participants to ADRD studies.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by Texas A&M University Institutional Review Board IRB00000397. The studies were conducted in accordance with the local legislation and

institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

RW: Data curation, Formal analysis, Investigation, Visualization, Writing—original draft. JF: Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Writing—review and editing. EL: Data curation, Formal analysis, Investigation, Project administration, Resources, Supervision, Writing—review and editing. SF: Investigation, Writing—review and editing. MS: Investigation, Writing—review and editing. A-NG: Conceptualization, Supervision, Writing—review and editing.

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Conflict of interest

RW, JF, EL, SF, and MS were employed by Birkeland Current. A-NG was employed by Baylor Scott & White Health.

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Supplementary material

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Technology to support aging in place: key messages for policymakers and funders

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AgeTech, a subset of the health technology industry, uses technology to support healthy aging, and support care partners and health professionals to improve quality of life for aging adults. By enhancing and adapting alternative care approaches through emerging technologies, it is possible to enable and extend the ability for older adults to safely age in place within their own homes, improve care experiences, and/or decrease long-term care costs/needs. With the rapid development and proliferation of AgeTech into the consumer market, it is paramount for policymakers and funders to ensure that AgeTech solutions can be leveraged to support older adults to age well in place. This paper highlights five key messages for policymakers and funders drawing on experiences from Canada. First, it is essential to embrace a life course perspective on aging, recognizing the heterogeneity of older adults who experience diverse and evolving needs. AgeTech should adapt as needs and capacities evolve. Second, AgeTech should solve a real problem. Technology must be well aligned to the needs and preferences of older adults to be impactful. Third, health related AgeTech should empower, enhance, or support existing health care services, while recognizing the value of human interactions. In-person interactions can provide meaningful connection and important health data which should be enhanced not replaced. Fourth, the establishment and ongoing fostering of authentic partnerships to inform, co-create and co-design AgeTech solutions is key to developing successful products. Finally, policymakers and funders have an important role to play in enabling accelerated design, development and testing to meet current and future needs.

KEYWORDS

older adults, health policy, implementation science, AgeTech, aging in place, gerontechnology, Canada

1 Background

Many countries, including Japan, Germany, and Italy are already considered "super-aged" with over 25% of their populations over 65. Many other nations, including the United States, Korea, Sweden, New Zealand, and Australia, are expected to reach this status by 2030 (United Nations, 2019). Similarly, the population of Canada is going through significant demographic shifts, with older adults (65+) becoming the fastest-growing segment and projected to represent 25% of the country's population by 2050 (FP Analytics, 2018). While population aging represents accomplishment and positive opportunities for society, as the demographic landscape changes,

there is a pressing need to adapt healthcare, social, and economic systems to support older adults and their caregivers effectively and ensure financial sustainability. Indeed, this shift represents such a significance, that the United Nations (UN) declared the years 2021–2030 as the Decade of Healthy Aging, to improve the lives of older people globally (The World Health Organization, 2018).

Older adults in Canada, and around the world, have articulated a strong preference to remain in their homes and communities as they age and the Covid-19 pandemic further strengthened this preference (Peek et al., 2014; Garner et al., 2018; Huyer et al., 2020; National Seniors Strategy, 2020). Aging in place is a multi-faceted, complex concept and is related to the UN Decade of Healthy Aging conceptualization. The core concepts of the World Health Organization's (WHO) definition of Healthy Aging are functional ability, intrinsic capacity, and environmental characteristics. All of these need to be addressed in order to provide choices to older adults to age in homes and communities of their choice (The World Health Organization International, 2020). Further, the UN sustainable development goals (SDG) include the importance of supporting health and well-being (SDG 3) at the same time as ensuring Gender Equity (SDG 4), Reduced Inequities (SDG 10), Industry, Innovation, and Infrastructure (SDG 9) and Decent work and economic growth (SDG 5). These goals are critical to foster and sustain an AgeTech sector to support older adults to age in place (Antonucci, 2021).

1.1 Aging in place in Canada- challenges and opportunities

1.1.1 Functional ability and intrinsic capacity are key considerations affecting Canadians ability to age in place in later life

Currently, older adults constitute 17% of Canada's population but account for 47% of total healthcare costs (Canadian Institute for Health information, 2019). Aging is associated with the accumulation of cellular and molecular damage within the body which can manifest as frailty, cognitive impairment and/or chronic health conditions (The World Health Organization, 2022). This increases challenges that threaten older adults' independence and subsequently their ability to age in place. Some challenges include medication management, injury, poorly controlled chronic conditions, frailty and cognitive impairment.

1.1.1.1 Medication management

Many older adults are more likely to experience polypharmacy- defined as taking between 2–7 medications daily- which has been associated with increased risks of medication errors and adverse drug events (Shah and Hajjar, 2012). Research shows that 13% of people taking 2 or more medications will experience adverse events compared to 58% for those taking 5 or more and 82% for those taking 7 or more medications (Tsilimingras et al., 2003). Although medications are effective in combating diseases, their full benefits are often not realized because approximately half of patients do not take their medications as prescribed (Canadian Society of Hospital Pharmacists, n.d.). Medication non-adherence results in additional physician visits, extra laboratory tests, additional drug therapy, hospital emergency room visits, hospital admissions and readmissions, and short-term disability insurance payments.

1.1.1.2 Injury

Injuries from falls, accidents, and motor vehicle collisions are also a major risk for older adults in Canada. More than 25% of older adults report at least one fall in the previous 12 months and falling once doubles the chances of having further falls (Pearson et al., 2014). Hospitalizations due to falls account for approximately 85% of injury-related hospitalisations for older adults in Canada annually (Tsilimingras et al., 2003). Over one third of those who are hospitalised for a fall are discharged to long-term care (Government of Canada Publications, n.d.).

1.1.1.3 Poorly controlled chronic conditions

Many chronic conditions are ambulatory sensitive meaning they can be effectively managed in the home or community setting if there is an appropriate care plan, good health literacy and access to support. A 2011 report from the Canadian Institute for Health Information (CIHI) found that 76% of older adults reported having one or more of eleven chronic conditions, and being over the age of 60 was a significant risk factor for hospitalization with ambulatory sensitive conditions (Sanmartin et al., 2011). Hospitalization is associated with a number of preventable harms including deconditioning, delirium, and adverse events which can act as 'sentinel events' requiring transition to nursing home care (McAvay et al., 2006; Basic and Hartwell, 2015).

1.1.1.4 Frailty

Frailty is a medical condition of reduced function and health in older individuals. The risk of becoming frail increases with age, but frailty is distinct from normal aging. Approximately 1.5 million Canadians are living with frailty and they are over-represented at all levels of the healthcare system (Canadian Frailty Network, n.d.). Older adults living with frailty are at higher risk of major deterioration and health decline following minor illnesses and are more likely to be hospitalised, need long-term care, or die (Nuernberger et al., 2018).

1.1.1.5 Cognitive impairment

Approximately 500,000 older Canadians are living with some form of dementia (Chambers et al., 2016). People with dementia have twice as many emergency department visits and hospitalisations compared to peers, and every year approximately 25% of the population with dementia either visit the emergency department or are hospitalised (Godard-Sebillotte et al., 2021). A 2020 study by Huyer et al. found that a diagnosis of dementia was strongly associated with admission to a nursing home prior to death (Huyer et al., 2020).

These issues are all further amplified by shortages of health human resources (doctors, nurses, personal support workers, and social workers) who would typically support older adults to mitigate these risks.

1.1.2 Environmental context is a key consideration also impacting older adults ability to age in place

The health related functional and intrinsic characteristics that older Canadians face are often compounded by social, financial, and infrastructural barriers that directly impact older adults' abilities to age in place. At the systems level, one major challenge with the current healthcare system in Canada is that it was designed when the average age and life expectancy of the Canadian population was younger.

Funding is commonly reactionarily allocated and focused on acute care with limited and often fragmented underfunding in primary and community care. The 2020 National Seniors Strategy for Canada and the Canadian Medical Association both state that the needs of older adults living in the community are inadequately met (National Seniors Strategy, 2020; Canadian Medical Association, 2021) increasing the risk of potentially avoidable transitions in care location and an increasing burden and demands of family caregivers. Recent Canadian studies suggest that up to 22% of older adults who had recently transitioned into nursing home care could have stayed at home had appropriate support been in place (Nuernberger et al., 2018; Canadian Institute for Health Information, 2020). However, across Canada the demand for home care services and support greatly exceeds the supply available (Home care Ontario, 2018). Furthermore, the regular turnover of staff and scheduling issues mean there are concerns about continuity of care and issues with patient safety when multiple providers are involved but not communicating effectively (Sanmartin et al., 2011).

A key social consideration impacting aging in place is family caregiver distress. As the number of older adults who need care and support increases, so do the number of family caregivers who provide unpaid care. In Canada, as in other countries, urbanization and increased mobility are impacting younger demographics, as they move from rural areas to towns and cities for better economic and social opportunities (Dandy and Bollman, 2009). This trend has resulted in rural and suburban areas aging faster than major urban centres, leading to a rising number of adult child caregivers living farther away from their aging parents (Canadian Institute for Health information, 2019). Research indicates that there are approximately 8 million Canadians who are currently caring for or supporting a family member. Almost half (47%) are caring for a parent or in-law and around 13% are caring for a spouse or partner (Statistics Canada, 2018). While caregiving can be a meaningful and rewarding activity, it can also result in emotional, financial, mental and physical stresses that place immense burden on the family caregiver. Family caregivers may experience stress from both objective burden - defined as tasks of care or physical requirements - and subjective burden - defined as the emotional or mental impact of caregiving (Montgomery et al., 1985). Presence of a family caregiver is typically protective against nursing home admission in the short term (Boaz and Muller, 1994), but distress, burden and burnout are strong indicators and predictors of a transition in care (Nuernberger et al., 2018). Recent analysis from the Canadian Longitudinal Study on Aging demonstrated that spousal caregivers were spending an average of 32 h per week, and adult child caregivers are spending an average of 20 h per week (Li et al., 2021). In Canada, caregiving responsibilities are estimated to result in the loss of 18 million work days per year, with a resulting cost of lost productivity estimated at $1.3billion. This illustrates the scale of the burden family caregivers are currently taking on.

In addition to social support, infrastructural support is necessary for aging in place. One such facilitator is the ability to move around one's community. Older people typically cease driving approximately 10 years before they die and become dependent on others or mass transit to move about their communities (Turcotte, 2012). Mass transportation, including buses, trains, and airplanes, still have barriers that prevent fulsome use by many older adults (Patterson et al., 2019). Additionally, older adults can be particularly vulnerable to financial pressures. An increasing number of older adults fall into the category of "low income," with the rate rising from 12% in 2005 to 14.3% in 2015 despite national poverty rates remaining stable (Waddell et al., 2018). This has translated into a growing number of older adults living in shelters or reporting being homeless or vulnerably housed (Reynolds et al., 2016). Older adults are frequent targets of cybercrime and financial abuse in Canada, resulting in an estimated annual cost of $650 million (Crane, 2019). Given these challenges and barriers to aging in place, there is growing interest in the potential for technologies to play a key role in supporting older adults and preventing transitions in care (Duan-Porter et al., 2020). The perception of older adults as "technophobic" is increasingly out of date as evidence gathered during the Covid-19 pandemic indicated that over 75 percent of older adults are confident in engaging with technologies (Freeman et al., 2022). However, adoption remains a challenge due to the social, infrastructural and financial barriers previously mentioned. Additionally, lack in understanding the needs, values, and preferences of older adults regarding current and future technologies result overall in less than 25% of older adults who are actively using technologies to support their health and wellbeing (Astell et al., 2020).

1.2 Agetech can be leveraged to support aging in place

Providing choices to older Canadians, their care partners, and health and social care systems is essential to meet the unique social, fiscal, and medical challenges associated with the needs of our rapidly aging population (Blackman et al., 2016). Technologies that are designed to improve the lives of older adults is one promising way to increase choice and support for older Canadians. The term to describe these innovative solutions is AgeTech, which refers to hardware or software solutions that aredesigned explicitly for or with the potential to provide benefit to older adults and their caregivers. This includes a range of innovations supporting aging in place, healthy aging, staying connected, and more. Given the complexity of aging and challenges to support aging in place, AgeTech includes a diverse portfolio of innovation from digital health, assistive technologies, Internet of things (IoT), medical devices/diagnostics, robotics, wearables and other sensor-based technologies. AgeTech includes digital technologies, digitally enabled technologies, and hardware solutions that support older adults to age in place. AgeTech is also referred to as GeronTech, ElderTech and SilverTech (Etkin, 2022). Assistive technologies- such as walkers, hearing aids, corrective lenses- are a subset of AgeTech, but older adults and their caregivers are now able to access a wider range of tech-enabled or enhanced approaches and technologies to support a holistic approach to healthy, active, socially connected aging. AgeTech tools and devices can help older adults to age in place by preventing transitions in care through improved health and wellbeing, enabling people to live well with advances in frailty and ill health, and/ or creating age-friendly communities and social structures. By enhancing and adapting alternative care approaches through emerging AgeTech, it may be possible to enable and extend the ability for older adults to safely age in place within their own homes, reduce and/or delay need for long term care facility supports, and/or decrease home care costs/needs (Freeman et al., 2023).

Information and Communications Technologies (ICT), defined as a diverse set of technological tools and resources used to transmit,

store, create, share or exchange information (Zuppo, 2012), play an integral role in the daily life of most people (Freeman et al., 2020). The vast majority of newly developed or augmented technologies are ICT-based. Other types of technology specifically designed to support aging in place, such as emergency help systems, remote vital signs monitoring, and fall detection systems, are commonly referred to as smart home technology (Balta-Ozkan et al., 2013).

The ability to use ICTs, smart home technologies, and other digital tools is referred to as digital literacy (Gilster and Glister, 1997). Also adapted to support aging in place is the concept of electronic health or eHealth. WHO defines eHealth as the cost-effective and secure use of ICT in support of health and health-related fields. ICT has been demonstrated to reduce health system costs, while simultaneously improving care experiences for older adults in society (Mantovani and Turnheim, 2016). The Covid-19 pandemic was an accelerator for the proliferation of AgeTech for accessing health services, with the rise of virtual care, a subset of eHealth, and expanded investments in digital infrastructure across Canada (Sixsmith et al., 2022). However, there are still people who remain unable to access the necessary internet and digital resources to support reliable and ongoing access. These continued barriers in access to virtual care and digital infrastructure has further reinforced inequities and exacerbated what is commonly referred to as the digital divide (Fang et al., 2019; Freeman et al., 2022). To achieve equitable access and desired impact it is essential to ensure thoughtful technology design considerations, accounting for current digital literacy gaps as well as diverse levels of access to technology infrastructure, e.g., internet and cellular services (Health Canada, 2021). By leveraging these rapid technological advancements, AgeTech could revolutionize the aging experience as part of a systemic approach to supporting aging populations, by empowering and enabling older adults and their caregivers.

It is critical that AgeTech industries establish ample infrastructure to promote inclusive and sustainable industrialization as well as foster an innovation ecosystem which recognizes the changing needs and abilities of individuals as they age. While change and adaptation of AgeTech are necessary and inevitable, organizations and systems leaders must embrace these transformations and remain nimble and flexible to respond to expected and unforeseen changes. In Canada, the National Research Council of Canada (NRC) launched the Aging in Place Challenge Program in 2021 with a seven-year mandate and an overarching goal of developing technologies and innovations to support an increase in the number of older adults who remain in homes or communities of their choice by 2031. The program is collaborating with older adults and family caregivers as well as partners in academia, industry, and government toward enabling advancements in AgeTech in Canada. At a more regional level, the Centre for Technology Adoption for Aging in the North (CTAAN) supports aging in northern and rural communities by making technologies more available to older adults, caregivers, and the healthcare systems that support them (www.ctaan.ca). CTAAN is a collaboration between the University of Northern British Columbia (UNBC), Northern Health, and AGE-WELL, Canada's National Technology and Aging Network.

Through an iterative approach, CTAAN researchers, NRC scientists and their partners including an advisory panel of older adults and caregivers have been leveraging learnings from their collaboration to equip AgeTech industry leaders, community champions, and health decision-makers with practical skills and guidance. In doing so, they aim to enhance AgeTech to be more accessible, inclusive, responsive, and sustainable over time. This paper highlights five learnings from our experience to date, and then presents implications for policymakers and funders when considering the role of AgeTech to facilitate aging in place. The lessons shared in this paper emerge from preliminary research findings, process evaluations, and feedback from partners including scientists, granting agencies, older adults and community care organizations. These experiences stem from Canadian context, but the messages may be generalizable across diverse portfolios and geographies.

2 Key messages

2.1 Key message one: It is essential to embrace a life course informed perspective on aging, as older adults are heterogeneous and experience diverse needs that evolve over time

Taken individually and at a specific point in time, technologies may be able to effectively solve a problem however the sustainability of a proposed solution and its impact may be reduced if designers and policymakers fail to embrace a life course informed perspective on aging. The term "older adult" serves as an umbrella phrase encompassing individuals aged 65 and above, yet it is imperative to acknowledge the remarkable diversity within this cohort. Age is not only limited to a chronological number. Indeed, aging among individuals can differ greatly by biological aging, physical aging, and social aging processes. This may lead to great diversity experienced across chronological ages.

Older adults have a mosaic of profiles which intersect with factors such as age, gender, race, disability status, and geographical location. A "life course perspective on aging" is useful to understand this diversity. The life course perspective on aging is a well-recognized theoretical framework that highlights the impact of individual experiences and unique trajectories throughout life (Mayer, 2009), as well as the social forces that influence the experience of aging. It is now widely adopted across sectors, including in public health where it provides a foundation for policy focusing on improving health and health equity (Mayer, 2009). The life course perspective encourages a holistic approach to understanding how past experiences and capabilities influence experiences of aging taking into account both individual chronological age as well as cohort membership (Dannefer and Kelley-Moore, 2009). While individual characteristics affect experiences of aging, factors impacting diversity across the life course are often also interpersonal or socially determined in nature (Settersten, 2017).

Given the objectives of AgeTech it is crucial to be attuned to the diversity that accompanies the aging experience to ensure that designs account for a multitude of preferences and capabilities. The profile of those easiest to reach for health research and engagement is typically Caucasian, urban dwelling, well-educated, individuals who possess high levels of technological literacy (Bonevski et al., 2014). However, failing to engage with a sample representative of a broader population may result in research data that is non-generalizable, and potentially not applicable to those groups who have the highest burden of disease or most need (Sydor, 2013). To

create technologies that meet the needs of older adults and their caregivers, diverse stakeholders must be consulted and engaged throughout the innovation process. Involvement of these older adults and caregivers in health and aging innovation can result in new technologies and processes that are more likely to meet their needs and preferences (McNeil et al., 2022). In addition, approaches to knowledge generation and implementation science that involve the collaboration of multiple academics across scientific disciplines and other experiential non-academics across sectors (e.g., industry, policymakers, health professionals) has been recognized as best practice in this area (Sixsmith et al., 2021).

Another key consideration for designing technologies for older adults, is the potential for the needs and capabilities of the end user to evolve with time. There is a clear link between aging and the development of certain health conditions such as frailty, dementias, musculoskeletal conditions, and sensory impairments. Good examples of this phenomena can be found in e-readers that offer both traditional reading and audiobook options to enable older adults to engage with literature in a variety of formats. The duality of modes in e-readers allows the older adult to continue using the technology they are familiar with even if they develop a cognitive or sensory impairment that makes traditional reading difficult. Another good example can be found in smartphones that have a variety of accessibility options such as modifiable text size, voice to text communications, and variable levels of access security that can be enabled or disabled based on user preference and capability. Embedding these evolutionary capacities into technology is aligned with the principles of user centric design which theorises that the technology should be built around, and adapt to the user and not the other way around, ensuring high degrees of usability (International Organization for Standardization, 1999).

Failing to recognize and embrace the complexity of aging in the process of AgeTech design and evaluation can lead to technologies that fail to effectively address the multi-causal pathways toward impact. This in turn hinders innovation adoption by older adults and their caregivers, limiting sustained utilization. One common critique of technology acceptance models is that they fail to account for evolutionary capacity and adapting functional ability (Peek et al., 2014). The most effective AgeTech is designed with evolving capacity and capability in mind to enable the older adult to continue to utilize and benefit from the technology over time.

Embracing a life course perspective is essential to ensuring research on aging in place is reflective of the diversity of experiences that older adults have over time. There is an opportunity to design more equitable policies and funding opportunities when embedding elements of life course theory. An example of good practice in this area from Canada is the Canadian Institute of Health Research's (CIHR) Strategy for Patient-Oriented Research (SPOR).[1] With a mandate to catalyze patient-oriented research, the ultimate goal of SPOR is to improve health outcomes through evidence-informed care. To do this, SPOR partners with various levels of government, researchers, health providers, patients, and other key parties to create hubs of expertise and fund research in areas of importance to patients themselves. In practice, the SPOR network engages experts by lived experience across the country across various levels such as setting the research agenda, advising on initiatives and participating in health related research.

2.2 Key message two: Agetech should solve a real problem

AgeTech must be aligned to the actual wants and needs of older adults and caregivers for innovation to facilitate aging in place. It is important that technology solutions are well aligned to the day to day challenges older adult and caregiver end users face. Ensuring that the problems they experience are being appropriately addressed is key to successful AgeTech development and deployment.

Technology development is rarely undertaken by older adults themselves, and thus the onus is on developers and researchers to ensure they have a solid understanding of the experiences and needs of older adults. In 2019 a review, Wang et al., found that a key barrier to technology adoption is "top-down" design process that rely on technologists preconceptions of the needs of older adults with little consideration of user perspectives and preferences or their real-world constraints (Wang et al., 2019). The growing complexity and diversity of healthcare management for older adults requires thoughtful approaches to identifying what challenges are appropriate for a technology enhanced/supported solution. Failing to design for real problems that older adults are facing risks designing technologies that add layers of complication and confusion for older adults without having a substantive impact on their wellbeing or ability to age in place.

Several factors that influence adoption of technology for aging in place include: (1) user concerns (e.g., high cost, privacy implications and usability factors); (2) expected benefits (e.g., increased safety and perceived usefulness); (3) user needs (e.g., perceived need and subjective health status); (4) available alternatives (e.g., help by family or spouse); (5) social influence (e.g., influence of family, friends and professional caregivers); and (6) user characteristics (e.g., desire to age in place) (Peek et al., 2014; Macedo, 2017). It is essential to ensure there is appropriate alignment of the needs, preferences and intended uses of the technology with the end users context otherwise there may be an elevated risk that the technology will be used sub-optimally or not used at all (Scherer, 2017). Barriers such as the concern for privacy and issues of trust (Canadian Institute for Health Information, 2020) must be addressed in order for technology to be perceived as acceptable. This illustrates the importance of the technology being well aligned with challenges or barriers older adults are facing in order for it to be perceived as useful and therefore acceptable. When adopting technologies for use, older adults balance between degree of privacy for the benefit of staying in their home (Jaschinski and Ben Allouch, 2019). Research has shown that older populations are very aware of privacy issues (Al-Shaqi et al., 2016; McNeill et al., 2017) and that privacy considerations are key factors in the adoption of assistive technologies. Privacy may be a larger issue for technologies designed for aging in place, particularly since older populations with health issues must learn to manage their personal health data (Kolkowska and Kajtazi, 2015). Older adults have also expressed preferences for what functions technology is used to support. For example, older adults report an interest in robotics that support instrumental activities of daily living (e.g., housekeeping, laundry, medication management) and enhanced activities of daily living (e.g.,

1 https://cihr-irsc.gc.ca/e/51036.html

entertainment, hobbies, learning opportunities), but are hesitant to embrace robotics that support personal care activities (e.g., bathing, shaving etc.) (Smarr et al., 2012). This may be attributable to concerns about social isolation and loneliness if technology is perceived to replace in person interaction with professional and familial caregivers (Clayton and Astell, 2022).

Caregivers also commonly express openness to technologies that can support others to age in place, and intergenerational encouragement is identified as a key driver of adoption (Freeman et al., 2020). As many caregivers in the Canadian context are providing support from geographically dispersed locations, technology is uniquely positioned to enable long distance support. Technology is perceived by caregivers as an effective means of reducing caregiving burden as it can decrease reliance on in-person interactions. For example, automated medication management solutions can reduce the need for daily in person visits to ensure medication adherence. However, some caregivers fear that technology may add to their burden by making them more available and increasing the volume of monitoring and caregiving tasks they are responsible for Madara Marasinghe (2016). Ensuring technologies are solving for 'pain points' without adding complication or additional tasks for caregivers is key to ensuring the solution will be embraced.

It is essential for technology developers and researchers to conduct robust gap analysis and ensure technologies being proposed or designed are aligned with the needs and preferences of older adults and caregivers. Through its Calls for Innovation, the CAN Health Network[2] is an example of encouraging this needs based way of working. The CAN Health Network supports joint-problem solving between companies and participating health systems in Canada. Innovation through CAN Health begins with health care system partners putting forward user-defined needs from their organizations for which they would be ready to procure a solution. Technology products are then identified to address these needs and research projects are co-created to ensure market value and system readiness of the technology are evaluated.

2.3 Key message three: Agetech should complement and support existing health care and social services and supports, not functionally replace human resources

It is essential to design AgeTech that complements, enhances, and supports the healthcare system. The demand for care in Canada far exceeds the resources and budget available, leading to many older adults struggling to access "best practice" care and support. There is a growing need for technologies that can support and complement the strained healthcare system without aiming to replace highly skilled human resources.

Older adults have clearly indicated their preference for shared decision making, circle of care approaches, and relationship centric approaches that include care partners (Elliott et al., 2016). These attributes are most effectively embedded in care approaches that enable continuity of care and ongoing relationships between practitioner and patient. This is particularly notable for those who receive ongoing support for activities of daily living (such as assistance with dressing, bathing, and personal care). Where technologies are leveraged to streamline care processes, augment care, improve outcomes or support better clinical decision making, the innovation is welcomed. For example, older adults were the highest users of virtual care during the Covid-19 pandemic as the users benefited most from avoiding in-person visits and the corresponding increased risk of serious infections (Bhatia et al., 2021). However, where technology is viewed as replacing a human resource, replacing in person interactions, or increasing workload, then there is increased hesitancy to embrace that technology. This may be attributable to perceptions that accepting technology may be a gateway to social isolation (Clayton and Astell, 2022).

Additionally, there is a risk that replacing an in-person interaction with a technology may result in missed diagnosis or poor care outcomes. Geriatric medicine is by nature complex, and distilling care down to narrowly defined data points provided by a technology without being able to access broader contextualization risks missing important data. Providers of geriatric care use multiple sources of information, including observation, clinical measurements, and patient self report as a barometer for overall health and functionality. These multiple convergent sources of information allow the high skilled practitioner to tease out nuances and important details. Geriatric medicine often focuses on "ability to live well with chronic conditions" which differs from many other branches of medical care that tend to focus on restorative or curative functionality. Geriatric practitioners frequently focus on "the 5 M's of geriatrics" – mind, mobility, medications, multi-complexity, and 'matters most'. Matters most is a key element of geriatric medicine that focuses on the personal preferences and values of the individual to support enhanced care planning, defining goals of care and ultimately defining preferred outcomes (Health in Aging, 2019). This is achieved meaningfully through cultivation of a relationship between patient and care provider.

Nevertheless, there are many opportunities to integrate technology into care for older adults that can improve, enhance and support practitioners without replacing their clinical judgment. Technologies that provide data from the home context may be able to more accurately assess function and risk as they provide data from people's typical living circumstances vs. lab or hospital based data (Wu et al., 2023). Assessment of capability in hospital setting versus the home setting is a known risk for transition to nursing home care (Nuernberger et al., 2018) which may be attributable to routine underestimation of ability by hospital staff (Bender and Holyoke, 2018). Consumer availability of smart devices and wearables has led to an abundance of potentially relevant clinical data being collected. The primary question is how to integrate that data from smart devices and wearables into clinical practice in a way that is accessible, acceptable, and helpful. Technology may also have a role in reducing time, effort, or human resources for administrative tasks that are currently being done by skilled health resources. It is not sustainable for caregivers (professional or familial) to continue to be asked to do more with less. Technologies should aim for "zero- effort" and output data that are easy to interpret and integrate into routine activities. Interoperability and data sharing will play a key role in enabling data to be meaningfully shared and actioned.

Funders can support the development of technologies that assist health systems by requiring partnership with frontline care providers

2 canhealthnetwork.ca

in codesign. Providing funding for use case development and validation could also ensure alignment between development objectives and health system needs. The *Fonds de soutien à l'innovation en santé et services sociaux* set up as part of the Quebec Life Sciences Strategy of the Quebec Ministry of Health in collaboration with the Ministry of Economy and Innovation, is a good example of coordination of efforts toward accelerating adoption of relevant innovations [Fonds de soutien à l'innovation en santé et en services sociaux | Ministère de l'Économie, de l'Innovation et de l'Énergie (gouv.qc.ca)]. This initiative aims to support the *Bureau de l'Innovation* mandate to integrate innovation. It is intended to provide financial support for projects that test the validity and usefulness of innovations in a real health care and service environment.

2.4 Key message four: Partnership with the right collaborators is key to AgeTech success

While end-user engagement is recognized as "best practice" in design, integration of these principles in AgeTech innovation has been slow to become mainstream. Designing from a position of partnership means restructuring the relationship between designer and end-user in a way that recognizes older adult end-users as experts through lived experiences, and designers as experts through technical or scientific knowledge (Manafò et al., 2018). There are several benefits to codesign which include (i) creative idea generation through the sharing of knowledge, (ii) increased speed of adoption of interventions due to local ownership, (iii) development of interventions which are more inclusive and accurately reflect user experience, (iv) increased user satisfaction with services, and (v) lower costs for the organizations implementing the interventions (Steen et al., 2011).

Emphasis on end user involvement, especially when engaging older adults and their care partners, is constantly challenged by the scarcity of resources available to facilitate substantive involvement and the limited capacity of staff who are often juggling multiple responsibilities. All too often, engagement work is treated as "off the side of the desk" or allocated to a "champion" who takes responsibility for embedding the approach across multiple projects. End user engagement takes time and skills and must be embedded within standard procedure otherwise it risks becoming a tokenistic gesture.

When undertaking codesign and engagement it is important to include end users with a diversity of perspectives and experiences. It is essential to consider the heterogeneity of the older adult population and plan engagement accordingly. Inclusive design principles stress the importance of including marginalized representation in the sample as the needs of individuals at the margins are typically more diverse. Considering those needs reinforces the inclusive character of the technology solution (Inclusive Design Research Centre. OCAD University, 2023). The responsibility for creating an environment that is conducive to engagement lies with researchers and developers. These stakeholders can create foundations for successful engagement by educating themselves on relevant equity, diversity and inclusion considerations as well as integration of gender-based analysis.

Co-production is a long-term process, and change will happen at the speed of trust between the partners. To speed up the process, it is helpful to partner directly with organizations that already have trusting relationships with end users (Bonevski et al., 2014). This may include SPOR programs, advocacy networks, and community based organizations. Partnering with organizations or individuals who have existing relationships enables developers to benefit from the foundations of trust and authenticity while still working to the necessary timelines for agile technology development.

An example of this partnership in action is illustrated by 'AgeTech Discussions which Explore User Perspectives on Technology'-referred to as ADEPT workshops. These workshops are a key service CTAAN provides to introduce AgeTech to potential users. ADEPT workshops showcase an emerging AgeTech to stakeholders in northern and rural areas, describing the applicability, usability, and feasibility of a featured AgeTech from end users' perspectives. Through workshops, end users participate in facilitated discussions and provide important insights and recommendations to inform design and adjustments of featured AgeTech. This process provides technology developers and companies with evidence that helps form the next steps to scale their products and services to northern and rural areas. At its core, the ADEPT reports generate new evidence to inform AgeTech leaders of the utility, feasibility, and perspectives from Canadian health systems leaders, healthcare providers, care partners, and older adults. CTAAN has spent years developing trusting relationships with collaborators in the community which has created a shared language between diverse individuals and the facilitators at CTAAN.

Policymakers and funders can support meaningful engagement and partnership development by encouraging research and AgeTech development teams to include staff dedicated to the role of community engagement. Furthermore, policymakers and funders can support longer research fellowships, and provide living wages for highly qualified personnel to allow trainee's time to build meaningful relationships with community partners. This may avoid academic precarity or cost of living concerns impacting their research productivity and career progression.

2.5 Key message five: Agetech design, development and testing needs to be faster and more flexible to meet current needs

Digitalisation offers opportunities to address current health and care system challenges. There is agreement from stakeholders across the Canadian AgeTech ecosystem that technology design, development and testing need to move faster and be more flexible to meet the existing needs of today (Desveaux et al., 2017). When tackling complex problems, a pragmatic approach is best suited. There is a need to challenge the existing hierarchy of research evidence that venerates clinical trials as the "gold standard (Greenhalgh and Russell, 2010). When it comes to evaluation there is a mismatch between the underlying philosophies of clinical trials and the pragmatism needed for AgeTech evaluation.

One reason AgeTech is not always well suited to clinical trial methodology is that the complexity of aging related illness, and concurrent complexity within the healthcare system cannot be replicated or randomized in an artificial lab setting. Complex problems demand complexity informed evaluations. In contract, clinical trial methodology requires the researcher to control for complexity and externalities. This is particularly relevant when assessing technologies for aging in place as the logical indicator of success is perceived to be avoidance of transition in level or location

of care. However, the decisions about aging in place are multifactorial and generally involve multiple stakeholders. It can be extremely difficult to isolate the impact of a technology on that complex decision-making process. If appropriate, and contextually sensitive evaluation metrics are not selected, a novel technology may be deemed a "failure" or "non-impactful" when an individual using that technological intervention moves into a formal care setting. When focusing only on that outcome measure, the evaluation will not capture the actual impact or "successes" of the technology.

This challenge is compounded by the tension that is reported between researchers and technology developers when "ways of working" are perceived as incompatible. Adaptation and adjustment of research structures are needed to foster successful collaboration. Both of which require flexibility and transparency in timelines, process, and expectations. For example, in traditional research structures the process of gaining research ethics approval, especially if multiple academic and clinical boards are involved, can take several months. This timeline represents a delay which is unacceptable to many developers. However, with effective partnerships it is possible to create overarching research infrastructure. One such tool is an umbrella ethics approval that cover the research team and key research activities. Tools such as these allow for each new development opportunity to be treated as an amendment to the approved ethics application. This approach, which is used by CTAAN to quickly respond and provide ADEPT workshops, enables more rapid turnaround and progression of development research, while also ensuring the principles of ethical research are upheld.

Another useful tool is the minimum shared data set. This data set comprises metrics that matter most to each of those most affected parties in the development process. Having the core dataset agreed upon in advance will ensure that technology iteration and development can occur alongside continuing academic research. This approach again ensures that technology development is backed by core research principles while addressing the issue of incompatible timelines between academic research and industry. An additional benefit of the minimum shared data set also is the potential to support technology adoption into health systems. These systems have timelines that are often perceived as slow, are generally risk averse and rely heavily on evidence and data to inform decision making. Co-creating the minimum data set with health system partners or intended adopters at the outset of a design and development process ensures that the outputs of the project will be aligned to the key evaluation metrics the adopter will be assessing the final output against. This can avoid duplication of effort and delays in the innovation to adoption pipeline. Partnership with the right stakeholders is key to effective development of usable, accessible and helpful technologies.

It is well known and recognized that healthcare systems tend to slowly adopt new technologies because lives could be at stake and safety and security always come first. As a result, the digital health industry moves faster than what the systems are able to absorb, AI-based technology adoption is lagging and regulatory bodies have difficulties adapting with rapidly changing innovations. While individuals may desire access to digital healthcare it is not being used to its full potential in Canada because technology adoption is slow. Reported barriers include geographic variation in payment models, licensing, and regulation requirements across Canadian provinces and territories (Virtual Care Task Force, 2020).

Policymakers and funders can support agile technology development by providing funding opportunities that align with industry preferred approaches while simultaneously supporting longer term research projects that are complexity informed. Encouraging policymakers to facilitate industry opportunities that create shorter term, rapid funding cycles to allow researchers and developers to iterate will support refinement and technology progression. Ensuring research funders are concurrently facilitating longer research cycles to allow research teams to embrace longitudinal, complexity informed evaluation will help generate more meaningful and contextual impact evaluations.

A recent example of a funding opportunity from Canada that embedded these elements was CIHR's eHealth Innovations Partnership Program (eHIPP) (Canadian Institutes of Health Research, 2017). This was a collaborative funding program designed to create healthcare innovation by funding projects with partnerships between Canadian technology companies, researchers, and health care system partners. The funded projects needed to articulate a methodology of co-development and a focus on integration plans for their innovative e-health solutions. The program supported pragmatic evaluation to ensure that the technologies would deliver real-world health care value.

There is a need to progress work on AgeTech standard based solutions that provide guidance on metrics and a shared framework for design and evaluation. Policymakers and funders can support the development and sharing of data to inform AgeTech evaluations. This approach will balance the need for academic rigour and agility by ensuring high impact metrics are prioritized to support technology integration. Funders should ensure that these are developed by multidisciplinary partners, including industry and experts by lived experience as it is recognized that together these partners can provide valuable insights.

A recent example of this is the NRC Aging in Place Program actively supporting the development of AgeTech standard based solutions for design and evaluation. Through a multidisciplinary project the objective is to co-create recommended AgeTech design and evaluation frameworks, guidelines, and best practices, to expedite the development, validation and dissemination of effective technologies that can address the needs of older adults in a safe and reliable way. The project will explore best practices, guidelines and standards for AgeTech that might be used by innovators and industry (i.e., technology developers and adopters) to expedite time to market and help guide the choices of older adults and their care partners to age more independently in the place of their choosing. This project will employ a multidisciplinary perspective and will include experts by lived experience to ensure that the outputs matter to users of AgeTech.

3 Discussion: Implications for policymakers and funders

Policymakers and funders are key to directing how AgeTech research and development evolve. They must work collaboratively to ensure organizational policies, structural mechanisms and application parameters support the good practices proposed here. Through thoughtful authentic codesign and deliberate structure of funding mechanisms, policymakers and funders can ensure good practices are embedded within future research. Below are some recommendations:

Ensure life course theory and complexity informed evaluations are embedded in AgeTech development. Policymakers and funders can play a key role in encouraging and enabling these perspectives though careful design considerations when structuring calls for applications. Experts by lived experience need to be engaged throughout the innovation process. This collaboration will allow for the challenging of assumptions and opportunities for building equity considerations specific to older adults. To encourage diverse life course perspectives, funders can require older adults to be part of a research team as project partners or as members of an advisory board. Funders can also include older adults as part of their review panels to ensure the perspective of end users in evaluating funding applications.

Prioritize policies that remove barriers and enhance participation of hidden, hard to reach, and seldom heard populations. For example, funders can include participant payment and reimbursement of expenses to remove financial barriers to participation. Policymakers and funders should also consider allowing payments for respite care to enable caregivers who have sole or primary responsibility to participate in research and design without the barrier of care expense or anxiety about leaving the care recipient alone. This is already considered 'good practice' in research, but is not embedded into many funding calls.

In recognition of the essential need to engage with diverse populations, policymakers and funders should ensure Equity, Diversity and Inclusion (EDI) and Gender-Based Analysis Plus (GBA Plus) plans are mandated components of granting opportunities. Training opportunities for highly qualified personnel, scientists, and staff involved in AgeTech development in EDI/GBA plus can support the creation of meaningful EDI/GBA plus plans that ensure the principles of recognizing and redistributing power, and including perspectives of diverse individuals throughout the innovation process.

AgeTech funding should support dedicated staff members to work on relationship building and engagement activities. To ensure co-design and collaboration are done in a fulsome way, it is essential to recognize that engagement and codesign are distinct skills. Funders should articulate that research teams have such dedicated personnel and include description of this role and experience in this work as part of the evaluation criteria. Policymakers can also ensure the terms of funding allow for "flow throughs" to community organizations to enable research teams to partner with community organizations that have existing relationships with those who have "often ignored perspectives." Lastly, funders can encourage research teams to critically consider "who is missing" from the discussion and include plans for how to engage those participants in their funding applications. This action of requiring an appraisal of missing collaborators upfront can ensure funding goes to research teams that are able to effectively capture a life course informed perspective.

Embrace design approaches that allow teams to rapidly iterate and refine AgeTech. This may include rapid review and fundings cycles to allow teams to create use cases and prototypes and validate concepts with the community. Funding opportunities must be designed to enable teams to "fail fast" and "fail smart," allowing them to learn from feedback and rapidly iterate. Rapid iteration will encourage better alignment between tech developers and end users by enabling early and frequent feedback during the development cycle without unduly hampering the commercialization process.

Favor methodologies and practices needed to study complex or "wicked" challenges. By supporting research that utilises methodologies that are pragmatic in nature and leverage multi-method evaluation, complexity can be properly considered. Aging in place is multi-faceted and frequently involves multiple decision makers. To fully explore the effect of technology on the ability to age in place, researchers must be able to interact longitudinally with multiple partners. When longitudinal studies are most appropriate, funders can embrace complexity informed theories of change as part of the funding call to ensure that scientists and those collaborating on a project are gathering the evidence needed to demonstrate impacts of AgeTech.

Integrate robust needs and gap analysis into funding application processes. It is insufficient to simply suggest or recommend inclusion of robust gap analysis; it must be structurally embedded within the funding mechanisms and directly tied to application evaluation criteria. Embedding these measures within application structure provides a mechanism to standardize evaluation and highlights the importance of gap analysis as part of project design. To keep up with the rapid pace of new and evolving AgeTech innovations entering the consumer market, these analyses must be conducted in a timely manner and tailored to address the information needs of the user and/or the consumer. Funders can encourage or require multidisciplinary teams to include healthcare professionals which helps ensure proposed innovations will complement, enhance and support the healthcare system.

Finally, move away from funding applications which merely showcase novelty of an innovation. Instead, require applicants to concretely demonstrate potential for tangible impact. For theoretical science, low Technology Readiness Levels (TRL) and developmental projects this may take the format of including named older adult and care partner experts by lived experience on the project team. Ensuring consideration of end users is embedded in the project design from the point of ideation provides assurances on real world needs. For higher TRL products or evaluations, funding applications should include a section for applicants to showcase previous engagement with end users and community groups. Previous engagement should highlight articulated potential use cases from the perspective of experts by lived experience. Embedding this content requirement into funding applications should catalyze behavior change as funding applicants are required to engage end users to access further funding.

4 Conclusion

Technology can be an effective means of supporting aging in place as it can provide rigour and objectivity to clinical decision making, supporting older adults and their caregivers and augmenting strained health human resources. However, there is a risk that technology without proper design and evaluation considerations may add layers of complication to an already complex system without actually creating the impact that is intended. The goal of AgeTech must be to improve outcomes by offering support, decreasing burden, and expanding access to resources, without causing undue confusion or stress for older adults and their caregivers. It is crucial to avoid placing excessive burden on caregivers, whether professional or familial. It is no longer the case that healthcare providers and care partners can be called upon to do more with less. Instead, sustained implementation

of AgeTech must offer tangible benefits and solutions in terms of time savings or improved outcomes for caregivers. Technology needs to be an asset rather than a source of additional stress, and should remain accessible to all to avoid accentuating inequities.

Policymakers and funders must consider demographic shifts and proactively ensure the well-being and proper support of older adults and their caregivers in Canada. Technology has the potential to play a pivotal role in addressing challenges associated with aging in place. To do so it must be thoughtfully designed, developed, and implemented. AgeTech design and evaluation should be pragmatic. Designers, scientists, and policymakers should partner with older adults and their caregivers to better understand needs and implement impactful solutions. Real-world evaluation of AgeTech solutions should be conducted to quantify the investment and support required to foster sustained use including human, financial, education resources. With the rapid development and proliferation of AgeTech into the consumer market, it is paramount to cultivate an innovation ecosystem that ensures AgeTech solutions are co-created and evaluated in a good way in order to support older adults to age well in place.

Author contributions

CG: Conceptualization, Project administration, Writing – original draft, Writing – review & editing, Methodology. HM: Conceptualization, Writing – original draft, Writing – review & editing, Validation. PD: Writing – review & editing, Supervision, Validation. SF: Conceptualization, Writing – original draft, Writing – review & editing, Formal analysis.

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Conflict of interest

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A systematic review of gerontechnologies to support aging in place among community-dwelling older adults and their family caregivers

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Objective: Paucity of information concerning the efficacy of gerontechnologies to support aging in place among community-dwelling older adults prevents potential users, healthcare professionals, and policymakers from making informed decisions on their use. The goal of this study was to identify gerontechnologies tested for home support in dyads of community-dwelling older adults with unimpaired cognition and their family caregivers, including their benefits and challenges. We also provide the level of evidence of the studies and recommendations to address the specific challenges preventing their use, dissemination, and implementation.

Methods: We conducted a systematic review of the literature published between 2016 and 2021 on gerontechnologies tested for home support in dyads. Two independent reviewers screened the abstracts according to the inclusion/exclusion criteria. A third reviewer resolved eligibility discrepancies. Data extraction was conducted by two independent reviewers.

Results: Of 1,441 articles screened, only 13 studies met the inclusion criteria with studies of moderate quality. Mostly, these gerontechnologies were used to monitor the older adult or the environment, to increase communication with family caregivers, to assist in daily living activities, and to provide health information. Benefits included facilitating communication, increasing safety, and reducing stress. Common challenges included difficulties using the technologies, technical problems, privacy issues, increased stress and dissatisfaction, and a mismatch between values and needs.

Conclusion: Only a few gerontechnologies have proven efficacy in supporting community-dwelling older adults and their family caregivers. The inclusion of values and preferences, co-creation with end users, designing easy-to-use technologies, and assuring training are strongly recommended to increase acceptability and dissemination.

Systematic review registration: https://www.crd.york.ac.uk/prospero/display_record.php?RecordID=310803, identifier CRD42022310803.

KEYWORDS

Gerontechnology, AgeTech, Community-Dwelling Older Adults (CDOA), Family Caregivers (FC), Aging in place, Home support, Older adult, Aging

Introduction

In the past decades, the world population has shown a steady increase in the proportion of individuals aged 65 years and older. Approximately 10% of the world's population is comprised of older adults (United Nations, 2021). This proportion is approximately double in Canada (18%) (StatCan, 2022) and other developed countries. This population trend poses worldwide challenges in the management of the health and well-being of older adults and their family caregivers.

Older adults prefer to live independently in their homes rather than in alternative living arrangements such as assisted living or long-term care (Kim, 2021). Independent living goes beyond a mere preference since it is linked to increased engagement with care service providers, self-determination, participation in problem-solving daily challenges, and improvement of mental health (Hurstfield et al., 2007). Considering these important benefits, governments around the world are shifting their policies to fund home and community-based services for older adults.

Older adults living with physical or cognitive difficulties may choose to move to a long-term care facility when they realize that there may be important risks for their health. Most older adults move to long-term care because they can no longer manage or be managed at home, and it is often someone else who makes the decision. The risk of social isolation, malnutrition, falls or other accidental injuries, as well as physical and cognitive deconditioning are important factors to consider (Moreland et al., 2012; Crichton et al., 2019; Fakoya et al., 2020; Di Lorito et al., 2021). For family caregivers, overload, burden, and compassion fatigue associated with high levels of chronic stress should be prevented or treated (Alves et al., 2019; Liao et al., 2022).

Different stakeholders including researchers, healthcare professionals, and the industry have been striving to develop technologies that can support older adults at home to promote their independence and autonomy. Gerontechnology is a transdisciplinary field using technologies (systems and equipment) to promote healthy aging and to solve problems related to chores, leisure, communication, and safety (Halicka, 2019). Gerontechnologies are used to prevent, delay, or compensate for physical, cognitive, and sensorial decline due to aging. For instance, gerontechnologies are used to optimize communication with family caregivers, monitor older adults and the environment to increase safety, and to assist in daily living activities (Colnar et al., 2020). At the same time, older adults can face barriers using technologies, particularly when they experience cognitive decline (Ikeda et al., 2021). For this reason, early intervention, familiarization, and progressive adaptation of these technologies can increase their impact. Family caregivers play an important role in the development, selection, and adoption of technologies to improve care in older adults (Leslie et al., 2021). A current paucity of information about the efficacy of these technologies prevents older adults, family caregivers, healthcare professionals, and policymakers from making informed decisions about their use.

Objective and research questions

The objective of this study was to evaluate and synthetize information via a systematic review of literature published between 2016 and 2021 concerning gerontechnologies used for home support among Community-Dwelling Older Adults (CDOA) without cognitive impairment and their Family Caregivers. The systematic review was designed to answer four main questions:

1 What gerontechnologies have been tested for home support by both CDOA and their family caregivers?
2 What are the benefits, challenges, and opportunities provided by these gerontechnologies for CDOA and their family caregivers?
3 What is the evidence level of the studies conducted with dyads comprised of CDOA and their family caregivers?
4 What recommendations, if any, address the specific challenges preventing the use and dissemination of these gerontechnologies?

Methods

Search strategy and information sources

We followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). A systematic review of literature published between 2016 and 2021 was conducted by the principal investigator (AM) in collaboration with two librarians with a background in Psychology and Geriatrics. The two librarians participated in different iterations and validations of the search strategy. Databases searched included: CINAHL, Medline, PsycINFO, Web of Science, and AgeLine. The search terms included « home support », « older adults », « family caregivers », and « technology ». Table 1 presents the search strategy, as well as truncation symbols (denoted by *) and Boolean operators (AND, OR). The systematic review was registered in PROSPERO (registration number: CRD42022310803).

Study selection

Studies were included based on the following criteria: (a) studies reporting results on the efficacy or the feasibility of gerontechnologies tested at home; (b) gerontechnologies tested with dyads of CDOA and family caregivers; (c) tested with older adults without neurocognitive impairment; (d) studies using quantitative, qualitative or mixed data analysis methods; (e) studies available in Chinese, Spanish, French, or English. Studies were excluded if: (a) the sample included older adults with a diagnosis of cognitive impairment; (b) the gerontechnology was not tested with dyads of CDOA and family caregivers; (c) the gerontechnology did not

TABLE 1 Search terms and results from each database.

Database	Search strategy	References
PsycINFO	(((home adj2 care) or own home or (living adj2 independent*) or (aging adj2 independent*) or (base adj2 home) or community dwelling or living alone or aging in place).mp or Home Care/or Living alone/or Home Environment/or Aging in place/) AND ((techno* or gerontotechnology or gerontechnolog* or digital or tablet or intelligen* or touchscreen or computer or smart or machine or numeric or virtual or monitor* or sensor* or robot*).mp or Technology/or Digital technology/ or Mobile technology or Information and communication technology/or Assistive technology/or Wireless technology/or Monitoring/or Self-Monitoring/) AND ((Aging or ageing or senior* or old* adult* or old* person* or old* people* or elder* or late life or geriatric* or gerontolog*).mp or Older adulthood/ or exp. Aging/ or Gerontology/) AND (relative* or informal carer* or caregiver* or dyad* or spouse* or famil* or support person*).mp or caregivers/ or dyads/ Limite: 2016–2021	182
Medline	(((home adj2 care) or own home or (living adj2 independent*) or (aging adj2 independent*) or (base adj2 home) or community dwelling or living alone or aging in place).mp or Independent living/or Home care services/) AND ((techno* or gerontotechnology or gerontechnolog* or digital or tablet or intelligen* or touchscreen or computer or smart or machine or numeric or virtual or monitor* or sensor* or robot*).mp or exp. technology/ or wearable electronic devices/ or hearing aids/or exp. Video Recording or Reminder Systems/or Mobile Applications/or user-computer interface/or Geographic Information Systems/or self-help devices/ or communication aids for disabled/or Robotics/or exp. Monitoring, Ambulatory/ or exp. Signal Processing, Computer-Assisted/) AND ((Aging or ageing or senior* or old* adult* or old* person* or old* people* or elder* or late life or geriatric* or gerontolog*).mp or exp. Aged/ or exp. Aging/) AND (relative* or informal carer* or caregiver* or dyad* or spouse* or famil* or support person*).mp or exp. Family/or exp. Caregivers/ Limite: 2016–2021	603
CINAHL	TIAB((home N2 care) OR "own home" OR (independent* N2 living) OR (independent* N2 aging) OR (home N2 base*) OR "community dwelling" OR "living alone" OR "aging in place") or (MH "Home Care Equipment and Supplies") or (MH "Home Health Care+") AND TIAB(techno* or gerontotechnology or gerontechnolog* or digital or tablet or intelligen* or touchscreen or computer or smart or machine or numeric or virtual or monitor* or sensor* or robot*) or (MH "Technology+") or (MH "Assistive Technology Devices+") or (MH "Assistive Technology Services") or (MH "Robotics") AND TIAB (Aging or ageing or senior* or "old* adult*" or "old* person*" or old* people* or elder* or "late life" or geriatric* or gerontolog*) or (MH "Aged+") or (MH "Aging+") or (MH "Gerontologic Care") or (MH "Gerontologic Nursing") or (MH "Geriatrics") AND TIAB(relative or "informal care*" or caregiver* or dyad* or spouse* or famil* or "support person*") or (MH "Caregiver Support") or (MH "Caregivers") or (MH "Dependent families") or (MH "Patient-Family Relations") or (MH "Family relations") Limite: 2016–2021	432
Web of Science	Topic((home NEAR/2 care) OR "own home" OR (independent* NEAR/2 living) OR (independent* NEAR/2 aging) OR (home NEAR/2 base*) OR "community dwelling" OR "living alone" OR "aging in place") AND Topic(techno* or gerontotechnology or gerontechnolog* or digital or tablet or intelligen* or touchscreen or computer or smart or machine or numeric or virtual or monitor* or sensor* or robot*) AND Topic(Aging or ageing or senior* or "old* adult*" or "old* person*" or old* people* or elder* or "late life" or geriatric* or gerontolog*) AND Topic(relative* or "informal care*" or caregiver* or dyad* or spouse* or famil* or "support person*") Limite: 2016–2021 + Document type = Article	893

(Continued)

TABLE 1 (Continued)

Database	Search strategy	References
AGELINE	(TI elder$ OR AB elder$ OR TI senior$ OR AB senior$ OR TI geriatric$ or gerontolog$ or ag?ing OR AB geriatric$ or gerontolog$ or ag?ing) OR (DE "Geriatric Psychiatry" OR DE "Aging" OR DE "Geriatric Education" OR DE "Gerontology" OR DE "Geropsychology" OR DE "Geriatrics" OR DE "Older Adults" OR DE "Frail Elderly" OR DE "Gerontological Nursing" OR DE "Gerontological Research" OR DE "Gerontologists" or DE "Old Old") AND TI (caregiver$ or caregiving or family or relati$) OR (DE "Caregivers" OR DE "Long Distance Caregivers" OR DE "Long Distance Caregivers" OR DE "Care Receivers" OR DE "Caregiver Education" OR DE "Caregiving Burden" OR DE "Caregiving Rewards" OR DE "Dependent Parents" OR DE "Eldercare Programs" OR DE "Home Care Workers" OR DE "Informal Support Systems" OR DE "Respite Care" OR DE "Sandwich Generation") OR (DE "Family Assistance" OR DE "Informal Support Systems" OR DE "Emotional Support" OR DE "Family Relationships" OR DE "Filial Responsibility") OR (DE "Spouses" OR DE "Husbands" OR DE "Wives" OR DE "Relatives" OR DE "Adult Children" OR DE "Couples" OR DE "Daughters" OR DE "Extended Family" OR DE "Grandchildren" OR DE "Grandparents" OR DE "Great Grandparents" OR DE "In Laws" OR DE "Parents" OR DE "Siblings" OR DE "Sons" OR DE "Spouses" OR DE "Step Relatives" OR DE "Husbands" OR DE "Wives" OR DE "Couples") AND TI (technolog$ or smart$ or monitor$ or device$ or computer$ or artificial intelligence or gerontechnology) OR (DE "Technology" OR DE "Information Technology" OR DE "Information Technology" OR DE "Automation" OR DE "Computers" OR DE "Distance Education" OR DE "Assistive Devices" OR DE "Corrective Lenses" OR DE "Durable Medical Equipment" OR DE "Hearing Aids" OR DE "Orthopedic Equipment" OR DE "Pacemakers" OR DE "Prosthetic Devices" OR DE "Monitoring Devices" OR DE "Alarm Systems" OR DE "Computers" OR DE "Artificial Intelligence" OR DE "Automation" OR DE "Computer Aided Instruction" OR DE "Computer Software" OR DE "Information Technology" OR DE "Older Computer Users" OR DE "Technology") AND TI home or hous$ or smart house or design or living alone or aging in place OR (DE "Home Care" OR DE "Home Health Care" OR DE "Home Health Care" OR DE "Home Maintenance" OR DE "Repairs" OR DE "Home Modification") OR (DE "Living Alone") OR (DE "Housing Design" OR DE "Housing Improvement" OR DE "Housing Security" OR DE "Housing Characteristics" OR DE "Housing" OR DE "Housing" OR DE "Affordable Housing" OR DE "Housing Types" AND DE "Housing Characteristics" OR DE "Housing Conditions" OR DE "Housing Design" OR DE "Housing Improvement" OR DE "Housing Needs" OR DE "Housing Preferences" OR DE "Housing Security" OR DE "Residential Mobility")	10

provide in-home support; (d) the article was a research protocol; (e) the studies were available in languages other than Chinese, English, Spanish, or French. As shown in Figure 1, 2,120 references were identified. Two independent reviewers separately screened titles and abstracts based on inclusion/exclusion criteria (HS and KA) using COVIDENCE software (Veritas Health Innovation, 2014). Disagreements about inclusion were resolved by the supervisor (AM). A full-text review was then conducted for the remaining 109 references (HS and KA), with a total of 13 records compatible with the inclusion criteria.

Data extraction and synthesis

Titles and abstracts were screened by two independent reviewers (students in psychology and a student with a background in engineering) according to the inclusion/exclusion criteria. Interrater reliability was assessed as moderate for the title and abstract screening (Cohen's kappa coefficient of 0.48). Studies matching the inclusion criteria and those being unclear regarding their eligibility were retained for a full-text review. Interrater reliability was assessed as moderate for the full-text review (Cohen's kappa coefficient of 0.51). A third reviewer (AM) resolved eligibility discrepancies where the first two reviewers did not reach a consensus. Data extraction was conducted by two independent reviewers, and included the sociodemographic characteristics of the participants, the characteristics of the gerontechnology tested at home, the duration of the intervention with the gerontechnology, the cost, and the benefits and challenges of using each specific gerontechnology.

Quality assessment

Three independent reviewers (HS, KA, M-CS) evaluated the quality of the empirical studies included in the present systematic review with the Mixed Methods Appraisal Tool (MMAT – Hong et al., 2018). This tool is designed for quality assessment of empirical studies included in systematic reviews. The scores range from 0 to 5, where scores near 5 indicate an excellent methodological quality. A mean score was calculated using the ratings of the three independent reviewers.

Results

A total of 13 studies met the study criteria and were included in this systematic review. Four studies used a qualitative method (Galambos et al., 2017; Åkerlind et al., 2018; Bradford et al., 2018; Berridge et al., 2019), six studies used a mixed-methods approach (Bock et al., 2016; Suzuki and Hasegawa, 2018; Grgurić et al., 2019; Gutierrez et al., 2019; Tseng and Hsu, 2019; Corbett et al., 2021), and three studies used quantitative methods (Cohen et al 2016; Quinn et al., 2019; Pais et al., 2020). Most studies were conducted in the United States ($n = 5$) (Bock et al., 2016; Galambos et al., 2017; Berridge et al., 2019; Quinn et al., 2019; Corbett et al., 2021). Other studies took place in Switzerland ($n = 2$) (Cohen et al., 2016; Pais et al., 2020), Sweden ($n = 1$) (Åkerlind et al., 2018), Australia ($n = 1$) (Bradford et al., 2018), Chile ($n = 1$) (Gutierrez et al., 2019), Croatia ($n = 1$) (Grgurić et al., 2019), Japan ($n = 1$) (Suzuki and Hasegawa, 2018), and Taiwan ($n = 1$) (Tseng and Hsu, 2019). The collective sample of these 13 studies included 172 older adults, with a mean age of 78.5 years (SD = 7.6), and 134 caregivers with a mean age of 51.7 (SD = 7). Gender, the relationship with the family caregiver, and the caregiving situation were not systematically reported in all of the studies. For the studies reporting them, the majority included mostly females in both the older adults and family caregivers' groups. The family caregivers were mostly daughters. Only one study reported living arrangement, specifically, that 91.2% of the participants lived alone (Cohen et al., 2016). The technologies addressed different problems including the detection of medical emergencies (Åkerlind et al., 2018), falls (Galambos et al., 2017), or health issues (Cohen et al., 2016), the early detection of difficulties performing activities at home (Bradford et al., 2018), the lack of access to information or entertainment (Corbett et al., 2021), the need for rapid action when there are behavioral anomalies in older adults' routines (Grgurić et al., 2019), social isolation (Gutierrez et al., 2019), medication compliance (Suzuki and Hasegawa, 2018), and lack of intergenerational connection between older adults and their adult children (Tseng and Hsu, 2019).

Level of evidence of the studies

The results of the Mixed Methods Appraisal Tool (MMAT) revealed that studies had on average a moderate quality of evidence (Table 2). The mean score obtained by the three independent reviewers was 3.7 (SD = 1). Common factors limiting the quality of the studies were linked to the sample sizes. Notably, all samples were small, a few had a high rate of attrition and a potential selection bias. For example, in Bradford et al. (2018), participants selected themselves (self-selection), thus it was mentioned that it is possible that they were already prone to positively appreciate the technology. In another study, most caregivers earned more than 100,000 US$ per year, which is considerably higher than the mean American salary (Quinn et al., 2019). Also, for the studies using a mixed methods design, divergences between qualitative and quantitative results were often not addressed (e.g., Grgurić et al., 2019).

Description of gerontechnologies for home-support tested simultaneously with community-dwelling older adults and their family caregivers

Each of the 13 studies evaluated a different technology. The mean duration of the intervention was 11.3 months (SD = 20.3) for a total of 135.5 months of intervention combining the 13 studies. Interventions varied in terms of their duration between 1 week and 6 years. A review of these technologies and their functionalities is presented in Tables 3 and 4.

In terms of functionalities, the technologies tested with CDOA and their family caregivers can be summarized as: (a) monitoring technologies, (b) communication technologies, (c) daily life assistance technologies, and (d) health information technologies.

Monitoring technologies

Monitoring technologies are developed for supervision and to allow rapid detection of anomalies or dangers at home to ensure the safety of older adults. Most technologies (10/13) included a system to monitor individuals or the environment (Bock et al., 2016; Cohen et al., 2016; Galambos et al., 2017; Åkerlind et al., 2018; Bradford et al., 2018; Suzuki and Hasegawa, 2018; Berridge et al., 2019; Grgurić et al., 2019; Tseng and Hsu, 2019; Pais et al., 2020). Cameras and sensors were the most widely used monitoring technologies in these studies. Cameras were used to monitor older adults in bed during nighttime (Åkerlind et al., 2018) and to detect falls while older adults were walking in their homes (Galambos et al., 2017). Sensors were used to detect motion and record usual activity patterns (Bock et al., 2016; Cohen et al., 2016; Bradford et al., 2018; Berridge et al., 2019; Grgurić et al., 2019; Pais et al., 2020). For example, the Intelligent Wireless Sensor System (IWSS) consists of a set of sensors that record older adults' movements in different rooms of their homes. Messages are sent to family caregivers when there is a behavioral pattern modification (Cohen et al., 2016). Four technologies used a system of alerts to signal anomalies (e.g., fall detection or change in walking pattern) (Galambos et al., 2017; Berridge et al., 2019; Grgurić et al., 2019; Tseng and Hsu, 2019) or to confirm that an activity has been performed by the older adult (e.g., self-administration of medication) (Suzuki and Hasegawa, 2018). Alerts were sent by the system and received by the family caregivers through text messaging and phone calls.

Communication technologies

A few technologies are designed to enhance the communication between the older adult living at home and their family caregivers. Five studies presented technologies serving this goal (Åkerlind et al., 2018; Bradford et al., 2018; Gutierrez et al., 2019; Quinn et al., 2019; Corbett et al., 2021). Smarter Safer Homes (Bradford et al., 2018) and the ICMed technology (Quinn et al., 2019) allowed the sharing of information about the health and daily activities between the older adult and the family caregiver via a platform. Finally, four technologies included a system of communication via phone calls, videoconferencing and/or text messages to connect older adults with their social circle (Åkerlind et al., 2018; Bradford et al., 2018; Gutierrez et al., 2019; Corbett et al., 2021). This allowed family caregivers to communicate in real time, do check-ups, and provide reminders when needed.

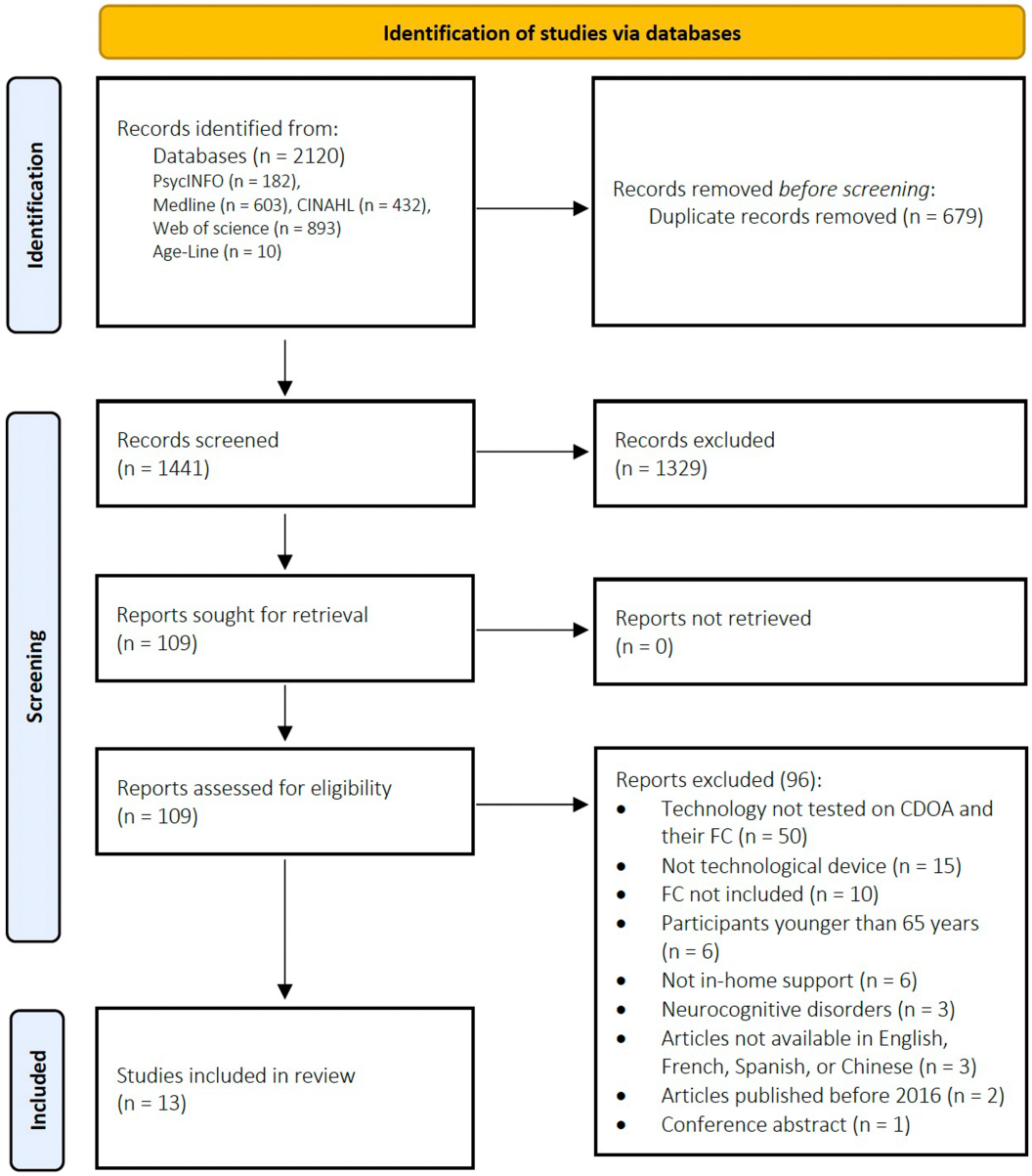

FIGURE 1
PRISMA flow diagram.

Daily life assistive technologies

A few technologies are designed to assist older adults in their daily life. These technologies include any electronic tool or equipment designed to help a person perform their regular daily activities, such as cooking, cleaning, entertaining, or planning. Two technologies served this purpose, namely the Virtual Home Assistant and the One-dose package medication support system. The Virtual Home Assistant is an electronic tablet used for entertainment, information search, planning (e.g., access to the calendar), and communication (Corbett et al., 2021). The One-dose package medication support system was used to help with medication compliance (Suzuki and Hasegawa, 2018).

Health information

Some technologies or applications are developed to increase access to evidence-based information that can help both older adults and their family caregivers manage their health and well-being. *ICMed* is a mobile application serving this goal. It uses the information collected on the older adult and their families to generate personal health advice (Quinn et al., 2019).

Benefits using gerontechnologies

Gerontechnologies have the potential to help CDOA maintain their autonomy and age in place when they are developed to respond to the specific needs of dyads. A review of the benefits found in the studies included: (a) increased communication and family participation, (b) increased sense of safety, (c) reduced stress of family members and CDOA, and (d) other perceived benefits.

Increased communication and family participation

Several studies revealed that the use of technology improved the communication between older adults, their family caregivers, and health care professionals (Åkerlind et al., 2018; Bradford et al., 2018; Quinn et al., 2019; Tseng and Hsu, 2019; Corbett et al., 2021). For instance, during an interview, a family caregiver who used the system Smarter Safer Homes shared the benefits of videoconferencing to assess the mood and state of the older adult (Bradford et al., 2018). Gutierrez et al. (2019) also showed that the Social Connector system can facilitate the interaction of family members and that video-calls were a highly appreciated activity by older adults. Tseng and Hsu (2019) found that the use of the Smart Care Interactive Systems (SCIS) with a chair significantly improved the quality of parent–child interactions. Hence, these technologies have the potential to decrease loneliness, by connecting older adults to their social network and improve the quality of relationships.

Increased sense of safety

Four studies revealed that in-home monitoring had a positive influence on feelings of safety (Cohen et al., 2016; Galambos et al., 2017; Åkerlind et al., 2018; Pais et al., 2020). For instance, older adults viewed the eHomecare system as a valuable resource to ensure safety. Family caregivers felt relief knowing that the technology was in place, because it provided information that the older adult was out of danger. It made it easier to keep balance with other responsibilities and social life (Åkerlind et al., 2018). Galambos et al. (2017) found that both family caregivers and older adults perceived an increased sense of safety using the Fall risk assessment sensor system. The Intelligent Wireless Sensor system was perceived as useful to ensure safety at home in case of falls by 34.8% of older adults and by 76.5% of family caregivers (Cohen et al., 2016). A higher proportion of older adults (74.5%) and a similar rate of family caregivers (70%) viewed the technology Domocare as useful to prevent falls and increase quality of life (Pais et al., 2020).

TABLE 2 Average scores of the Mixed Methods Appraisal Tool for the studies included in the systematic review.

Study	MMAT score
Åkerlind et al. (2018)	5
Berridge et al. (2019)	5
Bock et al. (2016)	2
Bradford et al. (2018)	4.7
Cohen et al. (2016)	3.3
Corbett et al. (2021)	3
Galambos et al. (2017)	4.7
Grgurić et al. (2019)	2
Gutierrez et al. (2019)	4
Pais et al. (2020)	4
Quinn et al. (2019)	3.7
Suzuki and Hasegawa (2018)	2.7
Tseng and Hsu (2019)	4

Reduced stress of family members and community-dwelling older adults

Improvements in communication and monitoring of potential threat is associated with stress reduction in older adults and the perception that gerontechnologies are useful to reduce family stress (Åkerlind et al., 2018; Bradford et al., 2018; Pais et al., 2020). For instance, family caregivers who used the eHomecare system noticed a decrease of concerns regarding the safety of the older adult. A total of 83% of older adults who used the Smarter Safer Homes system experienced peace of mind during the intervention (Bradford et al., 2018). Finally, older adults and family caregivers perceived that the use of Domocare could help reduce family stress by increasing the supervision of the older adult (Pais et al., 2020).

Other perceived benefits

In two studies, CDOA felt motivated to take better care of their health, after using technologies, such as the Fall Risk Assessment System (Galambos et al., 2017) and the ICMed Application (Quinn et al., 2019). Furthermore, the study on ICMed application showed that communication technologies have the potential to increase the participation of the older adult and their family caregivers in decisions regarding health (Quinn et al., 2019). Finally, the One-dose package medication support system was reported to be useful to compensate for forgetfulness and increase medication adherence (Suzuki and Hasegawa, 2018). All these benefits promote aging in place. However, several challenges need to be addressed to optimize the implementation of these technologies.

Challenges using gerontechnologies

Challenges and negative opinions have also been expressed by CDOA and their family caregivers. Their feedback is crucial for the development of gerontechnologies to be used at home that suit the profile, the preferences, and the needs of the dyads. Challenges included: (a) difficulties using the technologies, (b) technical problems, (c) privacy issues, (d) increased stress and dissatisfaction, and (d) a mismatch between values and needs.

Difficulties using the technologies

The use of technological devices often requires learning new skills. CDOA reported that learning how to correctly use technologies is a challenge (Bock et al., 2016; Bradford et al., 2018; Corbett et al., 2021). For example, older adults reported having difficulties learning how to use the technology and to identify its purpose (Bock et al., 2016). Participants reported that explaining how the data collected can be helpful to family caregivers and physicians would help them better understand their utility. It was also suggested that simplifying the visualization provided by the sensor system and demonstrations with case examples could increase its usability. In another study, older adults reported that it was challenging to adapt to a new device, especially when it served the same purpose as another technology already available in their homes (Corbett et al., 2021). Therefore, training was identified as an important need for technological implementation in older adults. Another study showed that the use of an iPad was perceived as difficult for a few older adults because of the visual and motor skills required, as well as lack of familiarity with the technology and its capabilities (Bradford et al., 2018). This is

TABLE 3 Description of gerontechnologies for home-support tested simultaneously in community-dwelling older adults and their Family Caregivers.

Authors	Gerontechnology name and description	Function	Price	Duration (months)
Åkerlind et al. (2018)	eHomecare is a Swedish technology offered by the municipality that replaces home care visits including a camera for supervision at night, a videophone, and an electronic mailbox. The videophone is used for social interactions and to send reminders. The mailbox is used for reminders and to receive information.	Communication and monitoring	222$ per month	6
Berridge et al. (2019)	QuietCare includes five interconnected sensors (bathroom door, bedroom door, apartment door, refrigerator, and environmental temperature sensors). The technology detects changes in movement and informs family members and social workers based on individual norms. QuietCare is connected to a telecare call center, the family emergency contacts, and the emergency medical service when no-one can be reached.	Monitoring and communication	6 to 16$ per month	72
Bock et al. (2016)	The Lab of things (LoT) is an open-source platform that manages smart home system deployment and integration. The platform runs on a laptop in the kitchen of the older adult and connects to the cloud-side component of LoT for data storage and central management. The LoT transforms the data created by sensors (one multi-sensor and two door/window sensors at home) into sensor firing data (e.g., when a door is opened) or environmental parameters such as temperature and humidity (in the case of the multi-sensor).	Monitoring	500$	3
Bradford et al. (2018)	Smarter Safer Homes platform is a system using roughly 30 in-home sensors, different electronic medical devices (weight scales, a thermometer, and a combined blood pressure monitor and glucometer unit) connected to an iPad for self-monitoring. Sensor and medical device data are uploaded to a website (family portal) where authorized relatives can remotely monitor health and daily activities of their family member. Communication with family caregivers is also facilitated using a videoconferencing application.	Monitoring and communication	–	9
Cohen et al. (2016)	The Intelligent Wireless Sensor system allows recording the movements and activity/inactivity of the home-dwelling older adults in strategic places of their living space (e.g., living room, bedroom, bathroom, time spent in bed, and time at which the fridge was opened). The system detects changes in movements and contacts caregivers depending on the participants' changing behavior patterns represented on a dashboard (by short message service, email, or smartphone application).	Monitoring and communication	–	-
Corbett et al. (2021)	Virtual Home Assistant is a second-generation Echo Show that had a 10.1-inch smart video screen and a third-generation Echo Dot smart speaker that was 3.9 inches in diameter and 1.7 inches high. Support persons received an Echo Spot that was 4.1 inches in diameter, 3.8 inches tall, and had a small video screen and smart speaker. The technology allows the older adult to have a voice-activated connection to the internet and receive vocal answers. It also allows videoconference communication with the primary caregiver, who received an Echo Spot.	Daily life assistance, communication	–	2
Galambos et al. (2017)	The Fall risk assessment sensor system includes a pulse-Doppler radar, a Microsoft Kinect, and two Web cameras. The system works to detect motion and falls using a machine learning approach.	Monitoring	–	24
Grgurić et al. (2019)	SmartHabits is a monitoring system using sensors to detect usual daily activity patterns. The system also contacts family members or caregivers when an unusual situation is detected. Data is stored in the Cloud Platform and used for pattern recognition and anomaly detection	Monitoring and communication	–	1
Gutierrez et al. (2019)	SocialConnector system is a PC tablet application created to facilitate family communication. The tablet is fixed on a wall or furniture inside the older adult's house. The older adult can interact with his surroundings using voice, video, or text messaging that can be controlled using voice commands or the touch-based screen (i.e., synchronous and asynchronous voice messaging, synchronous video messaging, text messaging, and multimedia messaging). Family members receive messages from the application to invite them to engage in conversations.	Communication	–	2.25

(Continued)

TABLE 3 (Continued)

Authors	Gerontechnology name and description	Function	Price	Duration (months)
Pais et al. (2020)	Domocare allows the monitoring of older adults using a system of ambient sensors (e.g., mobility, sleep habits, fridge visits, door events) and health-related events by wearable sensors (i.e., wearable activity tracker worn on the wrist, ECG)	Monitoring	–	12
Quinn et al. (2019)	ICMed App sends evidence-based and personalized advice based on the data collected about the health profile and the family health history of the older adults. The software is created to share information and connect older adults, family caregivers, and professional care providers.	Information and communication	–	1
Suzuki and Hasegawa (2018)	The ODP-MSS is an intelligent pill dispenser with an internal memory in which single doses of several medications intended to be taken at the same time are sealed in single film bags that are rolled onto a rotating drum. The ODP-MSS can dispense a maximum of six ODP doses per day for 60 days. The technology sends musical alerts to older adults to remind them to take medication and sends alerts to caregivers if the older adults did not take the medication. The memory stores the data that can be used by the pharmacist or physician and retrieved using a USB cable and a personal computer.	Daily life assistance and communication	–	3
Tseng and Hsu (2019)	Smart Care Interactive Systems (SCIS) is an intelligent chair that is used to monitor behaviors and heartbeat activity (e.g., user detection, heartbeat). Data are sent to a cloud and could be accessed by the caregiver using an app installed in a smartphone. The system can send alerts in case of unusual user behavior.	Monitoring and communication	–	0.25

compatible with other studies with smartphones and tablet use in older adults (Barnard et al., 2013; Wilson et al., 2022).

Technical problems

Three studies reported technical problems during the intervention phase (Cohen et al., 2016; Grgurić et al., 2019; Quinn et al., 2019). First, some connectivity problems with mobile phone network occurred in rural areas while using Intelligent Wireless Sensor System (IWSS) (Cohen et al., 2016). Hence, some family caregivers did not receive the alarm messages. Connectivity issues were also found using the ICMed Application, along with log in problems (Quinn et al., 2019). Variability in the Internet connectivity caused family caregivers to receive system-offline notifications (Grgurić et al., 2019). The prolonged use of technologies like the SmartHabits system requires a change of batteries for the sensors. Battery replacement needs planning to make sure that the technology will be constantly operating at home.

Privacy issues

The perception of intrusiveness and the discomfort regarding loss of privacy is part of the downsides of environmental or personal monitoring reported by older adults (Cohen et al., 2016; Åkerlind et al., 2018; Gutierrez et al., 2019). Privacy concerns have been reported by participants in two studies (Åkerlind et al., 2018; Gutierrez et al., 2019). Feelings of being watched were experienced by older adults using the Intelligent Wireless Sensor System and triggered conflicts in some families (Cohen et al., 2016).

Increased stress and dissatisfaction

The use of gerontechnologies has a different impact on the level of stress and satisfaction. For instance, frequent false alarms can increase stress in family caregivers (Berridge et al., 2019). A few family caregivers felt annoyed by the number of alarms and calls needing to be answered (Cohen et al., 2016; Suzuki and Hasegawa, 2018). For older adults in an emergency situation, language barriers in communication while interacting with an employee of the Telecare Center can be a stressful experience for non-English speakers (Cohen et al., 2016).

Mismatch between values and needs

Studies showed that the use of technology can sometimes create a mismatch between values and needs (Suzuki and Hasegawa, 2018; Berridge et al., 2019). For instance, technologies might not match the expectation of how the older adult wished to be cared for by family members and sometimes led to conflict with family caregivers. Devices like the ODP-MSS did not allow enough flexibility in the medication administration (e.g., the older adult could not take their medication if they were away from home). As a consequence, a few older adults felt obligated to remain at home. Furthermore, four out of nine older adults perceived the technology as not useful because they could take medicine without relying on the ODP MSSS (Suzuki and Hasegawa, 2018).

Discussion

The goal of this systematic review was to summarize the research findings on in-home interventions using gerontechnologies tested simultaneously with CDOA with unimpaired cognition and their family caregivers. More specifically, we aimed to describe the technologies, their benefits and challenges, and the evidence level of the studies about them published between 2016 and 2021. We also aimed to provide recommendations for technological development, implementation, and research. To our knowledge, this is the first study synthesizing the evidence concerning the efficacy of technologies designed to support CDOA-family caregiver dyads. The review was conducted to inform older

TABLE 4 Characteristics and main findings of the studies included in the systematic review.

Authors and year	Type of study (design)	Country	Study objectives	Measures	Results	User acceptance	Benefits	Difficulties using the technology	Adverse effets	Conclusion
Åkerlind et al. (2018)	Qualitative	Sweden	To extend descriptions of how older adults with granted eHomecare and their relatives understand safety, and further to describe how they experience safety in everyday life	Interviews about the perceived sense of safety	The videophone was experienced as creating closer contact and as a tool for the older adults and their relatives to inform each other about their conditions through image and sound	Privacy concerns and fear of safety threats could affect the willingness to try a new technology	eHomecare provides economic and practical benefits concerning older adults and their relatives' experiences of safety	Providing thorough and adequate information about the service was difficult	–	eHomecare can promote safety for older adults ageing in place and for their relatives
Berridge et al. (2019)	Qualitative	US	To examine the difference in experiences and insights of low-income, immigrant senior residents, family contacts, and staff of housing that offered a sensor-based passive monitoring system	Interviews about the how they made decisions about technology adoption or discontinuation, and about their experiences with the system	The reactions of immigrant older adults to the passive monitoring system reveal that this technology was often mismatched with their values, needs, and expectations	Asian immigrants discontinued the use at higher rate compared with other users due to fear that false alarms burden their families	Variable depending on culture	When calling to the telecare center (e.g., in case of emergency), the first response is always in English, which may cause stress to non-English speakers; the quantity of false alarms is an issue	-	Successful adoption of gerontechnologies by immigrant older populations must be culturally and practically relevant to these populations
Bock et al. (2016)	Mixed	US	To demonstrate the implementation of a smart home system using an open, extensible platform in a real-world setting and develop an application to visualize data in real time	Interview and usability questionnaire	Family members felt comfortable using the application, while older adults indicated it would be difficult to learn to use it and had trouble identifying its utility	There was a better acceptance rate from the family caregivers compared to older adults	In real time, consumers are able to view sensor events day-to-day relative to an average event level, which is useful to inform their family members, physicians, or family caregivers	Older adults had difficulties to learn to use the application and had trouble identifying utility	–	Although customization is challenging, older adults have expressed interest in smart home technologies, and one way to facilitate their adoption is through visualizations that incorporate data from smart home sensors into relevant and insightful resources

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TABLE 4 (Continued)

Authors and year	Type of study (design)	Country	Study objectives	Measures	Results	User acceptance	Benefits	Difficulties using the technology	Adverse effets	Conclusion
Bradford et al. (2018)	Qualitative	Australia	To seek the views and perspectives of Smarter Safer Homes (SSH) residents using in-home monitoring and explore the perspectives of relatives of SSH residents who were granted access to their relative's activity and health data via an online portal	Perceptions on the use of technology at home and modified versions of The Microsoft's Desirability Toolkit	Older adults experienced peace of mind from the health devices and, once accustomed, were unperturbed by the presence of sensors; there was an increase in family communication	With regards to the medical devices, residents varied in their frequency and use of them, however, all residents used at least one device once per week	To reduce the social boundaries that lead to isolation and loneliness in older adults, providing peace of mind to family caregivers	The iPad was found to be the most challenging component of the platform and inaccuracies in sensor data and difficulties in sensor placement proved frustrating for residents and researchers	Minor annoyances derived from sensor placement and function	There was an overall positive response to the system, despite a slight tendency for residents to modify their behavior due to perceived surveillance
Cohen et al. (2016)	Quantitative	Switzerland	To explore the acceptability (usefulness, satisfaction, ease of use, and intention to use) of an intelligent wireless sensor system (IWSS) among home-dwelling older adults	The Resident Assessment Instrument for Home Care, Confusion Assessment Method, Cognitive Performance Scale, Geriatric Depression Scale, Informed Questionnaire on Cognitive Decline in the Elderly, and acceptability of the IWSS using a home-made questionnaire	Both older adults and their family caregivers considered the performance and usefulness of the IWSS intervention to be low to moderate and the majority of the participants were unsatisfied with its ease of use, while their informal caregivers were more satisfied with the program	Only 26.1% of older adults and 53.3% of their family caregivers were satisfied, but participants felt that the IWSS was intrusive and that they were being watched	One-third of older adults and three-quarters of family caregivers considered the IWSS useful for older adults who wished to remain in their homes, and believed that the IWSS was an appropriate means of ensuring safety in case of falls	Family caregivers were dissatisfied with the need to acknowledge each alarm message with a telephone call, some rural areas were not always covered by the mobile phone network, and one-fifth of the participants or informal caregivers contemplated leaving the study	The perception of intrusiveness went so far as to create conflicts between participants and their family caregivers	IWSS programs installed were not always easy to use and generally demonstrated only low-to-moderate acceptability and the IWSS failed to precisely and rapidly detect every health issue in daily life

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TABLE 4 (Continued)

Authors and year	Type of study (design)	Country	Study objectives	Measures	Results	User acceptance	Benefits	Difficulties using the technology	Adverse effets	Conclusion
Corbett et al. (2021)	Mixed	US	To describe virtual home assistant (VHA) use and usefulness from the perspective of older adults and their support persons	PROMIS Global Scale for older adults, Caregiver Burden Scale for family caregivers and qualitative telephone interviews	Older adults and their support persons used the VHAs in similar ways to request information, listen to music, obtain weather forecasts, and enjoy other types of entertainment (e.g., jokes and podcasts)	Participants did not have privacy concerns about using a VHA	Benefits included the hands-free feature of the VHA and security by allowing older adults to contact someone in an emergency and the facilitation of interactions throughout the day reducing isolation (e.g., video calling feature)	Challenges integrating Alexa with other tools that served similar purposes and older adults' needs for more education and training about the capabilities of VHAs (e.g., "Getting Used to Another Device")	–	Participants used the VHA regularly over time, primarily for information, entertainment, or to receive prompts; while future desired uses included the health promotion and management of their health conditions
Galambos et al. (2017)	Qualitative	US	To explore the perceptions and preferences of older adults and their family members about a fall risk assessment system (FRAS)	Individual face-to-face interviews with older adults and face-to-face or telephone interviews with family caregivers of participants were made during the installation phase and at 6, 12, 18, and 24 months	Positive perception at the preinstallation phase (e.g., feelings of security), at 6 months (e.g., strong connection to their own health information), 1 year (e.g., appreciation of feedback and reports), 18 months (e.g., no interference with daily routine), and 24 months (e.g., sense of serving purpose)	Over time, the FRAS became a normal part of the environment, no longer a novelty, and was eventually accepted as a helpful device within one's living environment	The FRAS was regarded as a tool that helped increase their safety and activity level and served as a motivator to do better	The aesthetics of the system was mentioned as something that could be improved; some users did not like the color, location, or style of the wooden box that held the equipment	-	Sensor monitoring was regarded positively by both older adults and family caregivers, and as a means to hold on to independence to age in place

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TABLE 4 (Continued)

Authors and year	Type of study (design)	Country	Study objectives	Measures	Results	User acceptance	Benefits	Difficulties using the technology	Adverse effets	Conclusion
Grgurić et al. (2019)	Mixed	Croatia	To evaluate if the prototype system could successfully learn typical daily patterns, detect unusual situations in the household of the older person living alone, and notify family caregivers when an unusual situation is detected	Data analysis of the number of detection and amount of patterns learned. Usability questionnaire and a free form question (i.e., *"Is there anything else you would like to share about the system?"*)	During the pilot and testing phase, using six sensors the system was able to learn on average 23 patterns per single household in the first 30 days of the usage.	Older adults perceived that this technology is usable as they did not have to interact with the system explicitly or compromise their privacy, while family caregivers interacted with the system explicitly and received notifications if something unusual happened in the older adult's household	The home users, in general, liked the system based on the use of simple off-the-shelf sensors that do not invade privacy without explicit interaction of home users	There was no problem with the autonomy of the sensors, but for more prolonged and more extensive use, this would be an issue; the automatic resets of the Internet connection in the mobile Wi-Fi routers posed some disturbance without affecting the core-system functionality	The light coming from the hardware was sometimes too distracting	The proposed system can easily improve the quality of care with simple smart-home sensors that can provide essential and continuous information about the status of the occupant and the environment
Gutierrez et al. (2019)	Mixed	Chile	To evaluate the effect of introducing the SocialConnector system at the home of a sample of older adults, in the interaction with their family network	Data from automatically generated system usage logfiles pre-intervention (weeks 1–3), during the intervention (weeks 4–6), and post-intervention (weeks 7–9)	Mediating the interaction of family members with notification triggers does have an effect on the volume of calls, messages, and photos sent to the older adults	Older adults using SocialConnector did show increased social engagement, particularly with family members, when exposed to interacting with the system over a period of 9 weeks	The system involves the entire family network in the process	Major concern involving privacy matters and information disclosure across the family network and reticence on trusting the technology for mediating intergenerational communication about personal matters	–	This study proposes 20 recommendations that positively impact the usability of the devices, which consider not only the requirements of elderly people as part of the aging in place process, but also the typical capabilities and restrictions of the rest of the family members that support the process

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TABLE 4 (Continued)

Authors and year	Type of study (design)	Country	Study objectives	Measures	Results	User acceptance	Benefits	Difficulties using the technology	Adverse effets	Conclusion
Pais et al. (2020)	Quantitative	Switzerland	To evaluate the usability, functionality, and effects of a new in-home monitoring system—combining ambient and wearable sensors—among home-dwelling older adults, their family caregivers, and nurses for the support of home care	Semistructured interviews face-to-face or phone calls based on the French version of the Quebec User Evaluation of Satisfaction with assistive Technology (QUEST) for older adults and the caregiver quality of life scale for family caregivers	The majority of participants considered that in-home sensors were helpful (ambient and wearable) with more favorable opinions toward ambient sensors than toward Activity tracker, and ECG	The majority of older adults and family caregivers reported that they would like to continue using in-home sensors in case of insurance reimbursement	To help staying at home improving home care, preventing domestic accidents, and reducing family stress	Improvements of the technology could include the design of sensors that are smaller, lighter, and more user-friendly and comfortable for older adults, as well as advances in machine learning for detection of specific events at home	–	Overall, the opinions of older adults, family caregivers, and nurses were positively related to in-home sensors, but nurses were less enthusiastic about their use in clinical practice
Quinn et al. (2019)	Quantitative	US	To determine the usability of a mobile App in a community-based older adult population aged ≥65 years	Participant engagement was measured by weekly surveys sent via an App push notification, the quality of the App, and Usability	In fourth week post-intervention, 60% of participants were aware of their health conditions, 40% wanted to learn or felt motivated to take care of their health, and half of family caregivers indicated they wanted to use the App to manage health appointments, records, and share health information	While technology use was common in the cohort among well-educated older adults, engagement with the mobile App was average	The App may be used for older adults to improve participation in health care decisions made by family caregivers and providers, to self-manage health and social needs, and to improve engagement and social connections	Technical issues, including, but not limited to, log in and connectivity issues, discouraged participants and delayed or limited use, likely leading to loss to follow-up	–	Technology use is high among this population despite low participant usability and engagement

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TABLE 4 (Continued)

Authors and year	Type of study (design)	Country	Study objectives	Measures	Results	User acceptance	Benefits	Difficulties using the technology	Adverse effets	Conclusion
Suzuki and Hasegawa (2018)	Mixed	Japan	To evaluate a one-dose package medication support system (ODP-MSS) for medication support and telecare home monitoring of older adults	Interviews with older adults and family caregivers about missed medication and data log of medications taken or not taken, as well as automatic calling, from the memory of the ODP-MSS	Most older adults had 100% medication adherence and those who had missed doses due to forgetfulness took medicine after the caregiver called	Participants reported that the ODP-MSS provided a useful reminder to take medicine at the time of the alert	The device provided a useful reminder to take medicine, the caregiver's call was useful as a telecare home monitoring system, and older adults who had missed doses due to forgetfulness took medicine after the medication supporter called	Limitations included device jamming, patients feeling obligated to stay home during medication administration times as they could not take the medication when they left their homes, supporters receiving too many calls, and an irregular lifestyle interrupted routine taking of medications (e.g., ODP-MSS did not match their actual mealtimes)	-	The technology helped prevent missed doses resulting from older adults' forgetfulness and may serve as a useful component of telecare home monitoring for elderly people living independently at home, to reduce the burden associated with medication support, and to prevent medication errors
Tseng and Hsu (2019)	Mixed	Taiwan	To explore the use of a smart care interactive system with a chair (SCIC) to improve the intergenerational relationships at home	Intergenerational Relations Scale (IRS), usability questionnaire, and interviews	The SCIC was shown to significantly improve the emotional support and parent–child interactions with the elderly as well as the intergenerational relationships (e.g., parent–child interactions)	Well accepted, despite design limitations	Through the App, visual information display, and warning messages family caregivers are able to effectively understand the elderly's active and rest status	The design of the back of furniture is not long enough, the elderly users are dissatisfied with the neck support part, and it is very difficult to move the footrest that sometimes hinders the movement of elderly people in the living room	–	The interactive chair can significantly help the elderly in terms of emotional support and parent–child interactions (e.g., care about older adults' health and facilitation of interactions between older adults and family caregivers)

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adults, family caregivers, healthcare professionals, scientists, and policymakers about the gerontechnologies available to enable them to make well-informed decisions on their use and development.

Surprisingly, we found only 13 studies meeting our eligibility criteria. The technologies were usually tested on a small sample of participants and were designed to monitor older adults, promote communication between older adults and family caregivers, help with daily tasks, and provide useful information that can be used to optimally manage their health. Most studies were conducted in the United States. Only four studies were conducted in Europe and two in Asia, even though these continents represent most of the world's oldest population (United Nations, 2021). The majority of studies did not specify the price of the technology used, preventing people from making decisions based on the cost/efficacy. Large differences were found related to the intervention duration, ranging from 1 week (Tseng and Hsu, 2019) to 6 years (Berridge et al., 2019). The quality of studies also varied greatly, with mixed and quantitative studies receiving lower scores due to their small sample size and risk of non-response bias. Given their position in the development process, it is common for these studies to have small sample sizes. They are often the first step before conducting large implementation studies. In general, pilot studies allow for iterations to refine the technologies being tested. To our knowledge, none of these 13 studies has moved to a wider implementation phase.

Several benefits have been reported by dyads of CDOA and family caregivers, such as an increase in communication and feelings of safety. However, some gerontechnologies elicited different reactions in older adults and family caregivers, including reports of technical difficulties, learning challenges, emotional reactions (e.g., increased stress), and interpersonal difficulties (e.g., family conflicts). These differences in reaction can perhaps be addressed via co-designing technologies to facilitate their development, increase confidence levels in their use and efficacy.

The results of a systematic review of assistive technologies in dementia care showed similar results with good acceptance to facilitate daily living (Pappadà et al., 2021). Although they included intervention studies (e.g., telemedicine) and a different population (i.e., people with dementia), the potential of technology is clearly to provide monitoring and security of older adults, support in activities of daily living, and psychosocial support. The use of these technologies seems to be increasing and they can be very useful during future pandemics. Taken together, gerontechnologies provide concrete support to older adults and family caregivers when they respond to specific needs and the different problems that can be experienced in the continuum ranging from normal aging to dementia.

Currently, education about gerontechnologies and their efficacy is needed to inform the general population, clinicians, and policy-makers about the options available to promote independent living in the older adult population. Innovative solutions to quickly test, implement, and commercialize these technologies remains a challenge as there is a gap between their development and community implementation. Initiatives to educate the public in the availability of these technologies and promote research are currently underway (Aboujaoudé et al., 2023; envisAGE, https://www.envis-age.ca/en/). Still, the lack of evidence on their efficacy impedes informed decision-making. We provide the following recommendations based on the current systematic review to address some specific challenges preventing the use and dissemination of these gerontechnologies.

Recommendations for technological development, implementation, research, and public policies

Technology development

1. To develop gerontechnologies that are sensitive to the need for privacy of older adults. Privacy is an important ethical issue that must be considered during the development of gerontechnologies (Sundgren et al., 2020). For example, studies reported that cameras are less accepted because they are perceived as more intrusive (Boström et al., 2013; Claes et al., 2015). Alternative methods seem to be more appreciated by older adults (e.g., sensors for movement detection or wearable technologies for fall detection instead of cameras or microphones).
2. To develop technologies that are easy-to-use. Technologies that are easy-to-use can increase their acceptability. Also, considering potential physical, sensorial, and physical barriers in the development of gerontechnologies is a crucial step to make them more inclusive.
3. To develop technologies that respond to unmet needs at home. It is important that the functionalities respond to unmet needs identified through a co-construction process as it influences the perceived usefulness of gerontechnologies, which has been linked to positive attitudes towards their use (Chen and Chan, 2014). It is understandable that older adults would prefer using older technologies already in place instead of replacing them with new ones, since it does not require any adaptation or financial outlay.

Implementation

1. To provide training and guided practice to CDOA to help them learn new skills. Training was identified as a need in a few studies (Bock et al., 2016; Bradford et al., 2018; Corbett et al., 2021) as lack of it is a barrier to technology adoption. Training facilitates learning new skills and helps overcoming barriers to utilization of new technologies and devices (Chen and Chan, 2014). Strategies recommended include training by healthcare professionals, providing video or written instructions as well as providing access to continuous technical support. Also, providing a test period without penalty could allow older adults to explore the technologies before purchasing them to make sure that they really respond to their needs.
2. To evaluate the needs, the values, and the preferences of family caregivers and older adults simultaneously and explore the options available to the dyads. It is important that clinicians provide information about the interventions currently available and listen to the preferences of families. It is important to explore different alternatives to solve problems, such as forgetfulness, isolation, or mobility issues. Needs exploration can help families make informed choices and increase their feeling of self-determination, which is important to promote psychosocial health (Ntoumanis et al., 2021). Also, personalizing the interventions can ensure optimal results in CDOA and their family caregivers in their unique social, economic, and environmental context (Ebrahimi et al., 2021).
3. To ensure that the intervention proposed matches the current physical and cognitive autonomy level of the older adult. It has

been found that interventions are perceived as more acceptable depending on the perception of the benefits of the technology. For instance, older adults are more likely to accept monitoring technology when experiencing mobility issues if it allows them to stay in their homes. In contrast, feelings of being able to perform a daily activity without the technology can lead older adults to perceive it as not useful (Tseng and Hsu, 2019). More importantly, it can have negative consequences on older adults, such as increasing their feeling of becoming dependent on the technology to do something that they can still do without it.

Research

1. To adopt a co-construction approach. To maximize the agency of older adults and their family caregivers and to ensure that the interventions match their values and needs, we encourage the active consultation and participation of community stakeholders in research on development and adaptation of gerontechnologies (Closon and Léonard, 2016). Researchers are encouraged to describe the phases of development of their technologies, including the co-construction process and the persons involved in the different iterations.
2. To document the effects of interventions on quality of life, well-being and other psychological outcomes in CDOA and their family caregivers. In the majority of the studies included in this systematic review, these effects were not documented and would provide additional evidence of the benefits of gerontechnologies for the dyads of CDOA and their family caregivers. Personal variables are important in technology adoption.
3. To conduct scaled evaluation and implementation. Future studies must evaluate the effectiveness of interventions using gerontechnology with end-users and clinicians, in real-world contexts (e.g., integration in current psychosocial or nursing interventions). These studies should include different contexts to generate evidence of generalizability (e.g., different populations of older adults and geographical locations). Conducting randomized control trials with bigger samples of CDOA and family caregivers is not always possible considering the costs both of the technological development itself and of the research. However, alternative research methods can be used. For instance, interrupted time series or single pretest-post designs can be used (Wang et al., 2021)

Public policies

1. To give access to information and training on gerontechnologies to managers and healthcare professionals. This step is important to facilitate implementation of gerontechnologies for home support in different organizations (e.g., the healthcare system). University curricula need to include more training in technology, rehabilitation, and older adults' needs.
2. To fund studies evaluating the cost-effectiveness of interventions using gerontechnologies. This recommendation is based on the absence of studies evaluating the cost-effectiveness of interventions using gerontechnologies for CDOA and family caregivers. This type of study is crucial to influence future governmental investments for home support.

General conclusion

This systematic review identified gerontechnologies that have been tested to support aging in place among among CDOA without cognitive impairment and their family caregivers. It provided information on the benefits and challenges perceived by the dyads, the quality level of the studies included, and some recommendations to address challenges linked to dissemination and implementation of these technologies.

Gerontechnologies are an innovative solution to help older adults age in place and maintain their autonomy and independence. Efforts must be made by scientists, healthcare professionals, and policy-makers to make these interventions accessible and adapted to the specific challenges encountered by older adults and their families.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Factors influencing older adults' acceptance of voice assistants

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Introduction: Voice assistants (VAs) have the potential to uphold and enhance the quality of life for older adults. However, the extent to which older adults accept and benefit from VAs may be relatively modest.

Methods: This study developed a comprehensive model combined with product and personal characteristics to explain the acceptance of VAs among older adults, using semi-structured interviews (Study 1) and questionnaires (Study 2).

Results: Results revealed that in terms of product characteristics, perceived usefulness and perceived enjoyment significantly affect behavior intention. Regarding personal characteristics of older adults, technological self-efficacy and dispositional resistance to change significantly affect behavior intention. However, no direct impact of perceived ease of use and perceived trust on behavior intention. Additionally, perceived enjoyment influenced both perceived ease of use and perceived usefulness.

Discussion: Results suggested the significant role of technology self-efficacy and dispositional resistance to change in predicting the acceptance of VAs among older adults. Our newly developed model offers valuable insights for tailoring VAs to this demographic during design and implementation.

KEYWORDS

older adults, voice assistants, technology acceptance model, behavior intention, dispositional resistance to change

1 Introduction

Voice interaction is highly effective and humanized in Human-Computer Interaction (HCI) (Turow, 2021; Calahorra-Candao and Hoyos, 2024). The rapid development of intelligent voice technology, facilitated by advancements in deep learning, Internet of Things (IoT) technology, and enhanced computing power, is revolutionizing societal norms (Pham Thi and Duong, 2022; Ossadnik et al., 2023). A prominent manifestation of this technology is found in voice assistants (VAs). According to Juniper Research (2021), the number of VAs is projected to exceed the global population, reaching 8.4 billion by 2024.

1.1 Voice assistants and older adults

According to the 2022 Revision of World Population Prospects (Department of Economic and Social Affairs of United Nations, 2022), the proportion of the global population aged 65 and above is projected to increase significantly, exceeding 1.5 billion by 2050. As of the end of

2022, the elderly population aged 60 and above in China reached 280.04 million (National Bureau of Statistics of China, 2023). The current study defined elderly as the people aged 60 and above. As VAs become increasingly popular and permeate into our daily lives, it is foreseeable that there will be an increasing number of elderly users using VAs in the future.

Previous research has indicated that VAs can support older people in various aspects. Firstly, due to the significant decline in cognitive and physical functions caused by aging, the ability of older adults to perform instrumental activities of daily living (IADLs), such as using smartphones and computers and engaging in shopping, is weakened (Lawton and Brody, 1969; Liu et al., 2023; Werner et al., 2023). Voice interaction offers a more natural and straightforward interaction, making it easier for older people to learn and operate (Kebede et al., 2022; Kuoppamäki et al., 2023). Additionally, VAs can facilitate communication between older adults and others, especially those with visual or hand function impairments (Kowalski et al., 2019). It also found that VAs can serve as social companions to some extent (Corbett et al., 2021; Yan et al., 2024). Lastly, VAs can also assist in daily health activities such as health tracking, medication management, and meal planning, which could support the elderly's daily lives (Nallam et al., 2020; Schlomann et al., 2021; Yan et al., 2024).

Despite the potential of VAs to support the lives of the elderly and their overall good usability, previous research has indicated that the willingness of older adults to adopt VAs is relatively low (Song et al., 2022). Additionally, VAs were initially designed for younger people, and the designers are usually younger, having grown up in a more technologically advanced environment (Kim and Choudhury, 2021). As a result, the product design often overlooks older adults' physiological and psychological characteristics. Therefore, it is crucial to identify the factors that promote or hinder the use of VAs among older adults.

2 Literature review

To investigate the factors influencing the acceptance of VAs among older adults, we will review three aspects: the theoretical models related to technology acceptance, factors influencing technology acceptance among older adults, and research on the acceptance of VAs among older adults.

2.1 The theoretical models related to technology acceptance

Several theories have been proposed to understand the factors driving user technology acceptance, including the Theory of Reasoned Action (TRA, Fishbein and Ajzen, 1975), the Technology Acceptance Model (TAM, Davis, 1989), the Technology Acceptance Model 2 (TAM2, Venkatesh and Davis, 2000), and the Unified Theory of Acceptance and Use of Technology (UTAUT, Venkatesh et al., 2003). Among these proposed technology acceptance models, TAM is currently the most widely used model for predicting technology acceptance (Ma et al., 2021; Yu et al., 2022). TAM was initially proposed to provide an explanatory framework for the factors influencing computer systems within organizational settings. As TAM theory evolved, it has been widely applied to investigate user acceptance of new technologies (Nagle and Schmidt, 2012; Zhao et al., 2018; Zhu and Cheng, 2022). Perceived usefulness and perceived ease of use, as proposed by TAM, are the main determinants influencing users' intention of technology acceptance behavior. Perceived ease of use refers to the user's subjective perception of the ease or difficulty of utilizing a particular technology. Perceived usefulness refers to the user's subjective perception of the degree to which a technology is beneficial during use. Moreover, perceived ease of use positively influences perceived usefulness.

Furthermore, Ram and Sheth (1989) proposed the innovation resistance theory (IRT) based on consumers' resistance to innovation, which categorized innovation resistance into functional barriers and psychological barriers. Functional barriers encompass risks, value, and usage barriers, while psychological barriers include traditional and image barriers. Several studies employ the IRT theory to analyze consumer innovation adoption behavior, especially in the initial adoption stage (Borraz-Mora et al., 2017; Dotzauer and Haiss, 2017; Leong et al., 2021). IRT has emerged as the favored framework among scholars specializing in the study of innovation resistance, either as a standalone model (Borraz-Mora et al., 2017; Hew et al., 2019) or when integrated with other established frameworks such as UTAUT (Lian and Yen, 2014) and TAM (Agag and El-Masry, 2016).

2.2 Application of technology acceptance-related theories to older adults

Given older adults' physiological and psychological characteristics, many studies incorporate personal and perceptual characteristics variables when exploring technology acceptance among older adults using relevant theoretical frameworks. For instance, some studies have indicated that technological self-efficacy and technology anxiety play essential roles in the technology acceptance of older adults (Peral-Peral et al., 2020; Jeng et al., 2022). Chen and Chan (2014) found that these constructs may better predict technology acceptance behavior of older adults than the conventionally attitudinal factors (usefulness and ease of use). Furthermore, older adults tend to have a slower processing speed and a more challenging learning process when accepting and learning new technologies (Kebede et al., 2022). If using technology is enjoyable, older adults are more likely to adopt it (Talukder et al., 2020). Studies have found that incorporating perceived enjoyment can improve the predictive power of technology acceptance-related models (Phibbs, 2021; Zeng and Chen, 2022). Additionally, the fear of technology intrusiveness among older adults has been repeatedly identified as a significant barrier to adopting technologies (Fischl et al., 2017; Kong and Woods, 2018; Zambianchi et al., 2019). Song et al. (2022) found that perceived trust directly impacts the acceptance of VAs.

On the other hand, dispositional resistance to change (DRTC) within personality traits is also considered a valid antecedent for the technological acceptance of older adults. Due to the pro-innovation bias (Talke and Heidenreich, 2014), most researchers believe that consumers are willing to change and are thus tempted to try innovative products, as long as the benefits of the technology, such as perceived usefulness and perceived ease of use, are emphasized. However, the reality often is that consumers tend to reject innovation without considering the potential of the product, leading to the adoption process ending before it even begins. This is particularly evident among older adults (Ma et al., 2021). Despite successful implementation of innovation, there may still be resistance

(Laukkanen et al., 2008). Consumers often resist innovation due to changes in their current habits or norms required for accepting new ideas (Snyder, 1961). Previous research on VAs has found that older adults accustomed to traditional interaction methods involving input and output devices tend to exhibit resistance when adopting VAs (Trajkova and Martin-Hammond, 2020). However, no study has delved into the influence of DRTC on behavior intention of VAs among older adults. Furthermore, despite the inherent simplicity of VA interactions, older adults still encounter misunderstandings and challenges when using VAs during the initial stages (Kim, 2021), which may lead older adults with higher levels of DRTC to discontinue usage altogether.

2.3 Research on the acceptance of voice assistants among older adults

In recent years, the prospects for applying for VAs have expanded extensively. Numerous studies have initiated exploring the adoption and utilization of VAs among older adults.

Currently, research primarily focused on the advantages and disadvantages of VAs. VAs provided simplicity, convenience, and easy accessibility. It could support and enhance the social engagement, autonomy, and leisurely activities of older adults (Kowalski et al., 2019; Pradhan et al., 2020; Kim, 2021; Song et al., 2022; Werner et al., 2023). However, within VAs utilization, certain predicaments came to the forefront. Concerns about the privacy and security of financial information and recorded dialogues emerged (Bonilla and Martin-Hammond, 2020; Pradhan et al., 2020; Kim, 2021; Song et al., 2022; Werner et al., 2023). Additionally, challenges related to voice recognition were documented, including instances of speech misrecognition, difficulties in recalling specific commands, and issues with device response timing (Kowalski et al., 2019; Pradhan et al., 2020; Kim, 2021; Werner et al., 2023). Some older adults also believed VAs had not exhibited significant advantages and failed to demonstrate any discernible utility (Trajkova and Martin-Hammond, 2020; Kim, 2021).

Further research has delved into the impact of personal characteristics of older adults on the acceptance of VAs. Trajkova and Martin-Hammond (2020) found that many older adults refrained from using Echo. This avoidance was rooted in their belief in their ability to complete tasks independently. They hold a deep appreciation for this autonomy, potentially earmarking the adoption of such technology for a period when their physical state experiences a decline. Moreover, a lack of pertinent knowledge regarding VAs among the elderly may also engender difficulties in their utilization (Pradhan et al., 2020; Kim, 2021; Werner et al., 2023). Lastly, Song et al. (2022) have posited that self-efficacy might indirectly influence the acceptance of VAs among the elderly.

3 The current study

Previous studies have demonstrated the factors that promote or hinder older adults' acceptance of VAs, primarily focusing on the characteristics of VA products, as well as older adults' knowledge, experience, and physical condition as personal characteristics. DRTC and technological self-efficacy may have a stronger impact on older adults' acceptance of technology (Chen and Chan, 2014; Touchaei and Hashim, 2023; Werner et al., 2023), but have been overlooked in the investigation of VAs' acceptance. Therefore, it is necessary to further explore whether there are additional potential factors influencing the acceptance of VAs among older adults.

Moreover, to our understanding, most studies on the acceptance of VAs by older adults have relied on a single method. Except for Song et al. (2022), who used a questionnaire, current research has predominantly used qualitative methods to understand the viewpoints of the elderly towards VAs (Kowalski et al., 2019; Pradhan et al., 2020; Kim, 2021; Werner et al., 2023). However, the qualitative method has limitations, such as subjectivity, small sample sizes, and the inability to explore relationships between variables thoroughly. Further quantitative methods based on qualitative methods are an effective approach to remedy this limitation. Moreover, cross-validation between these two methods can enhance the credibility and accuracy of the research results, thereby bolstering the study's robustness and comprehensiveness.

Besides, COVID-19 may have also altered the attitudes of older adults towards digital technology. While previous research has indicated that privacy concerns can hinder the adoption of VAs among older adults (Bonilla and Martin-Hammond, 2020; Pradhan et al., 2020; Kim, 2021; Song et al., 2022; Werner et al., 2023), the ongoing stress caused by the pandemic has highlighted the potential of VAs to support independent living and help older adults cope with the pressures brought by COVID-19 (Carstensen et al., 2020; Werner et al., 2023). This may lead older adults to prioritize the benefits of adopting VAs over privacy concerns, a trade-off that could extend into the post-COVID-19 era. Furthermore, factors such as perceived ease of use and self-efficacy in using VAs have been found to play a crucial role in the acceptance of VAs by older adults (Song et al., 2022). However, the COVID-19 pandemic has accelerated the adoption of digital technology among older adults (Diehl et al., 2022), potentially impacting the influence of perceived ease of use and self-efficacy on behavioral intentions regarding VAs adoption (Kim and Choudhury, 2021). Therefore, it is necessary to re-examine the impact of these factors on the acceptance of VAs.

To address these research gaps, we propose the following approach. First, we will extract factors influencing the acceptance of VAs among older adults from existing literature and theories and develop a preliminary model. Second, we will conduct semi-structured interviews to explore further the factors influencing the acceptance of VAs among older adults. Lastly, we will incorporate the newly emerged factors from the interviews into the preliminary model and employ partial least squares structural equation modeling (PLS-SEM) to determine the mechanisms influencing the acceptance of VAs among older adults. The research process is illustrated in Figure 1.

4 Preliminary hypothesis development

Based on existing literature, we propose a preliminary model that extends TAM with the addition of relevant constructs specific to VAs (i.e., perceived enjoyment, value barrier, and perceived trust) (Nguyen et al., 2018; Trajkova and Martin-Hammond, 2020) and older adults (i.e., technological self-efficacy) (Chen and Chan, 2014).

Perceived trust and self-efficacy are unique characteristics of VAs and have been widely used as standard metrics for measuring experience in VAs research (Kim and Choudhury, 2021; Song et al., 2022). Value barrier also has been repeatedly mentioned in

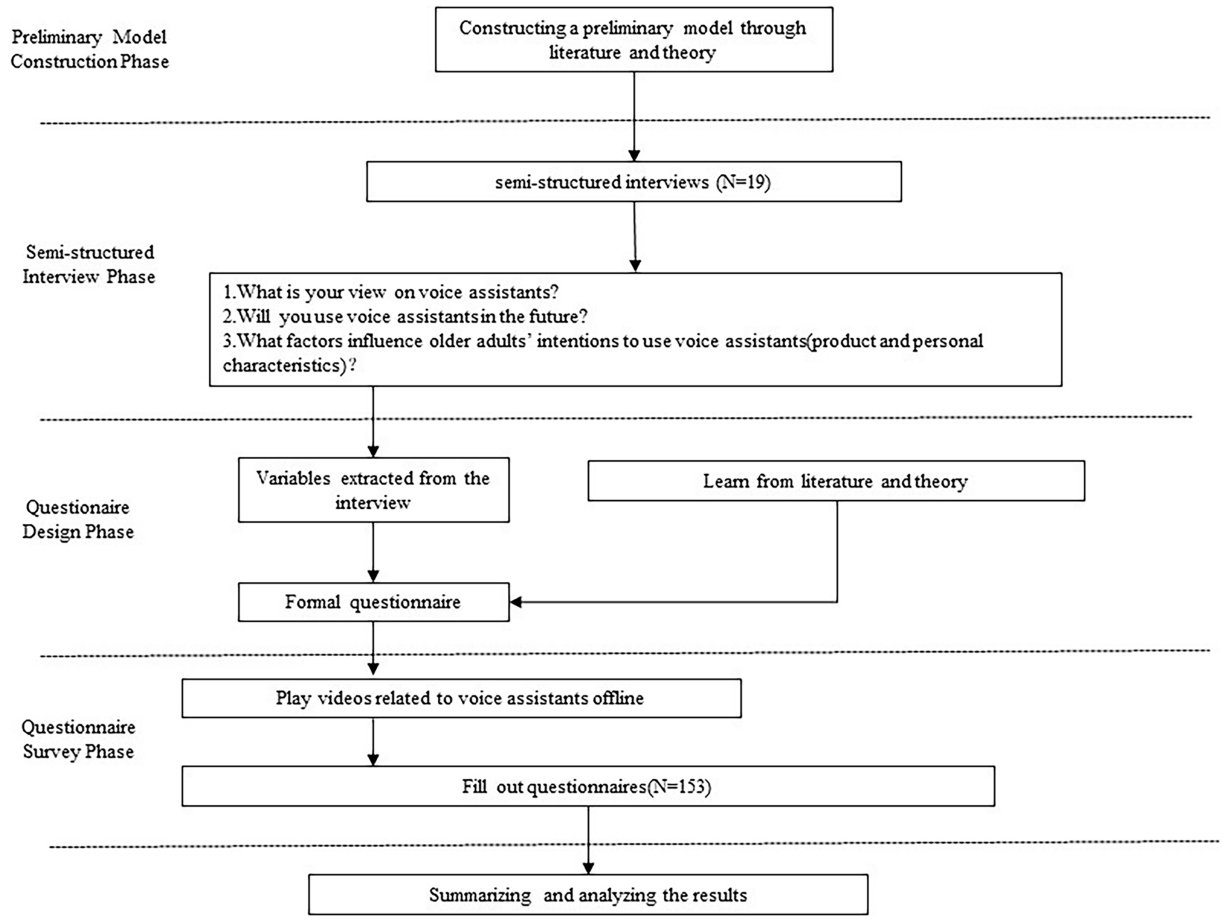

FIGURE 1
Research process of current study.

interview-based studies on older adults' perspectives on VAs (Trajkova and Martin-Hammond, 2020; Kim and Choudhury, 2021). Perceived enjoyment is also a relevant and unique factor for VAs, and has been explored among younger age groups (Nguyen et al., 2018).

4.1 Perceived usefulness, perceived ease of use, and behavioral intention

Perceived usefulness and perceived ease of use are determinants in TAM, widely used in exploring technology acceptance among older adults. Meta-analyses have shown positive effects of perceived usefulness and perceived ease of use on behavioral intention (Zhou et al., 2020; Ma et al., 2021). Previous studies have extensively considered the influence of perceived usefulness and perceived ease of use on VAs acceptance (Nguyen et al., 2018; Song et al., 2022; Zhong et al., 2022). Given the significant advantages of VAs compared to other technologies, such as natural and simple interactions that can support independent living among older adults (Song et al., 2022), we expect that the practical benefits and convenience will positively influence older adults' behavioral intention to use VAs. Furthermore, the similarity between interactions with VAs and interpersonal dialogues in daily life enables older adults to learn intuitively, and effortless learning can further enhance users' perceived usefulness. Previous research has already demonstrated the positive relationship between perceived ease of use and perceived usefulness in the context of VAs (Nguyen et al., 2018; Song et al., 2022). Therefore, the following hypotheses are proposed:

> *H1*: Perceived usefulness positively affects behavioral intention.
>
> *H2*: Perceived ease of use positively affects behavioral intention.
>
> *H3*: Perceived ease of use positively affects perceived usefulness.

4.2 Perceived enjoyment

Perceived enjoyment refers to the extent to which older adults perceive using VAs as entertaining and delightful, besides any expected performance outcomes (Davis et al., 1992; Nguyen et al., 2018). Empirical evidence from the research indicates that PE is one of the main reasons why mobile users access VAs (Nguyen et al., 2018). Hassenzahl (2018) also suggests that products should consider both utilitarian value and hedonic value, as the combination of these values better reflects the beneficial characteristics of the product. Therefore, in addition to perceived usefulness and perceived ease of use, Perceived enjoyment becomes another significant driving factor explaining behavioral intention in our comprehensive model. We propose the following hypothesis:

H4: Perceived enjoyment positively influences behavioral intention.

4.3 Value barrier

According to Ram and Sheth (1989), in this study, value barrier refers to the evaluation of value that older adults assign to VAs and their alternatives. Consumers typically use their current products as reference points. Suppose a new product does not offer more excellent value than the reference point, in that case, they are less likely to consider switching to an alternative because the perceived drawbacks of changing from the existing norm seem to outweigh the benefits (Leong et al., 2021). Trajkova and Martin-Hammond (2020) found that the main reason older adults discontinued using VAs was their difficulty finding valuable uses. Several studies have indicated that value barrier had a negative impact on behavioral intention in various contexts, including online shopping (Lian and Yen, 2014), mobile commerce (Moorthy et al., 2017), mobile banking (Laukkanen, 2016), and mobile payment systems (Kaur et al., 2020). Furthermore, when consumers attempt to assess the value difference between innovative and existing products, they consider various alternatives to accomplish their tasks, and the functions of VAs can also be replaced by other mediums (Trajkova and Martin-Hammond, 2020). This may also affect the perceived usefulness of VAs. Therefore, we propose the following hypotheses:

H5: Value barrier negatively influences behavioral intention.

H6: Value barrier negatively influences perceived usefulness.

4.4 Perceived trust

Trust is a significant factor influencing users' adoption of technology. Security concerns, privacy risks, and distrust are common reasons for digitally disengaging, mainly in web-based digital technologies (Kebede et al., 2022). VAs must record users' voice commands and daily speech to respond effectively, which may lead users to perceive more risks than other technologies (Song et al., 2022). In this case, trust helps alleviate users' concerns about sharing and potentially misusing their personal information (Nguyen et al., 2018). Therefore, we propose the following hypothesis:

H7: Perceived trust positively influences behavioral intention.

4.5 Technological self-efficacy

According to Chen and Chan (2014), in this study, technological self-efficacy refers to the belief of older adults in their ability to use VAs successfully. Contrary to a widespread belief or marketing claim that interacting with VAs is effortless due to their conversational capabilities, most participants found it challenging to engage in a smooth conversation with the technology (Kim, 2021). Furthermore, older adults face additional challenges in using VAs due to their lack of similar technological upbringing as younger generations (Charness and Boot, 2022) and age-related declines in physiological and cognitive functions (Kim, 2021).

The social cognitive theory posits that a heightened level of self-efficacy can enhance cognitive processes (Bandura, 1995). For older adults, a strong sense of self-efficacy can help them maintain a positive and proactive outlook. When faced with challenges in using VAs, old adults with high self-efficacy are more likely to approach the situation optimistically and proactively rather than dwelling on the difficulties. Werner et al. (2023) found that older adults who proactively initiate the use of VAs may believe in their ability to interact successfully with VAs, while those who do not initiate such usage may lack the same level of confidence. Numerous studies have also revealed a direct positive correlation between self-efficacy, perceived ease of use, and behavioral intention (Song et al., 2022; Zhu and Cheng, 2022). Therefore, we propose the following hypotheses:

H8: Technological self-efficacy positively influences perceived ease of use.

H9: Technological self-efficacy positively influences behavioral intention.

Based on the above, the preliminary research model is illustrated in Figure 2.

5 Study 1: semi-structured interviews

The aim of the semi-structured interviews was to explore further the factors influencing the acceptance of VAs among older adults and validate the preliminary model.

5.1 Participants

For practicality and accessibility, we collaborated with Tianjin communities using convenient sampling to recruit participants. A total of 19 participants (10 females), with a mean age of 71.68 and an age range of 61–80, were recruited to participate in the semi-structured interviews. All older adults signed an informed consent form and completed the Mini-Mental State Examination (MMSE) cognitive test (Folstein et al., 1975). The total score range of the MMSE scale is 0 to 30 points. With test scores influenced by cultural background, normal cutoff values are as follows: for illiterate individuals, the cutoff is >17 points; for those with primary education, the cutoff is >20 points; and for those with junior high school education or higher, the cutoff is >24 points. The participants were selected based on three criteria: normal cognition, age over 60 years, and experience using smart devices such as smartphones, tablets, smartwatches, and smart speakers. We aimed to include both current and potential users of VAs, and prior experience with smart devices was a prerequisite for using VAs (Song et al., 2022).

5.2 Procedure

Considering that older adults may be unfamiliar with VAs and have difficulties understanding the technology, the interviewers played

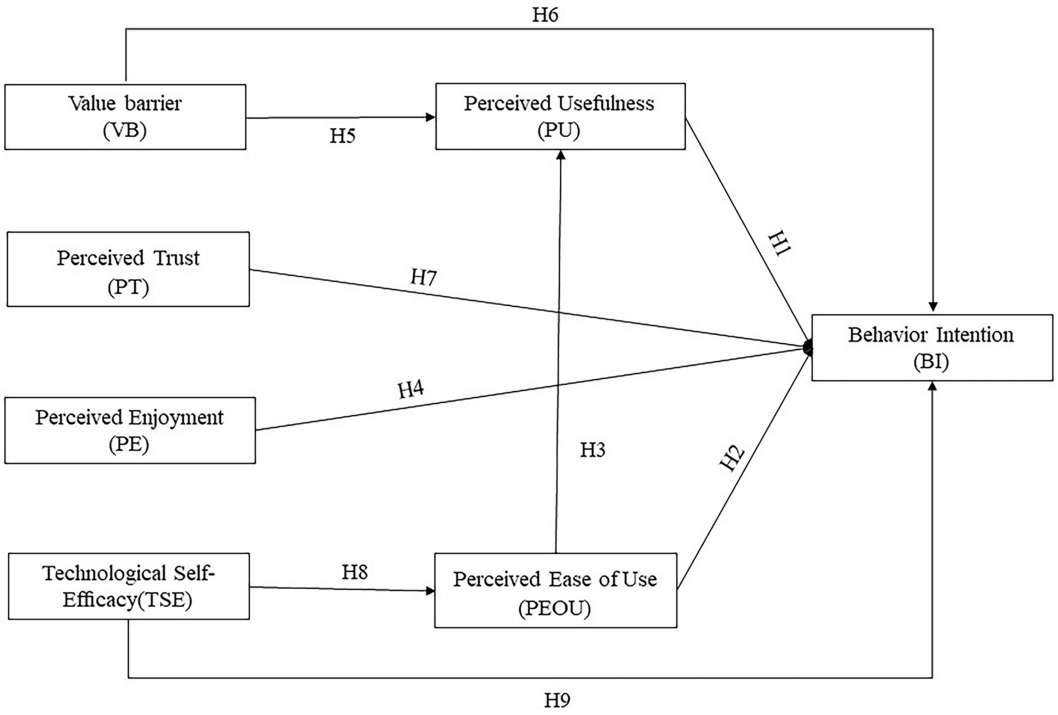

FIGURE 2
The preliminary model of current study.

a series of videos demonstrating the functions of VAs (such as setting reminders, searching for information, controlling home appliances, etc.). Additionally, the interviewers used Tmall Genie Cube Sugar (a widely used smart speaker in China with no secondary modality) for the demonstration. Each elderly participant engaged in a conversation with the smart speaker to gain an understanding of VAs. The interviewer provided explanations to participants if they had any areas of unfamiliarity. Once all participants clearly understood the functionalities of VAs, the interviews began. The interviews were concluded when the information obtained from the participants reached saturation (Braun and Clarke, 2006).

The interview outline consisted of three aspects:

1. What do you think of VAs?
2. Will you use VAs in the future?
3. What factors influence older adults' intentions to use VAs (product characteristics and personal characteristics)?

All interviews were audio-recorded and transcribed. To ensure the accuracy and consistency of the transcribed text with the interview results, researchers used the recordings to verify the transcribed results.

5.3 Data analysis

The interview data were analyzed using thematic analysis, following open, axial, and selective coding (Braun and Clarke, 2006). The first author continuously discussed the emerging themes with another author until the data reached saturation with repeated themes, and no new information emerged.

1. Open coding: The textual data was broken down into meaningful units (words, phrases, or sentences), and these dissected units were categorized and classified to form initial codes.
2. Axial coding: The codes obtained from open coding were further refined, adjusted, and grouped based on their similarities or connections. Similar or related codes were merged, and the underlying relationships between codes were clarified and organized through constant comparison, resulting in the development of categories.
3. Selective coding: At a more abstract level, the data from axial coding were further processed. The developed categories were consolidated and interconnected to explain the overarching themes and provide a comprehensive understanding of the data.

Through this rigorous analysis, the thematic analysis allowed for a systematic exploration and interpretation of the interview data.

5.4 Results

This research encompasses 121 reference points (i.e., meaningful units) extracted to obtain 14 relatively independent initial concepts. Subsequently, centered around the core concept of factors influencing older adults' acceptance of VAs, the 14 initial concepts were compared and categorized into seven distinct categories. Table 1 displays the initial concepts obtained through open coding and the categories formed by axial coding. Due to space constraints, only one reference point for each initial concept was shown here.

TABLE 1 Open coding and categorization.

Category	Original data	Initial codes [reference points]
Perceived privacy and security risks	5: I'm concerned about voice assistants stealing information about my financial accounts as well as my assets.	Worrying about security risks [2]
	7: The risk is okay; I also have no privacy.	Ignoring risks [6]
No or low confidence in using smart voice products	2: I do not want to use VAs because the senior citizens are too old to learn intelligent products.	Older adults lack confidence to utilize smart device. [10]
	6: I received guidance from others, but after a period of time, I would forget, and despite their attempts to teach me, I still could not grasp it.	Learning smart products with the assistance of others can also be quite challenging [8]
Perceived limited value compared to other mediums	8: Because now functions of VAs can be dispensable for the elderly.	Functionality is dispensable [8]
	11: The information from iPad is enough; the smart speaker is just a speaker.	There are other ways to substitute [15]
Perceived benefits for supporting independent living for older adults	5: VAs can help me find the phone, play the weather forecast, and sing a piece of opera for me; quite convenient.	The features such as companionship, entertainment, and living support are suitable for the elderly [13]
	17: How convenient and simple VAs are, very convenient for the elderly.	Voice assistants are suitable for the elderly [9]
Easy to use overall, but older adults still have difficulty using it	19: Tmall Genie is relatively simple to use; it will play what I want to listen.	Perceive that the process of using voice assistants is simple [14]
	7: We still have problems speaking Mandarin. VAs did not understand. I just said 11:20. VAs heard it as 2:00. Recognizing accent correctly is very important.	Troubled by the structured conversations and dialects that cannot be recognized [9]
Seeking comfort and stability, resisting change	10: Our generation finds it challenging to embrace new things and often tends to stick with established life habits.	Older adults tend to maintain the status quo [12]
	12: In my daily work and life, I tend to be more conservative, and I gradually accept many things over time.	Resist changes in life [7]
Perceived enjoyable	7: The process of using voice assistant makes me feel quite happy.	Content with the voice assistants experience
	18: I like to use simple products. The use of VAs makes me happy.	Easy to use makes the older adults feel happy [3]

Finally, this study consolidates the developed categories and constructs that influence older adults' acceptance of VAs into two themes: personal characteristics and VA product characteristics. These themes and connected categories were illustrated in Figure 3.

5.5 Summary and discussion

The results of the semi-structured interviews revealed factors influencing the usage of VAs among older adults can be categorized into two aspects: VA product characteristics and personal characteristics of older adults. We aligned the themes identified through thematic analysis with existing variables, ultimately determined that VA product characteristics including perceived usefulness, perceived ease of use, perceived enjoyment, value barrier, and perceived trust, while the personal characteristics including technological self-efficacy and dispositional resistance to change.

5.5.1 Product characteristics that could influence the usage of VAs among old adults

Regarding VA product characteristics, the interviews revealed that most older adults exhibited a positive attitude towards VAs, considering them as natural and straightforward interactions that support daily living and enable older adults to live more independently. The ease of activation through wake-up words or physical buttons on the devices makes VAs accessible to older adults, lowering the barriers to their usage. These results indicated perceived usefulness and ease of use were common factors influencing older adults' acceptance of VAs, which aligns with previous research findings (Song et al., 2022; Werner et al., 2023). However, some barriers affected the perceived usefulness and ease of use for older adults. For instance, short listening times of VAs, structured question-and-answer approaches, and limitations in speech recognition quality for users with accents could hinder the perceived usability. Additionally, many participants tended to compare VAs with other means of assistance, sometimes perceiving their value as optional. This is consistent with findings from Trajkova and Martin-Hammond (2020), who observed a high churn rate of VAs among older adults due to the lack of perceived utility. These results support hypotheses H1, H2, H5, and H6.

Similarly, consistent with the findings of Kim (2021), the interviews also demonstrated that older adults had concerns about privacy and security risks related to VAs. These concerns were associated with the continuous listening capability of VAs in private spaces like homes. Furthermore, participants worried that others could easily access their personal information by conversing with VAs. Among these risks, financial security was perceived as a more profound concern for some old adults when using VAs. However, some users believed that the security risks posed by VAs could be disregarded. One reason for this belief was cognitive bias, where they were unaware of the risks of using VAs. Additionally, some users were not concerned about the risks due to their usage patterns, as they believed they would not engage in conversations that involved sensitive information. This finding partially supports hypothesis H7.

On the other hand, the interviews revealed that some older adults expressed pleasure and delight in using VAs due to their simplicity, which aligns with previous research findings. Akdim et al. (2022) found that when users perceive virtual communities have humanized interfaces, the perceived enjoyment is enhanced, which could encourage continued engagement. Emotional needs continue to grow with aging. The interaction of VAs, which are naturally simple and

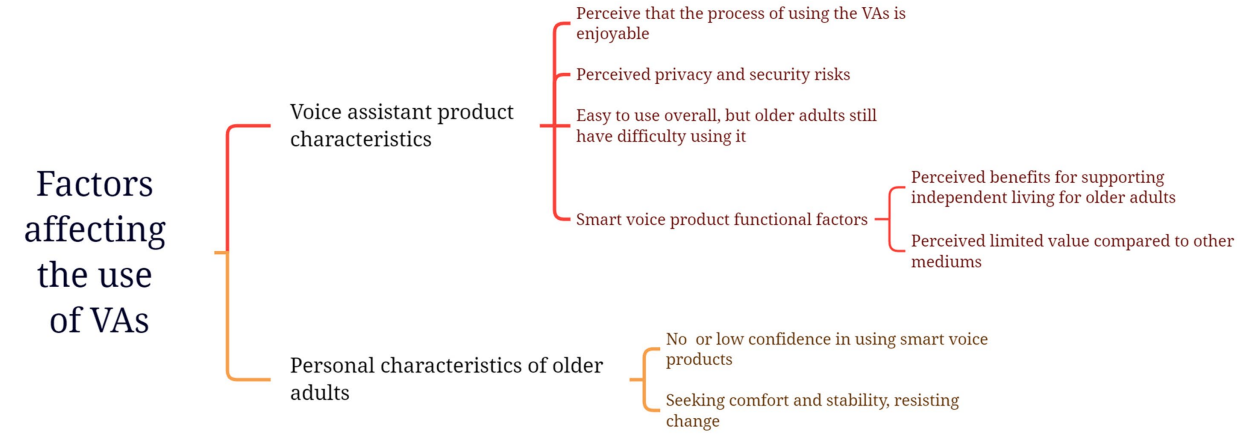

FIGURE 3
Categories influencing older adults' acceptance of VAs.

create a relaxed atmosphere, meet the emotional needs of older adults and may influence perceived usefulness. Therefore, we add the following hypotheses:

> *H10*: Perceived ease of use positively influences perceived enjoyment.
>
> *H11*: Perceived enjoyment positively influences perceived usefulness.

5.5.2 Personal characteristics that could influence the usage of VAs among old adults

Regarding the personal characteristics of older adults, the interviews revealed that the belief in their ability to use VAs successfully may directly influence their usage behavior. If older adults perceive themselves as lacking the capability to use VAs, they might be more inclined to give up on using them. Werner et al. (2023) also found that older adults who willingly use VAs likely have a higher level of confidence in their ability to interact successfully with VAs, while those who do not use VAs may lack the same level of confidence. This finding supports hypothesis H9.

Furthermore, the interviews revealed that older adults tend to find contentment in their existing comfort or stability and are often hesitant to explore unfamiliar environments or adopt new technologies. Many older adults cited this as a reason for their refusal to use VAs. It is inherent in human nature to cling to established habits rather than embracing change and venturing into unknown territories (Mazar and Wood, 2022). In extensive research on resistance to change and individual differences, Oreg (2003) proposed that this pursuit of comfort, stability, and resistance to change is not merely a situational behavior but a fundamental personality trait. Some scholars have emphasized the significance of the DRTC in technology adoption, but its impact has not been thoroughly addressed in IT adoption literature, necessitating further investigation (Mzoughi and M'Sallem, 2013; Touchaei and Hashim, 2023). Currently, DRTC has not received attention in the context of VAs. This study considers DRTC a potential barrier for older adults in adopting VAs, as it can influence their value assessment and usage intention towards VAs. Therefore, we add the following hypotheses:

> *H12*: DRTC positively influences the value barrier.
>
> *H13*: DRTC negatively influences behavioral intention.

Our research has yielded valuable insights that were previously overlooked by using semi-structured interviews. One such example is the ease of use that typifies VAs. The interviews revealed that ease of use can be a source of pleasure for older individuals and also enhances their perception of the usefulness of VAs. Furthermore, our findings indicated that a predisposition to resist innovation can impact the acceptance of VAs among older adults. Consequently, we have incorporated hypotheses H10 to H13 into the original model, resulting in the final hypothesis model depicted in Figure 4.

6 Study 2: questionnaire survey

To test the proposed model for older adults' acceptance of VAs, a survey was designed and conducted. Data analyses were conducted using partial least squares structural equation modeling (PLS-SEM).

6.1 Participants

The selection criteria and participant recruitment process were consistent with Study 1. A total of 154 individuals aged 60 and above were recruited. Among them, 153 participants (Mean age = 70.08, SD = 5.19, 60.1% female) were included in the study. The characteristics of the participants are shown in Table 2. Participants' experience with VAs can be found in Table 3.

6.2 Questionnaire survey methodology

6.2.1 Research design

We employed a quantitative approach using structured questionnaires to investigate the impact factors of older adults' intentions to use VAs. The questionnaire completion process involved

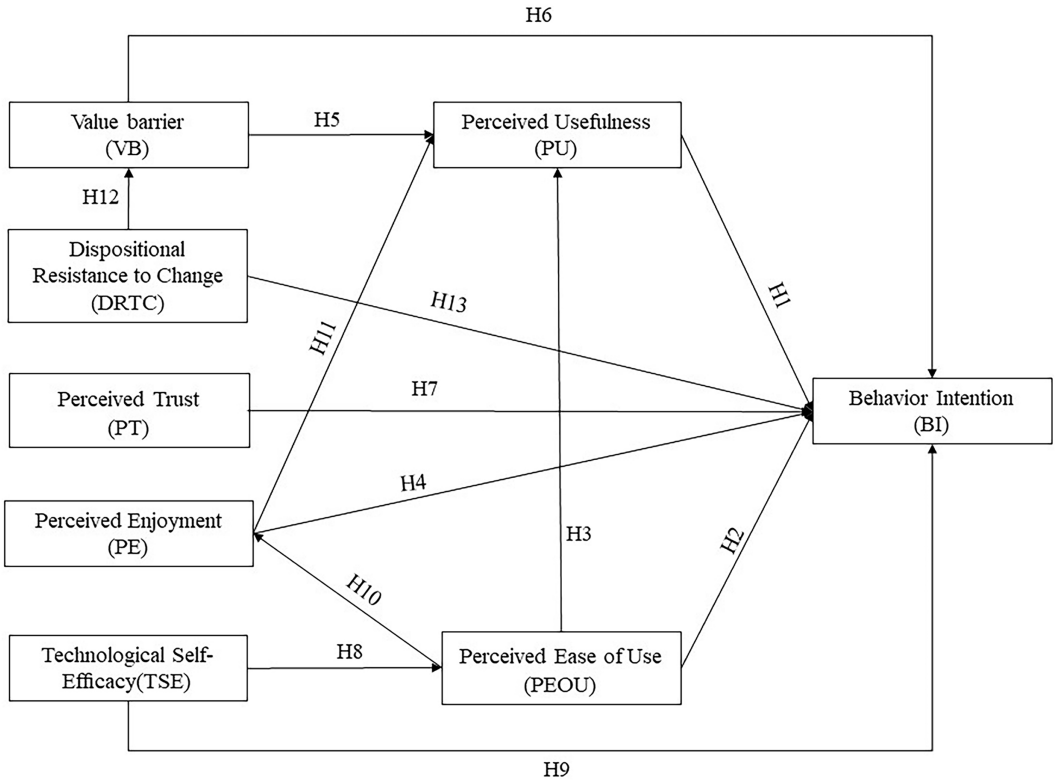

FIGURE 4
The final hypothesis model of current study.

face-to-face interviews to facilitate synchronous communication between the interviewer and the older adults while completing the questionnaire. The accuracy of responses was verified by repeating the participants' answers, which took approximately 30 min each participant. To ensure consistency in the survey, the interviews were conducted by the same experienced researcher. The questionnaire data was entered by two well-trained researchers and cross-checked upon completion.

6.2.2 Measurement development

The survey questionnaire for this study included the variables related to acceptance of VAs and demographic information. Table 4 presents the items related to the acceptance of VAs and its' impact factors used in the current study. All the variables and indicators in the questionnaire were measured by a seven-point Likert scale ranging from 1 (strongly disagree) to 7 (strongly agree).

6.2.3 Procedures

Given the potential unfamiliarity of the elderly with VAs, an introductory session was conducted before participants completed the questionnaire, following a similar approach as in Study 1.Older adults who completed the experiment were rewarded with a 30 yuan monetary incentive.

6.3 Data analysis

This study used the PLS-SEM approach for data analysis. The measurement model and structural model were analyzed using Smart PLS 3.3.9. PLS-SEM is selected due to its minimal sample size requirements, which are determined by the greater of the following two criteria: (1) ten times the maximum number of formative indicators employed to measure a single construct, or (2) ten times the maximum number of structural paths directed towards a specific latent construct within the structural model. It is suitable for analyzing complex structural equations with multiple latent variables and related items and is applicable for exploratory and predictive models in research and data analysis (Hair et al., 2017). PLS-SEM is widely used in various social sciences and related disciplines (Hair et al., 2019) and has been employed in TAM studies (Sagnier et al., 2020; Xu et al., 2023). As recommended, the data analysis was conducted in two stages. Firstly, we assessed the internal consistency, the convergent validity, and the discriminant validity of the measurement model (Hair et al., 2021). While it is unnecessary to report fit metrics, we reported the Standardized Root Mean Square Residual (SRMR), which is considered useful in detecting model misspecification (Xu et al., 2023). Secondly, following satisfactory results in the first stage, we proceeded with the structural model to test our hypotheses.

6.4 Results

6.4.1 Measurement model assessment

Composite Reliability (CR) and Cronbach's alpha assessed the internal consistency reliability. The combined performance of these two indicators objectively determines the internal quality of the constructed measurement model. Following the standards proposed by Hair et al. (2011), the minimum threshold for both indicators is set

TABLE 2 Characteristics of participants ($N = 153$).

Characteristics	Item	Frequency	Percentage
Gender	Male	61	39.90
	Female	92	60.10
Age	60–64	20	13.10
	65–69	51	33.30
	70–74	52	34.00
	≥75	30	19.60
Living arrangement	With family member(s)	127	83.00
	Living alone	26	17.00
Marital status	Married	129	84.30
	Divorced/ separated	16	10.50
	Widowed	6	3.90
	Never married	2	1.30
Education level	Elementary	4	2.60
	Middle school	41	26.80
	High school	42	27.50
	University and above	66	43.10
Income	<2000 yuan	4	2.60
	2000–4,000 yuan	59	38.60
	4,000–6,000 yuan	37	24.20
	6,000–8,000 yuan	34	22.20
	8,000–10,000 yuan	15	9.80
	>10,000 yuan	4	2.60
Smart voice assistant usage frequency	Non-user	99	64.70
	Occasional user	26	17.00
	General user	12	7.80
	Frequent user	10	6.50
	Very frequent user	6	3.90

TABLE 3 Frequency of specific use of participants with voice assistants using experience ($N = 54$).

Specific use	Frequency	Percentage
Listen to music, opera, radio, etc.	54	100
Checking the weather	26	48.10
Daily conversation	19	35.20
Set reminders	18	33.30
Search for information	14	25.90
Control home appliances	13	24.10
Find phone	7	12.90
Other	3	5.60

at 0.7. As shown in Table 5, all CR values are above 0.8, and all Cronbach's alpha values are above 0.7.

Convergent validity was evaluated by average variance extracted (AVE) and items outer loading. All latent variables, each consisting of three or more items, have standardized factor loadings greater than 0.7, and the AVE values for all latent variables are above 0.5, indicating high convergent validity of the measurement items in this study (Hair et al., 2021).

To assess discriminant validity, we used the Fornell-Larcker criterion and the HTMT values. Based on the Fornell-Larcker criterion, the bold values on the diagonal represent the square root of the AVE for each latent variable, and the values in the lower half of the diagonal represent the correlations between each latent variable and other latent variables. In this case, all AVE values were more significant than correlations with other constructs, and the HTMT values were less than 0.85 for all the constructs, confirming that the model has satisfactory discriminant validity (Hair et al., 2021). Table 5 presents the factor loadings and AVE values for all the constructs. Tables 6, 7 provide the AVE square root on the diagonal and the correlations among constructs and the HTMT results, respectively.

Moreover, the estimated SRMR value for the model in this study is 0.06, which is below the threshold of 0.08 (Hu and Bentler, 1999; Kline, 2023). This indicates that the model is acceptable in terms of model fit.

6.4.2 Structural model assessment

Before assessing the inner structural model, common method bias, each construct's multicollinearity test, model fit evaluation, and descriptive statistics were calculated. To examine whether common method bias was present in our data, we employed Harman's single-factor test. The highest eigenvalue corresponded to the first component, which accounted for 0.396 of the variances. This falls below the established threshold of 0.4 (Podsakoff et al., 2003), indicating that common method bias was not a significant concern in our study. Multicollinearity was assessed using variance inflation factors (VIF). The results showed that VIF values of all constructs ranged from 1.000 to 1.944, well below the threshold of 5.0 (Hair et al., 2016), indicating the absence of multicollinearity.

We used bootstrapping to test the relationships hypothesized in our model. Path significance was tested using a bootstrapping technique for the 153 cases with 5,000 samples (Hair et al., 2011). Table 8 lists all path coefficients and their significance. To assess the predictive strength of the model, we reported R^2 values for each endogenous variable. As a rule of thumb, we followed (Hair et al., 2011) to report the R^2 values where R^2 of 0.25, 0.50, and 0.75 are considered weak, moderate, and substantial, respectively. Results suggest that our model can explain 67.4% of the variance in behavioral intention (moderate), 27.3% of the variance in perceived usefulness (moderate), 23.8% of the variance in perceived ease of use (weak), 20.7% of the variance in perceived enjoyment (weak), and 12.0% of the variance in value barrier (weak). These R2 values are comparable to those reported in the literature (Xu et al., 2023).

According to the path analysis, perceived usefulness, perceived enjoyment, and technological self-efficacy positively influenced behavioral intention. DRTC had a negative impact on behavioral intention. However, the effects of perceived ease of use, value barrier, and perceived trust on behavioral intention were not significant. This means that H1, H4, H9, and H13 are supported, while H2, H6, and

TABLE 4 Constructs and measurements.

Construct	Measurement item		References
Behavior Intention (BI)	BI1	I am interested in using VAs	Davis (1989); Li et al. (2019)
	BI2	Using VAs is a good idea.	
	BI3	I intend to use VAs in the future.	
Perceived Enjoyment (PE)	PE1	I think VAs are attractive	Nguyen et al. (2018)
	PE2	I think it is fun to use VAs.	
	PE3	I find using VAs enjoyable.	
Perceived Ease of Use (PEOU)	PEOU1	I think it is relatively easy to use VAs	Chen and Chan (2014); Davis (1989)
	PEOU2	I feel that I can use the VAs skillfully.	
	PEOU3	I feel that the process of interacting with the VAs is straightforward and easy to understand	
Perceived Usefulness (PU)	PU1	I feel that the VAs can provide me with help	Chen and Chan (2014); Davis (1989)
	PU2	I feel that using VAs makes life more convenient.	
	PU3	I think VAs are very useful in life.	
	PU4	I think using VAs can make my life easier.	
Technological Self-Efficacy (TSE)	TSE1	I think I can master using VAs by learning it myself	Chen and Chan (2014)
	TSE2	I think I can complete the operation of VAs with the help of others.	
	TSE3	By reading the manual, I feel confident about using VAs.	
	TSE4	I can learn to use VAs if I put in the effort.	
Value barrier (VB)	VB1	VAs do not have significant advantages over other mediums	Lee and Kim (2022); Trajkova and Martin-Hammond (2020)
	VB2	It was difficult to find uses for VAs that were essential to daily.	
	VB3	It is more convenient to get information through other mediums rather than VAs.	
	VB4	If I can choose other mediums, I will use other mediums to do the same thing.	
Perceived Trust (TR)	TR1	I believe my information is safe when I use VAs	Nguyen et al. (2018)
	TR2	I do not think there is a privacy risk when using VAs.	
	TR3	I do not think I will be fooled by using VAs.	
Dispositional Resistance to Change (DRTC)	DRTC1	I generally consider changes to be a negative thing.	Oreg (2003)
	DRTC2	When things do not go according to plan, it stresses me out.	
	DRTC3	I sometimes find myself avoiding changes that I know will benefit me.	
	DRTC4	I do not change my mind easily.	

H7 are not supported. Furthermore, perceived ease of use had a positive influence on perceived usefulness and perceived enjoyment, while perceived enjoyment had a positive influence on perceived usefulness. This means that H3, H10, and H11 are supported. Lastly, technological self-efficacy had a positive influence on perceived ease of use, DRTC had a positive influence on value barrier, while value barrier had a negative impact on perceived usefulness. This means that H5, H8, and H12 are supported. Table 8 and Figure 5 present the results of the hypothesis testing and the structural model, respectively.

7 Conclusion and discussion

This study categorized the factors influencing the acceptance of VAs among older adults into VAs product characteristics and personal characteristics of older adults. Consistent with previous research, it was observed that perceived usefulness, perceived enjoyment, and technological self-efficacy significantly affected behavioral intention (Nguyen et al., 2018; Song et al., 2022; Zhong et al., 2022). However, there were several differences between the model created and the results produced by existing research. Primarily, inconsistencies existed in the research findings. Perceived trust and perceived ease of use were previously identified as significant factors influencing older adults' acceptance of VAs (Kong and Woods, 2018; Kebede et al., 2022; Song et al., 2022). However, our study did not find evidence supporting this. Nonetheless, our model indicated how ease of use influenced the mechanism of older adults' acceptance of VAs. Secondly, our research identified other important factors that influenced older adults' acceptance of voice assistants, such as DRTC, which was not previously highlighted as a significant factor affecting older adults' acceptance of VAs. The following sections explain the results in detail.

7.1 VAs product characteristics

7.1.1 Perceived usefulness, perceived ease of use, and perceived enjoyment

The result showed that perceived usefulness positively influenced behavioral intention, consistent with previous studies on the acceptance of VAs (Song et al., 2022; Zhong et al., 2022), indicating

TABLE 5 Convergent validity and construct reliability of measures.

Constructs	Items	Factor loading	Cronbach's alpha	CR	AVE
Behavior Intention (BI)	BI1	0.949	0.933	0.957	0.882
	BI2	0.947			
	BI3	0.921			
Perceived Enjoyment (PE)	PE1	0.924	0.936	0.959	0.886
	PE2	0.952			
	PE3	0.949			
Perceived Ease of Use (PEOU)	PEOU1	0.877	0.780	0.872	0.695
	PEOU2	0.824			
	PEOU3	0.798			
Perceived Usefulness (PU)	PU1	0.906	0.930	0.950	0.827
	PU2	0.906			
	PU3	0.897			
	PU4	0.928			
Technological Self-Efficacy (SE)	TSE1	0.887	0.908	0.935	0.784
	TSE2	0.865			
	TSE3	0.900			
	TSE4	0.888			
Value barrier (VB)	VB1	0.803	0.839	0.891	0.673
	VB2	0.802			
	VB3	0.816			
	VB4	0.859			
Dispositional Resistance to Change (DRTC)	DRTC1	0.814	0.893	0.926	0.759
	DRTC2	0.857			
	DRTC3	0.916			
	DRTC4	0.894			
Perceived Trust (PT)	TR1	0.918	0.866	0.918	0.788
	TR2	0.882			
	TR3	0.863			

that older adults who perceived the benefits of VAs are more likely to have a higher intention to adopt them. Consequently, older adults may be inclined to embrace VAs due to their perception of VAs as valuable and convenient technologies. Furthermore, results also showed a positive impact of perceived enjoyment on behavioral intention, which was consistent with previous research on VAs (Nguyen et al., 2018; Zhong et al., 2022). As older adults perceive time as limited, they prioritize emotional satisfaction over other goals (Carstensen, 1995), and positive user emotions and experiences contribute to their acceptance of the product. If users experience perceived enjoyment through their interactions, it can lead to an expectation of internal psychological rewards, encouraging them to continue using the technology (Suki and Suki, 2011; Akdim et al., 2022). Moreover, perceived enjoyment positively influenced perceived usefulness, which may be related to fulfilling their emotional needs through positive user experiences. Schlomann et al. (2021) also found that some older adults view smart speakers as social companions, meeting their emotional needs and enhancing their perceived usefulness.

The impact of perceived ease of use on behavioral intention wasn't significant, which contradicts previous studies (Song et al., 2022). However, perceived ease of use had a direct influence on perceived usefulness and perceived enjoyment. This may be because the effect of perceived ease of use on behavioral intention was indirect. In other words, if older adults perceive the natural and simplistic nature of voice interaction, they would consider VAs useful and enjoyable, leading to the intention to use them. VAs possess the distinctive advantage of being easy to use, allowing older adults to use them effectively without any major operational difficulties. While it is not considered a direct factor that influences the intention to use, it does play a significant role in enhancing the user experience including the perceived usefulness and enjoyment. This indicated the crucial role of perceived usefulness and perceived enjoyment in the process of older adults accepting VAs.

7.1.2 Value barrier

Results indicated that value barrier did not directly influence behavioral intention, suggesting that VAs were not perceived as hindrances. This is not considered a barrier because VAs are not complicated and have a humanized interface. However, value barrier negatively impacted perceived usefulness, indicating that if older adults perceived VAs as less valuable compared to existing methods, they might have had doubts about their practicality. The role of value in motivating older adults to adopt new technologies was crucial (Melenhorst et al., 2006). Older adults need to have gained more benefits than the effort required to understand and use VAs to perceive no value barriers.

7.1.3 Perceived trust

The research indicated that perceived trust did not directly influence behavioral intention, but numerous studies found that fear of safety and invasion of privacy were barriers to digital engagement (Fischl et al., 2017; Kong and Woods, 2018; Zambianchi et al., 2019; Kebede et al., 2022). However, privacy calculus theory posits that disclosing personal information is based on a trade-off between perceived privacy risks and perceived benefits of information disclosure (Dinev and Hart, 2006). If the perceived benefits of information disclosure outweigh the perceived risks, users may be willing to disclose personal information despite their privacy concerns. Schomakers and Ziefle (2022) suggested that as long as certain boundaries are not crossed, security-related benefits may outweigh privacy concerns. For older adults, although they are aware that using VAs may lead to a partial loss of privacy due to their real-time listening capabilities, they may still choose to use them due to other features, such as simple and enjoyable interactions, after weighing the trade-offs. Additionally, the COVID-19 pandemic has increased social isolation among older adults, impacting their sense of security at home and their need for support, particularly for those living alone, which may lead them to be more willing to disclose some information to enhance their sense of security (Conroy et al., 2020; Schomakers and Ziefle, 2022).

7.2 Personal characteristics of older adults

7.2.1 Technological self-efficacy

The research findings indicated that technological self-efficacy had a significantly positive impact on perceived ease of use, consistent with previous studies on VAs (Song et al., 2022). Moreover, technological self-efficacy also significantly positively influenced

TABLE 6 Correlation matrix among constructs and square root of AVEs.

	BI	PE	DRTC	PEOU	PU	TSE	PT	VB
BI	**0.939**							
PE	0.658	**0.942**						
DRTC	−0.540	−0.537	**0.871**					
PEOU	0.510	0.455	−0.361	**0.834**				
PU	0.597	0.479	−0.332	0.395	**0.909**			
TSE	0.670	0.499	−0.415	0.488	0.436	**0.885**		
PT	0.458	0.378	−0.322	0.283	0.284	0.375	**0.888**	
VB	−0.403	−0.442	0.347	−0.275	−0.351	−0.255	−0.297	**0.820**

BI, behavior intention; PE, perceived enjoyment; DRTC, dispositional resistance to change; PEOU, perceived ease of use; PU, perceived usefulness; TSE, technological self-efficacy; PT, perceived trust; VB, value barrier. Diagonal values in boldface are the square roots of the AVEs.

TABLE 7 HTMT (heterotrait-monotrait ratio of correlations) results.

	BI	PE	DRTC	PEOU	PU	TSE	PT	VB
BI								
PE	0.701							
DRTC	0.593	0.586						
PEOU	0.593	0.525	0.431					
PU	0.637	0.513	0.365	0.459				
TSE	0.726	0.540	0.461	0.580	0.472			
PT	0.505	0.414	0.363	0.331	0.306	0.417		
VB	0.445	0.489	0.397	0.324	0.380	0.294	0.342	

BI, behavior intention; PE, perceived enjoyment; DRTC, dispositional resistance to change; PEOU, perceived ease of use; PU, perceived usefulness; TSE, technological self-efficacy; PT, perceived trust; VB, value barrier.

TABLE 8 Results of path analysis and hypotheses testing.

Hypotheses		Path coefficient	*T*	*p*	Result
H1	PU → BI	0.233**	2.720	0.007	Supported
H2	PEOU → BI	0.071	1.048	0.295	Not supported
H3	PEOU → PU	0.208*	2.544	0.011	Supported
H4	PE → BI	0.224**	2.977	0.003	Supported
H5	VB → PU	−0.154*	2.177	0.029	Supported
H6	VB → BI	−0.042	0.694	0.488	Not supported
H7	PT → BI	0.114	1.785	0.074	Not supported
H8	TSE → PEOU	0.488***	5.566	<0.001	Supported
H9	TSE → BI	0.311***	3.672	<0.001	Supported
H10	PEOU → PE	0.455***	6.644	<0.001	Supported
H11	PE → PU	0.316**	2.829	0.005	Supported
H12	DRTC → VB	0.347***	4.617	<0.001	Supported
H13	DRTC → BI	−0.136*	2.015	0.044	Supported

BI, behavior intention; PE, perceived enjoyment; DRTC, dispositional resistance to change; PEOU, perceived ease of use; PU, perceived usefulness; TSE, technological self-efficacy; PT, perceived trust; VB, value barrier.
*$p < 0.05$; **$p < 0.05$; ***$p < 0.001$.

behavioral intention, and it was the strongest predictor of older adults' intention to use VAs, suggesting older adults' perception of their capabilities plays a substantial role in the acceptance of VAs. Although this contradicted the conclusions of TAM, which indicated that self-efficacy was not considered as a predictor of behavioral intention (Venkatesh and Bala, 2008), TAM's samples mainly consisted of young individuals, who generally possessed higher levels of self-efficacy in using technology (Czaja et al., 2006). Recent research suggested that older adults' technology usage was more driven by their perception of their abilities than the technological features represented in TAM (Jokisch et al., 2021). This could be attributed to cohort effects, as the current generation of adults has already acquired basic information and communication technology skills daily, leading to a generally higher rate of technology adoption (Charness and Boot, 2022). They have more role models in their social environment who demonstrate beneficial integration of the internet into daily life or provide support in case of technological issues. However, these advantages may not be as prevalent among older adults. As a result, technological self-efficacy emerged as the most influential factor in predicting the acceptance of VAs among older adults, surpassing the significance of perceived usefulness.

7.2.2 Dispositional resistance to change (DRTC)

The result revealed the negative impact of DRTC on behavioral intention, indicating the inhibiting effect of DRTC on seniors' intention to adopt VAs. Devaraj et al. (2008) also suggested that

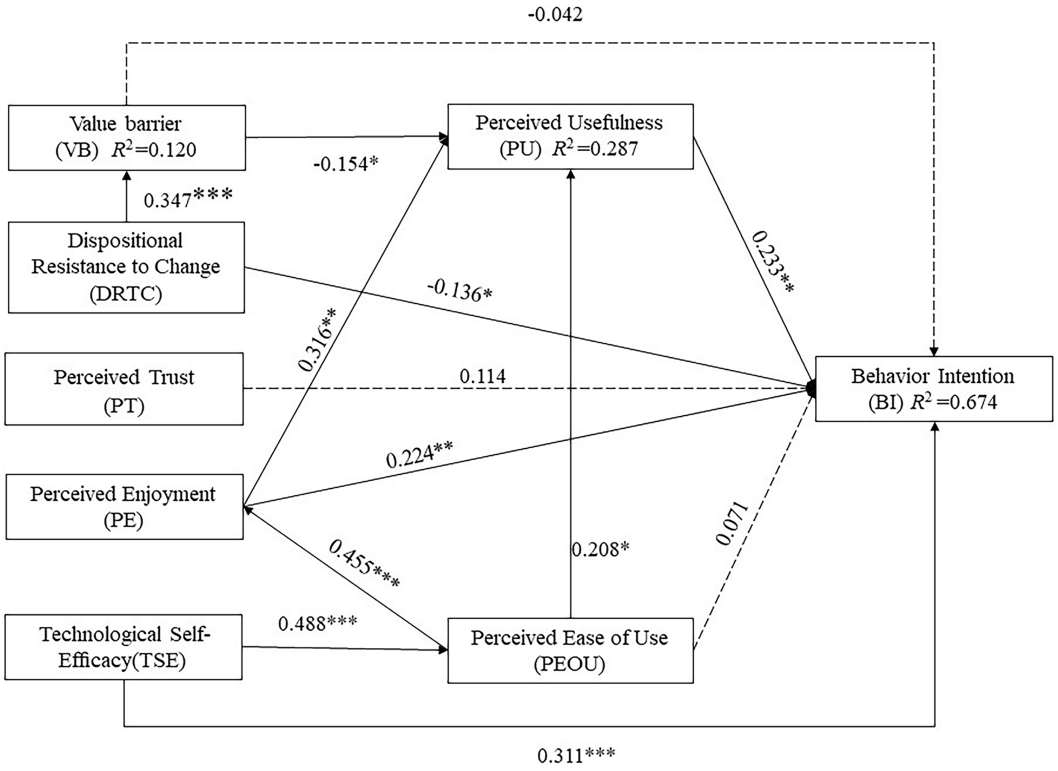

FIGURE 5
Results of the structural model of current study Note: *p<0.05, **p<0.05, ***p<0.001; Three dotted lines indicating non-significant paths were added in making all proposed factors shown in an integral model.

incorporating personality traits into theoretical models can enhance their predictive ability in explaining technology adoption by users. The result of this study could partly explain why some seniors show reluctance in VAs adoption. Since VAs are regarded as an innovation, they may be incompatible with their habits and of little practical use. Furthermore, older adults exhibit a high level of resistance to change and technological innovation (Hoque and Sorwar, 2017), and the tendency to embrace familiarity impedes their experience of VAs.

In addition, DRTC positively influenced value barrier, indicating that older adults with a high inclination towards resisting innovation tend to perceive VAs as less valuable than existing products. This may be because VAs disrupt their traditional way of life. Individuals accustomed to and satisfied with their conventional lifestyle may alter their value assessment of VAs to maintain the status quo and persuade themselves (Talukder et al., 2020).

8 Implications

Over the past decade, VAs have become widespread and integrated into various devices used in various scenarios. The benefits of VAs should be accessible to everyone, especially vulnerable groups like older adults (Song et al., 2022). Initially designed for younger users, research on VAs has paid less attention to the personal characteristics of older adults. However, due to the heterogeneity of their physiological and psychological functions, older adults differ significantly from younger individuals regarding technology acceptance (Kim and Choudhury, 2021). This study identified factors influencing the acceptance of VAs among older adults, contributing to the development of enhanced voice assistants to facilitate the adoption of smart technology among seniors. Moreover, previous research has indicated that VAs support older adults in various domains. They assist in daily health activities, such as health monitoring, medication management, and meal planning, thereby enhancing overall well-being. VAs also serve as social companions to some extent, addressing social isolation and loneliness. By identifying factors influencing older adults' acceptance of VAs, this study sheds light on the social issues faced by this demographic, including social isolation and loneliness, health and well-being concerns, ageism and stereotypes, as well as technology accessibility.

Regarding VA product features, the critical focus of improvement and optimization should be enhancing speech recognition and natural language processing quality. The perceived practicality, ease of use, and enjoyment of VAs depend on speech recognition accuracy and natural language processing capabilities. Specifically, efforts can be made to reduce the impact of environmental noise and user accents on speech recognition. Providing appropriate feedback, such as offering reasons for query failures or suggestions to improve query results, can guide users correctly and enhance the responsiveness of VAs.

Concerning the negative impact of value barrier on perceived usefulness, it is worth noting that smart voice products, such as smart speakers, are not specifically designed for older users, and many of the

functions they need may not be available. Therefore, adding more features suitable for older adults, such as fall detection alerts, medication purchases, and hospital appointment arrangements, can enhance older adults' perception of usefulness.

Furthermore, concerning the positive impact of perceived enjoyment on the use of VAs among older adults, it is essential to consider the prevalent risk of social isolation and susceptibility to feelings of loneliness and depression faced by this vulnerable demographic. Designers should contemplate crafting a unique persona for VAs, which can significantly reduce the psychological distance perceived by older users. Meticulous consideration should be given to creating an ideal personality, encompassing gender, tone, and speaking style. Given that older adults bear a lower cognitive load, employing easily memorable and concise vocabulary, such as "OK" and "got it," can be beneficial (Song et al., 2022). Designers can also endeavor to break free from passive reliance on users' established patterns and actively engage with them. Initiating greetings and informal conversations or increasing interaction during tasks can make the user experience more enjoyable and engaging.

Although trust does not directly influence the acceptance of VAs among older adults, it does not diminish the importance of trust-related concerns to them. Trust considerations may very well be a part of the deliberation process for older individuals. Given that voice data constitutes a common and significant category of information in people's daily lives, designers should prioritize enhancing user data storage and utilization transparency. Providing clear information on how users can access and delete their voice data and offering privacy protection clauses can foster a sense of trust and reassurance among older users.

Regarding the personal characteristics of older adults, this study further reveals that individuals with higher levels of technological self-efficacy demonstrate greater ease of use and willingness to use VAs. When promoting VAs, marketers should adopt different communication strategies for older adults with varying levels of self-efficacy. For those with lower self-efficacy, it is essential to emphasize the ease of use of VAs, particularly highlighting the advantages over traditional interaction methods.

Considering the negative impact of DRTC on behavioral intention, personalized services tailored to their preferences could be implemented. VAs could be designed to learn and adapt to users' interactions in real-time, identifying recurring usage patterns and adapting to individual habits. Allowing users to customize voice output settings, such as speech speed, tone, and intensity, can accommodate the lifestyle preferences of older adults and reduce the influence of DRTC. Furthermore, VAs should possess the capability to operate a wide array of devices, including smartphones, televisions, computers, and such. This expansion of usage scenarios for various applications facilitates the seamless integration of intelligent services into users' lives (Abdolrahmani et al., 2018; Esau et al., 2022), thereby attenuating the impact of DRTC.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. All participants signed an informed consent form.

Author contributions

XC: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Writing – original draft, Writing – review & editing. HZ: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Writing – original draft, Writing – review & editing. BZ: Conceptualization, Data curation, Formal analysis, Methodology, Validation, Writing – review & editing, Investigation. DW: Conceptualization, Project administration, Resources, Supervision, Writing – review & editing, Methodology. CC: Conceptualization, Data curation, Investigation, Writing – review & editing. XB: Conceptualization, Project administration, Resources, Supervision, Writing – original draft, Writing – review & editing, Methodology.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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"Like another human being in the room": a community case study of smart speakers to reduce loneliness in the oldest-old

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This community case study examined the potential benefits of smart speakers to tackle loneliness in the oldest old adults living in supported accommodation. The program was established as a collaboration between the supported accommodation provider and a technology company to explore the feasibility of smart speakers to alleviate resident loneliness. Loneliness in later life often accompanies a shrinking social circle, loss of a spouse or increased disability. People aged 85 years of age and over are increasingly likely to experience these life events, leading to an increased risk of social isolation and loneliness. Five older people, mean age 90 years of age, who resided in supported accommodation, were given a smart speaker for 8 weeks to examine their experience with the voice assistant. The experiences of the five older adults are explored as case studies, with each person interviewed both before and after receiving the smart speaker. All five valued their smart speaker, recognised its potential for tackling loneliness, and wanted to keep it. The three most lonely individuals reported that their smart speaker made them feel less lonely and isolated through two mechanisms: (i) creating a presence and (ii) having some control over their situation. Although only a small study, these experiences suggest providing smart speakers for lonely and isolated oldest-old people, could be one way to help combat loneliness in community settings.

KEYWORDS

social isolation, loneliness, oldest-old people, smart speaker, agency, presence

The problem: loneliness among the oldest-old

The number of "oldest old" (Suzman et al., 1992) people in the UK is rising because of improving standards of living and healthcare. A distinction may be drawn between those older people in the third age and fourth age (Laslett, 1991; Higgs and Gilleard, 2015); the difference is between an older, healthy and productive life in the third age, and illness, disability and need for care and support in the fourth age. Although not determined by chronological age, the third age and fourth age have been associated with the "young-old" (60–70) and "old-old" (after 70) respectively (Baltes, 1998). However, the term oldest old has been variously applied to people over 75 years (Poon and Cohen-Mansfield, 2011), 80 years (Gjonca et al., 2010), and 90 years of age (Dini and Goldring, 2008), with the most widely used definition as 85 years of

age and over (Key and Culliney, 2018), which is the population the current study is concerned with.

In the United States, the oldest old are the fastest growing segment of the over 65 population, with an estimated 6.6 million adults over age 85 in 2019 (Administration for Community Living, 2021). In the UK, the Office of National Statistics (2018) found that the fastest growing older group are the over 85 s; predicting they will constitute 4% of the population by 2041. More recently, the United Nations, Department of Economic and Social Affairs, Population Division (2020) highlighted that the number of over 65 s worldwide will more than double by 2050 after previously predicting there will be 25 million centenarians by 2,100 (United Nations, 2015).

As the number of oldest old has grown, so has the research into this population, with a particular focus on health-related topics (Lund and Wang, 2020). This focus is unsurprising as, for example, hospital and community care costs in the UK, are estimated to be up to three times higher for people over 85 years than those aged 65–74 years (Cracknell, 2010). Factors that influence mental in later life well-being have been studied through analysis of longitudinal datasets and suggest increased vulnerability to depression in the oldest old (Lee et al., 2020) and increased risk of loneliness (Victor et al., 2008). In the UK Newcastle 85+ study, for example, both mild and severe depression (using GDS; Sheikh and Yesavage, 1986) increased the risk of loneliness in the oldest old (Brittain et al., 2017). At entry to the study, 55% of respondents over 85 years of age reported they were often or always alone, with women spending more time alone than men. A recent systematic review of the longitudinal risk factors for loneliness in older adults found several consistent associations with loneliness including depression, partner loss and poor health (Dahlberg et al., 2022).

Recent widowhood and disability accord with the five ways older adults experience loneliness proposed by Clayton (2018): (i) A feeling of loss or sadness triggered in the moment (e.g., by symbolic events such as sitting down to watch TV and realizing a life partner is not there); (ii) a change in identity (e.g., loss of former roles, moving away from familiar community, becoming a caregiver for a family member); (iii) a loss of intimacy and grief (e.g., loss of close personal relationship, often after many years); (iv) reduced choice and control (e.g., over where to live, where to go out); or (v) poor health and disadvantage (e.g., physical, and mental deterioration, lack of mobility), all factors mentioned in studies of the oldest-old.

Additionally, the UK Understanding Society Wave 3 dataset identified the oldest old at increased risk of social exclusion compared with adults aged 65–84 years of age. In this analysis, social exclusion was defined as exclusion from services and exclusion from social relations (Key and Culliney, 2018), both of which contribute to loneliness and social isolation. From a research perspective, loneliness and social isolation are considered as two separate but related constructs. Loneliness is the *subjective* experience of being alone and is described as a mismatch between the quantity and quality of our social relationships, and those that we want to have (Perlman and Peplau, 1981). While loneliness is a subjective experience, social isolation is the *objective* social state of having limited social contacts or interactions with other people. Methodologically, social isolation can be measured by counting the number of contacts a person has (National Seniors Council, 2017), which influences an individual's experience of loneliness (Weiss, 1973).

Traditional approaches to tackling loneliness favour befriending and social groups but the Covid-19 pandemic, with its enforced social isolation and movement of many vital services online, highlighted the potential and importance of digital technology (Clayton and Astell, 2022). However, the oldest-old adults may be disproportionately excluded from accessing internet-based resources (Friemel, 2016). Voice Activated Technology, including smart speakers and voice assistants, is considered more accessible than many other digital devices (Pyae and Joelsson, 2018). Voice provides more natural interactions, ease of use and control for the user (Pradhan et al., 2018). In their study of 12 adults over 65 years of age using Google Home Hub for 16 weeks, Kim and Choudhury (2021) reported that the participants became more confident using voice assistants and developed "digital relationships". Other studies have found that users may form an attachment with voice assistants as they become embedded into their everyday lives (Lopatovska and Williams, 2018; Ramadan et al., 2021). In one study, 62% of Smart Speaker users felt less isolated (Argenti, 2018), with voice assistants offering a form of companionship (O'Brien et al., 2020). Companionship is also experienced by older adult users of voice assistants (Corbett et al., 2021). The experience of companionship may be due to anthropomorphism where the voice assistants are attributed humanlike traits (Liu, 2023). Additionally, anthropomorphism, appears to play a role in reducing loneliness (Jones et al., 2021). Together, these findings suggest the potential for voice assistants to impact loneliness amongst oldest old adults.

Background and rationale

This community case study was initiated by a provider of supported accommodation in the UK collaborating with a local technology company. Supported accommodation, also referred to as assisted living or sheltered accommodation in the UK, is a type of housing where individuals have their own rooms or apartments, with access to shared facilities including catering, social space and activities, plus on-site support staff. The location for this project is home to 25 residents and provides on-site support between 9 am and 6 pm. The two companies were interested in offering their older residents the opportunity to try a smart speaker – Google Home – to explore the impact on loneliness.

The technology company is a human tech agency that utilises digital equipment and data to create engagement between people to improve quality of life. The company saw the potential for voice technology to help one of their clients, a provider of supported accommodation for older people, to further their mission to alleviate loneliness amongst their residents. Their residents are often the oldest old who have experienced bereavement, which can lead them to experience loneliness. This pilot aimed to meet the human need to talk to others by introducing personal smart speakers into the lives of a small number of older people supported by the provider and seeing if talking to the assistant helped alleviate loneliness. The academic partner was invited to join the collaboration to provide the research background and context to the study and co-produce a means to evaluate the pilot study that could be conducted in the community setting. The rationale for the study was to determine if adults over 85 years of age experience benefits found in previous studies relating to companionship and social isolation.

Methodology

The #VoiceForLoneliness project[1] was established in and undertaken in a community setting as a partnership between different stakeholders. The participants lived in the same supported accommodation and were interviewed in their own homes. We adopted the format of a community case study after Smith et al. (2016) which comprises: description and reflection on an intervention (in this case, providing smart speakers to residents), within a community setting (the supported accommodation) to improve the health or functioning of an individual (reduced loneliness). The intention was to document the experience of older adults using smart speakers to cope with loneliness in supported accommodation to contribute to future evidence-based practice.

Participation in the study

Five residents were selected by the house manager of the supported living accommodation where the initial pilot was due to take place. The inclusion criteria were to be over 85 years of age, have no diagnosis of dementia or current mental illness, able to speak, read, write, and understand English (with the use of corrective devices, e.g., glasses, hearing aid, if necessary). Two males and three females, all Caucasian, aged between 87 and 95 years of age, with a mean age of 90 years of age, took part. They all lived alone and were residents in the same supported living accommodation. All participants had experienced bereavement and the loss of their spouse. In some cases, this prompted their move into supported housing.

Ethical approval

The study received approval from the University of Reading Research Ethics Committee (2019-089-AA). Each participant was provided with information about the study and invited to discuss it with members of their family and the research team. Once their questions were answered, those who were interested were asked to provide written consent. Participants were advised that the smart speaker would record their voices but that they could withdraw from the study at any time.

Procedure

A pre-smart speaker semi-structured interview was conducted individually in each participant's room or apartment before installing the smart speaker. The interview included collecting data on age, gender, current mobile/smartphone use, current computer use, current pastimes, and asking a single-item loneliness question taken from the Centre for Epidemiologic Studies Depression Scale (CES-D: Radloff, 1977). The CES-D loneliness question asks about loneliness during the past week reported as "rarely/none of the time", "some or little of the time", "occasionally or moderate amount of time", and "most or all of the time", scored from 0–3.

After the interview, the smart speaker was installed (Google Home smart speaker; current cost for comparison £49.00/$45.00) by the technology company, and each participant received instructions plus a demonstration of how to use it. The demonstration included how to activate the assistant, how to adjust the volume, and different types of questions it could be asked, such as what the weather will be or how to start playing a game. The residents were encouraged to practice asking questions, so they became familiar with the correct format. A "cheat sheet" including all of the above instructions was also given to each participant. Each demonstration was tailored to the support needs of each participant to ensure they were comfortable and confident using the device.

Each participant had the smart speaker for their personal use for eight weeks. After this time, a second interview was completed, again using a semi-structured approach. This interview covered the participant's thoughts on the smart speaker, the impact of the device on their life, what they used the device for, daily routine with the device, thoughts on voice technology, other features they would like, whether they would keep it, and how they would feel without it. Both pre-and post-interviews were video recorded using an HD video camera and transcribed for analysis.

Data treatment

Data from the pre/post-interviews data were combined to form 5 individual case reports of a wider community study to gain an in-depth understanding of a small number of cases located in real-world contexts (Yin, 2009). Using the pre-and post-interview data, experiences could be compared and contrasted between the five participants using the smart speakers. This allowed different aspects of the experiences to be revealed and understood, deconstructing, and reconstructing the phenomenon (Baxter and Jack, 2008). In the results that follow, pseudonyms are used for all participant's case stories. The presentation of stories is in a narrative form below, giving agency to "cases" rather than simply variables (Bazeley and Jackson, 2013).

Results

The five participants were all over 85 years of age, putting them in the category of the oldest old (Table 1). Three out of the five participants reported feeling lonely some or all of the time. The other two had previously experienced loneliness but did not report it being a current problem during the first interview. All used a mobile phone and all but one owned a tablet or computer (Table 1). None had previously used or owned a voice assistant.

Case 1 – Jack

Ninety-two-year-old Jack had recently moved into supported accommodation following the death of his wife. Jack reported at the start of the study that he was lonely all of the time, finding evenings particularly difficult when everyone would go to their room or apartment after dinner.

1 https://www.thehumantech.agency/what/voiceforloneliness

TABLE 1 Participant characteristics before using the voice assistant.

Case (number) name	(1) Jack	(2) Angela	(3) Jean	(4) Susan	(5) Peter
Sex	M	F	F	F	M
Age	92	87	87	89	95
Mobile phone	Y	Y	Y	Y	Y
Computer/tablet	Y	Y	Y	Y	N
Loneliness (pre-smart speaker)	All of the time	Sometimes	Sometimes	Rarely or none of the time	Rarely or none of the time

> "I feel lonely most of the day because I lost my wife in March after 76 years. The most lonely time is in the evening, after our evening meal. Everything seems to shut up and we just go to our various rooms and either listen to the radio or watch television. I feel lonely, I am completely on my own."

In terms of how he was spending his time at the start of the study, Jack went out on his motorized scooter to two local towns and saw his family once per week. Within the residential accommodation, he spent his afternoons playing Scrabble with other residents, watching television, or reading. Jack owned a mobile phone and tablet, which he used for emailing, and searching the internet for medical research, politics, and historical information.

At the end of the eight-week trial, Jack said he felt less lonely because of the smart speaker:

"[it] keeps me company. I can talk to it, and it's like another human being in the room." In terms of how he used the smart speaker, Jack listened to the radio and music, and asked general knowledge questions, for example, to help with crosswords. He also used the smart speaker to play games and set alarms and liked to listen to his music. He described how his routine had changed to include the hub which:

> "wakes me up at half seven. I listen to Radio 4 in the morning to catch up with the news. In the early evening I use it when I'm doing my crossword and then I listen to Classic FM until bedtime."

When asked about his feelings towards the smart speaker, Jack said:

> "I feel very grateful for it. I think it is a wonderful thing because it brings another person into the room…I can listen to the radio, listen to any kind of music I like. I can ask it silly questions and it just keeps me company. It prevents loneliness…I can talk to it, and it just keeps me company, like another human being in the room."

Jack found the smart speaker easy to use and very accessible:

> "It's easy. It knows my voice now, and there is no need to raise my voice. You do not have to get up to turn something on you just use your voice. Tell it to do something or ask a question and it comes with the answer. So, for a disabled person, it is even better, you can do everything you can do with a tablet, pretty well do everything if you are that way inclined. The trouble with old people these days is that they do not like using technology. They say they cannot do it, but they can. Nothing to turn on, the tuning or anything like that. You just ask it to do something like radio 4 or LBC, whatever you are listening to just use your voice."

When asked if he would like to keep the device, Jack said:

> "I would like to keep it permanently. I would be lost without it. If I didn't have it, it would be like losing somebody in my flat. I have company in my flat now with that, the [smart speaker], and without it, I would be lost…"

Case 2 – Angela

Angela, an 87-year-old woman reported feeling lonely some of the time at the start of the study. She revealed that following the death of her husband, she had felt very lonely living in the flat they had shared as she "never saw anyone." However, moving into supported accommodation had helped alleviate this to a certain extent. At the start of the study, she reported that she went out regularly, either walking or taking the bus into the local town. She also met with other residents for coffee and lunch and enjoyed occasional visits with her son. In the afternoons she watched television in her apartment. Angela used her mobile phone for communicating with her family and her computer for email and searching the internet, primarily to follow the news. When learning about the study Angela initially felt that Smart Speakers were perhaps a *"gimmick"*.

After using the smart speaker for eight weeks Angela reported that she found it "*filled the gap between television programs*." In terms of how she used the device, Angela specifically used it to listen to music both on the radio and on Spotify. Angela said:

> "I haven't done anything apart from music as I am quite happy with that. I get out but if I didn't get out, I would definitely want to hear a book, look at emails and look at the news, maybe learn a language… I would look things up."

In terms of her daily routine, she reported since having the device:

> "I get up and listen to the news and then I listen to music while I have my breakfast to cheer me up."

Regarding the potential of smart speakers for tackling loneliness, Angela particularly remarked on the feelings listening to old, familiar music evoked:

> "… I think these devices do help bring out certain feelings of nostalgia and satisfy nostalgia…it would go a long way to help isolation."

At the end of the study, Angela purchased her own smart speaker.

Case 3 – Jean

Jean was an 87-year-old woman who had moved into the supported housing from outside of the area due to mobility issues. She had been widowed for many years and did not have children. At the start of the study, she reported feeling lonely some of the time, but less so than before moving into supported accommodation. Jean particularly missed her earlier life when she ran a community art group with several companions, and it was the loss of this role and shared activity that made her feel lonely. To address this, she tried to go out every day but found that her mobility issues meant that she did not always make it. She used her mobile phone for calling taxis to take her out and speaking to her friends. Jean also used an iPad which she had owned "*for a very long time*," of which she said:

> "I couldn't live without. It has all my friends on it, and I use it for everything. I email my friends and send them copies of my paintings."

Over the eight weeks, Jean, like Angela, primarily used the smart speaker to listen to the radio and music. She particularly found that the ability to select whatever music took her fancy beneficial:

> "It has changed my life in that I know I can listen to lovely music whenever I feel a bit lonely. When I am drawing or reading then the background music is very nice."

Jean also reported another way that she used the smart speaker to lift her mood:

> "I can ask it to tell me a joke every now and then. They are only children's jokes, but they are quite good. Every now and then I ask [it] to tell me a joke and it lightens the whole situation, that is very nice."

Additionally, Jean used the smart speaker to listen to the news and had incorporated it into her daily routine by asking it to play music when she woke up in the morning. She reported an overall positive impact of the smart speaker:

> "Having this device has changed my day, simply because it relaxes me and I am able to concentrate on other things and that is terribly good for the brain, at least for my brain, I don't know about other people. I would have thought it will be good for every brain."

After using the smart speaker, Jean, like some of the other participants, reported that it created a positive presence for her. This supported her mental well-being and reduced her experience of loneliness:

> "I always feel lonely, that is part of my personality. I think this device has changed my day simply because it makes me feel there is a presence in the room which is rather nice."

Jean also commented that it was "*nice to command*" the device with her voice which she found particularly helpful. For example, she could control it from the patio without having to get up and go back inside, which she had to do for the radio. The control this gave her was very important for improving her life. Asked if she would like to keep the device, Jean said:

> "I cannot think how I existed without it – I always have Spotify on."

Case 4 – Susan

Susan was an 89-year-old woman living with mobility problems, which contributed to her moving into supported housing. She had been a widow for 21 years but maintained strong family relationships, which were important in keeping any feelings of loneliness at bay. At the start of the study, she reported that she was unable to walk outdoors, so would take a taxi into the local town. She also reported being on good terms with most other residents with whom she had occasional chats, and spending time watching television, which she did not have time for before moving into supported accommodation. She always used her mobile phone, especially for text messages, and owned a tablet but reported that she did not know how to use it.

Susan found using the Smart Speaker *"very interesting and very useful."* She mainly used it to find out information and check the weather. She particularly enjoyed asking questions and getting answers about sporting events and also used it to play games and set alarms.

> "I enjoy using the device, simply because of what it does and the technology, which is quite remarkable and modern. I would say it is excellent and if anyone asked me about it, I would be encouraging them to have it."

Although she did not feel lonely, she could see the potential for the smart speaker to help others, and maybe herself in the future…

> "I do think it will be very helpful to some people for that purpose [loneliness]… there might come a time when I would need it more, if I was not in much contact with people."

Finally, when asked how she would feel without it, Susan thought it would be difficult because she would want to find things out and would struggle to find answers without it. She added, *"I hope I'm not sounding greedy, but I would not like to be without it now."*

Case 5 – Peter

Ninety-five-year-old Peter had lived in supported housing for 4 years. Before moving into the supported housing, he had experienced loneliness following the death of his wife. Since moving, he reported the companionship at the supported housing had helped alleviate his loneliness. He supported a neighbour in the next-door room, by reading her letters and newspaper to her and changing batteries in her devices. He got on well with all of the residents and enjoyed shared dinners and conversations. At the start of the project, he went out every day to buy a newspaper and spent time sitting on his balcony "watching the world go by." He also had regular visits with his son-in-law, who had adopted Peter's dog, which he particularly enjoyed seeing again.

After using the smart speaker for eight weeks Peter described it as a *"miracle"*. He was amazed by what it could do…

> "…I do the crossword in the newspaper… It comes up with the answers. It is all very helpful. General Knowledge. Now that I have had it and used it some time, I would not like to be without it. I just marvel at its ability to provide knowledge and answers. I enjoy it, wherever it gets its information from."

Although he did not feel lonely, Peter found the interactive aspect also meant he had companionship, even feeling the device was *"becoming a friend"*…

> "My life is different now because where in the past I was on my own in the room, and now I feel like I've got a companion. It's nice to know that if you need to talk, it's there and it's like having a companion in the room that you talk to if you need to."

Peter also saw that the smart speaker could be helpful for lonely people:

> "It is comforting to think you have got a device that you can turn to if you need to. If you need to feel comfortable in the room without a companion that is the next best thing…if people do feel lonely and need companionship, beyond having someone sitting in the chair opposite you, it is nice to know that it is to hand and it would help. I am sure it would help somebody who did feel lonely. It would take some of the loneliness out of them."

Like the other participants, Peter had incorporated the smart speaker into his daily life. At the end of the study he wanted to keep it, saying, *"It's a wonderful thing and adds something to your life"*.

Discussion

This community case study demonstrated the feasibility of introducing smart speakers to a small group of oldest old adults in a community setting and the ways in which these could provide a means of alleviating loneliness. The ease of using voice to control the device was a key factor in the successful commencement and adoption of the technology. These five older adults found that the smart speaker quickly became an indispensable item. As reported in other studies, they formed an attachment to their smart speakers which became embedded into their daily lives (Lopatovska and Williams, 2018; Ramadan et al., 2021). Convenience, including ease of use, along with the emotions they evoke and the identity they reinforce, is important for the experiential value older adults attribute to digital technologies (Desai et al., 2022). In the present study, these older adults all valued their smart speakers after eight weeks of use.

The impact of smart speakers on loneliness was attributed to two interrelated features: *presence* and *agency*. Presence was a tangible experience for the participants that mitigated loneliness and social isolation. As Jack reported: "*I have company in my flat now*," suggesting that the oldest-old experience the same benefits of companionship as younger adults (O'Brien et al., 2020). Angela's description of the smart speaker *"filling the gaps between television programs,"* suggested that for her it emulated a chat with a companion in the advertising breaks. Similarly, Peter, who did not feel lonely, reported that the device was "becoming a friend." This echoes findings in previous studies where participants have formed digital relationships with smart speakers (Kim and Choudhury, 2021), particularly those who are lonely (Pradhan et al., 2019), who view them as companions (Corbett et al., 2021). Previous studies have identified a role for anthropomorphism in both companionship (Jones et al., 2021) and in mediating loneliness (Liu, 2023). In our small sample, the men treated the voice assistants as friends, which maybe a gendered issues to consider in future research where female voices are used.

Alongside presence, the oldest old participants in this study experienced *agency.* That is, the voice assistants gave them a means of not being alone. Essentially the availability of the smart speaker meant that older adults could choose not to be alone by hearing a voice or having an interaction with the device. Having the means to alter one's situation is of major significance to people who are lonely and one that distinguishes smart speakers from interactions with telephones, computers, tablets or video calls. These latter modalities are used to connect to known contacts and are contingent on the other parties responding. People who are socially isolated by definition have very small social networks, which shrink further in later life (Clayton, 2018). Additionally, many older people report unequal social relationships, where they wait for family to contact or visit them (O'Neill et al., 2020). Being able to interact with the voice assistant whenever they choose, provides a new dimension to their experience of being alone.

In addition to creating an interactive presence for those who are alone, smart speakers are enjoyable and entertaining, fostering rather than hindering a sense of self and adding to the quality of life of these oldest-old adults. In this study, the participants reported that the smart speakers extended their interests and activities by providing access to new things. The three participants in this study who reported feeling lonely some or all of the time had experienced bereavement, along with feelings of loss and sadness resulting from changes to identity associated with being older (Clayton, 2018). Interacting with smart speakers, which filled the silence with music, jokes, and general knowledge, helped them cope with their loneliness.

The findings add to the growing body of evidence of how voice assistants can impact the experience of loneliness and social isolation. In addition to companionship, agency emerged in this study as a key factor in addressing loneliness and social isolation among these oldest-old adults. This has potential relevance for other socially isolated populations who have limited social networks. Additionally, these findings which confirm the ease of use of voice assistants can inform strategies to support implementation and adoption in housing and care settings for older adults and other populations who are digitally excluded (Holmes and Burgess, 2022).

Limitations

Generalization of the findings of this pilot study is limited by the small sample size who were all current technology users and living in supported accommodation. Using a community setting and case study approach, however, facilitated the elicitation of individual experiences within a real-life community context (Baxter and Jack, 2008; Creswell, 2014). Whilst all five participants wished to keep the smart speakers, further research is required into their longer-term usage and benefits within supported accommodation and the wider community.

Conclusion

In this community case study, smart speakers addressed loneliness among the oldest old adults, through providing a presence in their home. Voice control provided agency to these oldest-old adults to change their situation, an experience not afforded by other digital tools. Further research into the extent to which smart speakers can alleviate loneliness in the longer term is however necessary. Social care and health commissioners have not historically used this type of technology to address loneliness and the state of knowledge about the benefits of voice assistance is still emerging. This study contributes to building this evidence base.

A recent report for Vodafone (2019) highlighted that along with medical and social prescribing, there may be a case for "digital prescribing". This is where pieces of technology may be purchased targeted at certain well-being outcomes like loneliness. As the older population is increasing and living longer, demand for this type of assistance is likely to increase. It is within this context, that smart speakers could be one such "digital prescription" as a device easy to procure, widely available, cheap, and programmable to help the oldest of old people cope with loneliness.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by University of Reading, Reading, UK. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

AA: Conceptualization, Writing – original draft, Writing – review & editing. DC: Formal analysis, Writing – review & editing, Writing – original draft.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Profiling early adopters of 'iSupport-Portugal': a country-specific version of a worldwide adapted digital support program for informal caregivers of people with dementia

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Introduction: Informal caregivers are the backbone of dementia care. iSupport is a World Health Organization digital support program for caregivers of people with dementia (PwD) that has been culturally adapted in several countries. iSupport was previously assessed for its feasibility in Portugal, and this country-specific version is now being utilized as a remote measurement tool (RMT). It constitutes the first internationally developed iSupport platform that is technically and scientifically enhanced to collect data on sociodemographic, clinical, and psychosocial variables of dementia care dyads. This paper characterizes the early adopters of iSupport-Portugal and discusses its exploration as a RMT.

Methods: Cross-sectional data were collected between February and July 2023 from users registering on isupport-portugal.pt. To characterize caregivers and PwD, eligibility was limited to unpaid caregivers assisting community dwelling PwD (n = 173). Data were collected through self-administered instruments in users' accounts. Caregivers completed psychosocial measures on burden, anxiety, depression, quality of life, desire to institutionalize and usage of community services. Textual data on caregivers' needs underwent content analysis.

Results: Among the early adopters of iSupport-Portugal (n =365), 52.3% were informal caregivers, while 44.7% were health/social care professionals or others. Most caregivers were female (82.7%), middle-aged (M 51.7years), highly educated (M 15.3years) and supporting a parent (70.5%). Caregivers cared for a median of 24h/week and 60.8% lived with the PwD. Neuropsychiatric symptoms were reported for 94.1% of PwD, who scored as moderately dependent (Barthel Index: M 14.0). Significant burden was reported by 88.4% of caregivers (≥21 on ZBI-22). Among caregivers scoring borderline or abnormal (≥8 on HADS) for anxiety, depression, or both (75.5%), 30.8% sought mental health counseling. Caregivers supporting a PwD not using community services scored higher on anxiety (p=0.003), and depression (p=0.009). Text data revealed unmet practical, emotional, and informational needs.

Discussion: iSupport-Portugal has garnered fair initial interest from caregivers, particularly from those who are children, highly educated, and employed. Early adopters exhibited significant psychological distress, and both practical and emotional needs, which contrast with limited use of support services for themselves and the PwD. iSupport-Portugal shows promise for descriptive research on care dyads, particularly among newer generations of caregivers.

KEYWORDS

caregivers, dementia, digital technologies, mental health, remote measurement

1 Introduction

Dementia represents a significant global public health challenge, affecting approximately 55 million individuals worldwide (World Health Organization, 2021). In 2019, Portugal stood as the fourth-ranked country among OECD nations in terms of dementia prevalence, with an estimated rate of 21 cases per 1,000 inhabitants (OECD, 2019).

As dementia stands as the primary cause of dependence among older adults (Sousa et al., 2010), people with dementia (PwD) often require consistent care. A significant 84% of PwD worldwide live at home, where they rely on assistance primarily provided by family members, neighbors, or friends (Wimo et al., 2018). These supporters, commonly referred to as informal caregivers, shoulder the responsibility of unpaid and continuous assistance in basic or instrumental activities of daily living and/or in organizing care delivery by others. Informal caregivers worldwide serve as the linchpin of the care and support system, playing a pivotal role in enabling individuals to age in their own homes. Nonetheless, informal caregivers of PwD are at greater risk of experiencing depression and anxiety disorders, as well as hypertension, digestive, and breathing problems when compared both to the general population and to caregivers of people living with other chronic diseases (WHO, 2015; Gilhooly et al., 2016). These health issues often coexist with strained relationships, social isolation, and financial hardships. Dementia is linked to the necessity for particularly intensive and multifaceted care and its progressive nature. The still limited availability and uncertainties over recent disease-modifying treatments (NHS, 2024), and the complex psychological and behavioral symptoms are all instances of the distinctive challenges faced by dementia caregivers (Schulz et al., 2020).

Reflective of this evidence, the World Health Organization (WHO) Global Action Plan on the Public Health Response to Dementia has established the goal of having 75% of countries offering accessible support and training programs by 2025 to mitigate the adverse consequences of caregiving (WHO, 2017). As part of this plan, WHO has developed "iSupport for dementia," an eHealth program for caregivers of PwD (Pot et al., 2019). Additionally, iSupport was introduced in the form of a hardcopy manual to accommodate individuals facing challenges such as limited internet access or insufficient digital skills. The philosophy underlying iSupport aligns with Kitwood's model, emphasizing the centrality of personhood for individuals diagnosed with dementia (Kitwood, 2017). Care is thought of as interaction in accordance with the needs, abilities, and personality of each individual (Kitwood, 2017). Across the 23 lessons and 5 modules comprising the iSupport program, problem-solving and cognitive-behavioral therapy techniques are employed. These include psychoeducation, behavioral activation, cognitive reframing, relaxation, communication training, and antecedent-behavior-consequence (ABC) analysis (see Figure 1).

The digital program was initially designed to be freely accessible and self-guided. Caregivers can navigate the content independently, while selecting the lessons that best suit their needs and establishing personalized schedules for accessing the program. Informal caregivers frequently face substantial challenges in accessing conventional interventions. This is attributed to factors such as limited operating hours, difficulties coordinating with employment or full-time care responsibilities, and transportation issues (Pot et al., 2015; Teles et al., 2021). An online and self-guided program offers full flexibility regarding the intervention schedule, enabling individuals to progress at their own pace. Self-guided online interventions may improve the accessibility of psychosocial support. Additionally, they may contribute to reducing the costs associated with assisting an expanding number of PwD and their caregivers (Blom et al., 2015). To elevate engagement and user experience in iSupport, the program incorporates personalization features. Furthermore, iSupport integrates caregiving scenarios that replicate real-life situations, linking these scenarios to interactive exercises for skills training. The primary goal is to assist caregivers in internalizing the underlying theory presented in the lessons.

iSupport was originally crafted as a 'generic version' presented in English and featuring examples and scenarios from various cultures. Therefore, cultural adaptation to each implementation setting is necessary. This digital program aimed at improving the mental health of informal caregivers has been or is being adapted in over 40 countries. iSupport-Portugal (see Figure 2) stands as one of the pioneering culturally adapted versions (Teles et al., 2020) which was studied for its usability (Teles et al., 2021) and feasibility (Teles et al., 2022), yielding promising results. Other country-specific versions of iSupport have published results regarding their cultural adaptation, including for Australia (and Chinese-Australian caregivers (Xiau, 2020; Xiao et al., 2022)), Brazil (Oliveira et al., 2020), India (Baruah et al., 2021), Switzerland (Fiordelli and Albanese, 2020), Indonesia (Turana et al., 2023), Spain (Molinari-Ulate et al., 2023), Greece (Efthymiou et al., 2022) and Japan (Yamashita et al., 2022).

iSupport-Portugal is currently undergoing exploration beyond its initial intervention purpose. It is evolving into a research-intervention platform with the potential to remotely assess the sociodemographic, health, and psychosocial aspects of caregivers and PwD, nationwide and longitudinally. Web platforms and mobile apps have seen growing exploration as remote measurement tools or technologies (RMT). RMT provide alternatives to traditional and frequently cumbersome assessment methods by facilitating real-time and longitudinal monitoring of health variables and behaviors in a cost-effective and non-intrusive manner (Simblett et al., 2018). iSupport-Portugal is the

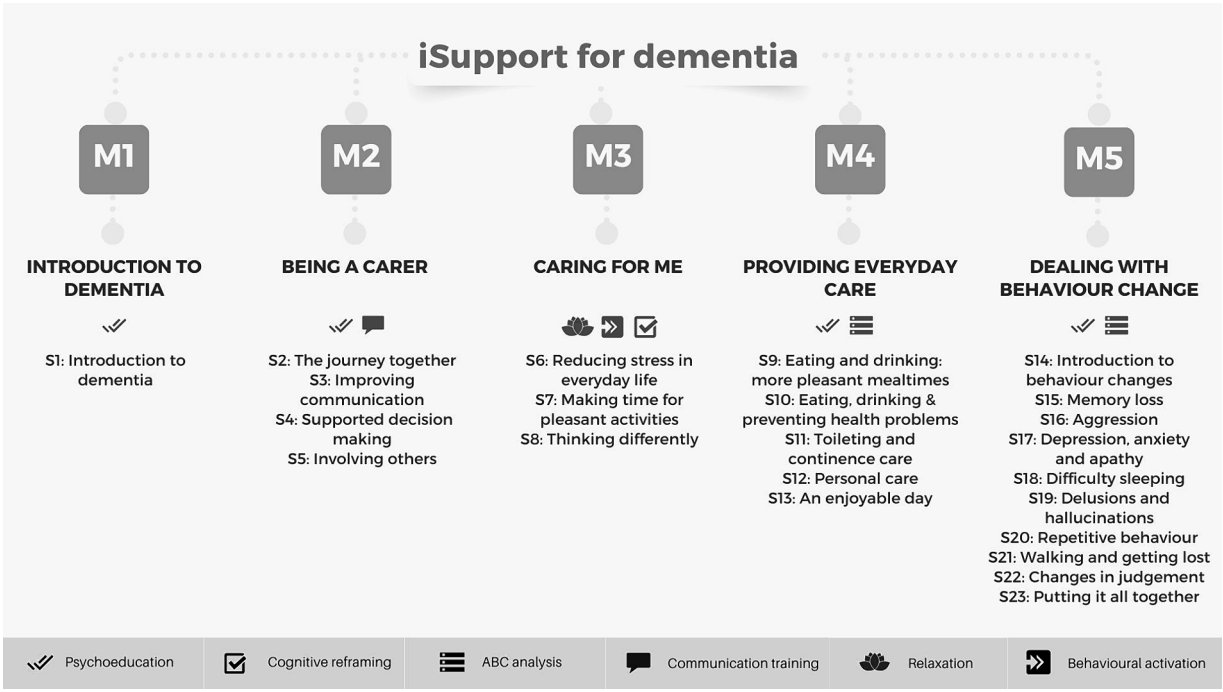

FIGURE 1
iSupport modules, lessons, and psychological techniques. Lessons names vary slightly in the European-Portuguese version.

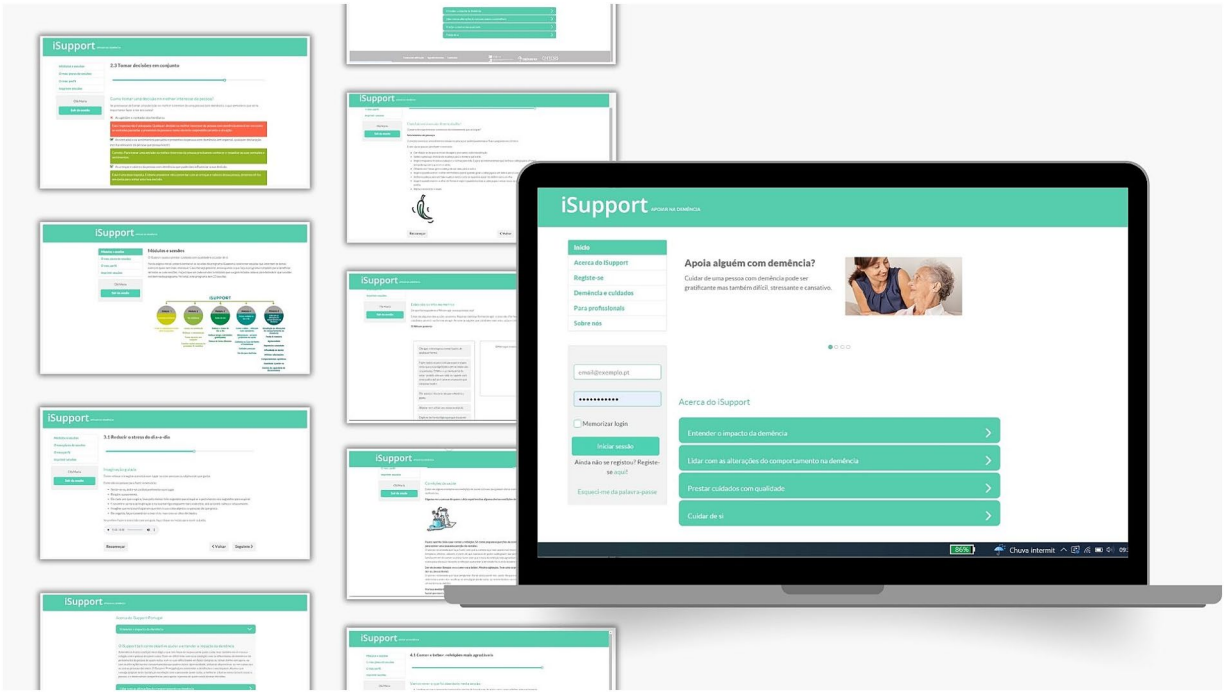

FIGURE 2
iSupport-Portugal screens (at isupport-portugal.pt).

first internationally developed iSupport platform that is technically and scientifically enhanced to collect and export data on sociodemographic, clinical, and psychosocial variables of dementia care dyads. This includes response data to surveys and scales, replies to interactive exercises, and paradata, i.e., actions on the interface, such as pages visited, and time spent on pages. The use of iSupport for collecting data for descriptive and predictive research on dementia care dyads is currently under exploration.

Many countries, including Portugal, lack national data on informal caregivers of PwD, including their number, characteristics, and the care

they provide (World Health Organization, 2021). While a recent national survey to informal caregivers indicated that dementia is the primary condition among care recipients (33%), the psychosocial profile of these caregivers remains undescribed (Movimento cuidar dos cuidadores informais, 2021). Regional or national projects have depicted caregivers of PwD as predominantly female (Gonçalves-Pereira et al., 2019; Paúl et al., 2019), spouses or children (Gonçalves-Pereira et al., 2019; Paúl et al., 2019), with lower levels of education (Gonçalves-Pereira et al., 2019; Paúl et al., 2019), and mostly unemployed (Paúl et al., 2019). However, due to availability, caregivers in intervention programs [e.g., Paúl et al. (2019)] may be more likely to be unemployed, providing full-time care, and have lower levels of education, as more educated caregivers are less prone to leave their jobs for full-time care (Flinn, 2018). A recent cohort study in Portugal observed a higher-than-expected percentage of participants with secondary or higher education (Gonçalves-Pereira et al., 2019). This observation may indicate a changing profile of informal caregivers. Current international reports have highlighted the emerging generation of family caregivers, who tend to be more schooled, employed, and the only children of the care recipient (Flinn, 2018; National Alliance for Caregiving, AARP, 2020). As the profile of caregivers continues to evolve, tools for collecting data on their characteristics and needs can be valuable for planning the organization of healthcare services.

This paper aims to provide a comprehensive characterization of the sociodemographic, clinical, and psychosocial profiles of informal caregivers and PwD, along with their utilization of community resources and caregivers' needs, among users of iSupport-Portugal. This digital platform and support program was utilized as a RMT to collect nationwide data on dementia care dyads at a distance.

2 Materials and methods

2.1 Preliminary measures

To exploit iSupport-Portugal as a RMT for collecting data on dementia care dyads, a series of preparatory steps were undertaken before the data analysis phase (see Figure 3).

First, these encompassed clearly defining data collection objectives and measures, as well as selecting, obtaining permissions for use, and programming assessment scales in accordance with licensing requirements. Simultaneously, this step involved designing complementary data collection forms, utilizing suitable form fields and validation to improve data accuracy. Measures were defined based on a literature review and previous iSupport-Portugal research. A mixed-methods pilot RCT, which included most of the measures utilized for the present research, provided insights into the adequacy of these measures (Teles et al., 2022). Furthermore, an expert panel discussion focused on the utility of embedded exercises within iSupport as information sources. These include, the open-text exercise providing data on caregivers' needs, as reported in section 3.4.

Second, the platform was prepared for data collection. This required integrating custom-built website components into iSupport-Portugal.pt. to facilitate the collection and export of data, as well as background analytics on survey use. Furthermore, proper, and secure data storage and backup mechanisms were put in place.

Third, steps were taken to ensure data security, privacy, and compliance, given the objective of collecting health and well-being data on dementia care dyads. A thorough analysis of the platform's security to identify vulnerabilities was performed and measures were implemented to enhance data security. These included encryption for data transmission, secure storage practices, and access controls to prevent unauthorized access. Compliance with data privacy regulations such as General Data Protection Regulation (GDPR) was ensured. The necessary consents from participants were obtained while guaranteeing a clear communication of participation conditions and privacy policies. To warrant compliance with data protection regulations and the appropriateness of informed consents, support was sought from the Data Protection office and the digital services of the University of Porto.

Fourth, data extraction, validation, and cleaning were performed to address any discrepancies or errors in the collected data. While data cleaning is a fundamental process for any dataset, doing so for online platforms demands considerable effort and time due to the large quantity and diversity of data.

All these systematic steps ensure the integrity, security, and ethical handling of the data collected through iSupport-Portugal. They provide the basis for robust and reliable analysis of data from dementia care dyads.

2.2 Design

Observational study, with cross-sectional primary data collected at registration to the online platform isupport-portugal.pt.

2.3 Participants and recruitment

All individuals who completed registrations on isupport-portugal.pt. between February and July 2023 were included in the analysis to characterize the user base of this platform. To characterize the sociodemographic, clinical, and psychosocial profile of caregivers and care recipients, eligibility was limited to i. adults (18 years and older), ii. resident in Portugal, iii. providing unpaid support, iv. to a person diagnosed with dementia, v. living in the community (i.e., not in permanent institutional care). Registered users discovered the platform through various dissemination channels. These include the websites of the program organizers and partners, media press articles, and recommendations from professionals.

2.4 Variables and measures

The study data were collected exclusively online through fill-in forms hosted at isupport-portugal.pt. To explore iSupport as a RMT, a diagnosis module was incorporated into the program, making it a unique addition to iSupport-Portugal compared to other international versions. The diagnosis module serves as the baseline assessment protocol of sociodemographic, clinical, and psychosocial variables pertaining to the caregivers and PwD. Therefore, it includes the selected measures outlined in sections 2.4.1 and 2.4.2. This module precedes the five intervention modules comprising iSupport. It is available and can be self-completed by the participants

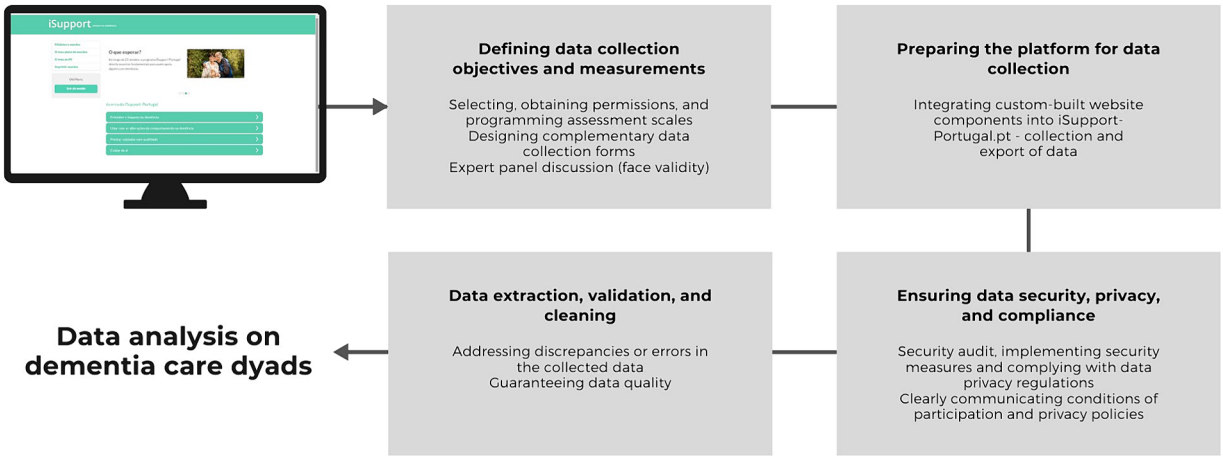

FIGURE 3
Preliminary measures to exploit iSupport-Portugal as a RMT for collecting data on dementia care dyads.

after giving their consent to participate in research, all through their user account. Once caregivers complete the registration process and consent to their participation in research, they are prompted to navigate and fill in questions within the diagnosis module. All data about PwD were collected through the caregivers' report. The instruments administered to the study participants are described in Table 1.

2.4.1 Data on informal caregivers

Informal caregivers provided sociodemographic information about themselves and details about the context of care. Use of services for caregivers was assessed, including psychoeducational, support or mutual aid groups, mental health counseling, or others. In addition, participants completed several psychosocial measures: i. the Zarit Burden Interview (ZBI-22) (Zarit et al., 1980; MAPI Research Trust, 2014); ii. the Hospital Anxiety and Depression Scale (HADS) (Zigmond and Snaith, 1983; Pais-Ribeiro et al., 2007); iii. The WHOQOL-BREF (World Health Organization, 1996; Vaz Serra et al., 2006); iv. the PAC (Tarlow et al., 2004; Gonçalves-Pereira et al., 2010); and v. the European-Portuguese version of the Desire to Institutionalize Scale (Morycz, 1985; Teles et al., 2023).

2.4.2 Data on persons with dementia

Caregivers provided sociodemographic and clinical information about the PwD in their care and reported on the use of services, including home care services, home health services, day, or night centers, cognitive or occupational therapy, or other. The Barthel Index (Mahoney and Barthel, 1965; Araújo et al., 2007) and the Neuropsychiatric Inventory Questionnaire (NPI-Q) (Cummings et al., 1994; Espirito-Santo et al., 2010) were also completed by caregivers.

2.5 Data analysis

Descriptive statistics were calculated, utilizing absolute and relative frequencies, as well as measures of central tendency and dispersion, where appropriate. For interpretability, raw scores on each WHOQOL-BREF domain were transformed into a scale between 0 and 100 according to the scoring guidelines (World Health Organization, 1996). Relationships between theoretically relevant variables and group differences were examined using parametric or non-parametric tests (Spearman's rank, Pearson's, or Kendall's tau-b correlation; chi-squared test for independence; independent samples *t*-test, Kruskall-Wallis, or Mann–Whitney *U* test), according to the conditions of applicability. All *p*-values are two-tailed with a significance level of 0.05. The Statistical Package for the Social Sciences/IMB SPSS Statistics version 27 (IBM Corp, 2020) (RRID:SCR_002865) was used for analysis.

The text data on the key needs of caregivers were subjected to thematic content analysis using NVivo software, version 11. The content was coded in categories defined in an inductive/data-driven approach. Results are presented as absolute frequencies for references coded by category. Text excerpts (translated into English) are used to illustrate content within categories.

2.6 Ethics and data protection

Upon registration at isupport-portugal.pt. to access the online program, all users consented to the use of their basic sociodemographic data entered in the registration form and their navigation data for research purposes. Additionally, users who self-identified as unpaid caregivers of a PwD were fully informed and invited to participate in the research by completing post-registration questionnaires. Informed consent was obtained online through the user's personal account at isupport-portugal.pt. The refusal to participate in the study did not impede the use of the program in any way. A pseudonymization process was implemented. This study was approved by the Ethics Committee for Health of the Faculty of Medicine of the University of Porto (ref: 76/CEFMUP/2022). An assessment of data protection issues for isupport-portugal.pt. was carried out by the Data Protection Officer of the University of Porto.

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TABLE 1 Instruments administered to study participants.

Instrument	Description
Sociodemographic characteristics of IC and PwD	
Sociodemographic questionnaire	All registered users: age, gender, years of formal education, region of residence (NUTS II) IC and PwD: marital status, IC-PwD relationship/kinship IC only: employment status, number of children and number of cohabiting children
Care context	
Care context questionnaire	Caregiving duration, hours spent caring per week, access to regular support for caregiving and (if so) type of support (unpaid, paid and specialized, paid but unspecialized), cohabitation with the PwD
Use of support services for IC and PwD	
Service utilization items	IC: current use of psychoeducational, support or mutual aid groups, mental health counseling, or other PwD: current use of home care services, home health services, day or night centers, respite services, cognitive or occupational therapy, or other
Clinical profile of PwD	
PwD clinical profile questionnaire	Type of dementia, time since diagnosis of dementia, level of dependency perceived by the caregiver.
Barthel index	Mahoney and Barthel (1965) / Portuguese version by Araújo et al. (2007) A 10-item instrument that assesses functional independence; items are scored from 0 to a maximum of 3, with total scores ranging from 0 to 20. Higher scores indicate greater independence. Cut-offs for dependence levels are total dependence (0–8 points), severe dependence (9–12 points), moderate dependence (13–19 points) and independent (20 points).
Neuropsychiatric inventory questionnaire (NPI-Q)	Cummings et al. (1994) / Portuguese version by Espirito-Santo et al. (2010) Assesses the presence or absence of 12 neuropsychiatric symptom domains: delusions, hallucinations, agitation/aggression, dysphoria/depression, anxiety, euphoria/elation, apathy/indifference, disinhibition, irritability/lability, aberrant motor behaviors, nighttime behavioral disturbances, and appetite/eating disturbances. The severity of reported symptoms in the past month is rated as mild, moderate, or severe, with the total NPI-Q severity score ranging from 0 to 36. Caregiver distress for each symptom reported is rated on a 6-point scale, with total NPI-Q distress scores ranging from 0 to 60.
Psychosocial profile of IC	
Zarit Burden interview (ZBI-22)	Zarit et al. (1980) / Portuguese version by MAPI Research Trust (2014) 22-item instrument assessing caregiver perceived burden; items are scored on a 5-point scale and the total ZBI score ranges from 0 to 88 points. Higher scores indicate greater burden.
Hospital anxiety and depression scale (HADS)	Zigmond and Snaith (1983) / Portuguese version by Pais-Ribeiro et al. (2007) A 14-item instrument that assesses symptoms of anxiety and depression in two subscales, each with 7 items scored on a 4-point scale; total scores per subscale range from 0 to 21. Higher scores indicate more severe symptoms of anxiety or depression.
WHOQOL-BREF	World Health Organization (1996) / Portuguese version by Vaz Serra et al. (2006) A 26-item instrument covering four domains of quality of life: physical, psychological, social relationships and environment, as well as items relating to overall quality of life. Each item is rated on a 5-point scale. Higher total scores indicate higher quality of life.
Positive aspects of caregiving (PAC)	Tarlow et al. (2004) / Portuguese version by Gonçalves-Pereira et al. (2010) An 11-item instrument assessing positive feelings resulting from caregiving; items are scored on a 5-point scale, with total scores ranging from 11 to 55. Higher scores represent more positive perceptions of caregiving.
Desire to institutionalize scale (DIS)	Morycz (1985) / Portuguese version by Teles et al. (2023) A 6-item scale assessing different stages of contemplating institutionalization; dichotomous response option ('yes' = 1 point; 'no' = 0 points) with an overall desire to institutionalize score ranging from 0 to 6 points. Higher scores indicate a greater willingness to institutionalize the PwD.
Unmet needs of IC	
Key caregiver needs	Session 2.4 of iSupport; non-mandatory exercise consisting of identifying the three main needs of caregivers (text entry/data).

IC, informal caregiver; PwD, person with dementia.

3 Results

3.1 Quantitative analysis

3.1.1 Registered users on iSupport-Portugal

Between February and July 2023, a total of 449 users registered on isupport-portugal.pt., 365 of whom completed the basic sociodemographic form presented at registration. Of these, 191 (52.3%) registered as informal caregivers of a PwD, 11 as paid caregivers (3.0%) and 163 (44.7%) as health/social support professionals or others.

3.1.2 Sociodemographic characteristics and care context

Among the eligible caregivers ($N = 173$), not all completed the baseline measures in full. For sociodemographic variables collected through the registration form (e.g., age), there are significantly more cases compared to other variables collected through post-registration questionnaires (see Table 2).

Most caregivers are female ($n = 143$, 82.7%), middle-aged ($n = 173$, M 51.7, SD 13.0, range: 20–89 years) and were caring for a parent ($n = 122$, 70.5%). On average, caregivers were highly educated ($n = 171$, M 15.3 years of education, SD 4.4, range: 3–25) and most were employed ($n = 63$, 64.3%). Caregiver education negatively correlates with the hours spent caring for the PwD ($n = 96$, $r_s = -0.295$, $p = 0.004$).

Care recipients are predominantly female ($n = 109$, 63.0%) and had a mean age of 78.8 years ($n = 173$, SD 8.5). The age range of PwD at the time of data collection (45–96 years) suggests a representation of young onset dementia cases.

More than half of the caregivers lived with the PwD ($n = 59$, 60.8%). Most had been providing care for two or more years ($n = 94$,

TABLE 2 Summary of sociodemographic variables for caregivers and PwD and context of care variables.

Variables	*N*	Descriptive statistics
Informal caregivers		
Age (years), *M* (SD)	173	51.7 (13.0)
Gender, Female, *n* (%)	173	144 (83.2)
Years of formal education, *M* (SD)	171	15.3 (4.4)
Marital status, Partnered [a], *n* (%)	97	61 (62.9)
Employment status, Employed, *n* (%)	98	63 (64.3)
Relationship with the care recipient	173	
Offspring, *n* (%) [b]		132 (76.3)
Spouses, *n* (%)		23 (13.3)
Other, *n* (%)		18 (10.4)
Children, Yes		
Among all carers, *n* (%)	96	63 (65.6)
Among offspring caregivers, *n* (%)	72	43 (59.7)
Among spousal caregivers, *n* (%)	16	14 (87.5)
Cohabiting children, Yes		
Among all caregivers with children, *n* (%)	63	41 (65.1)
Among offspring caregivers with children, *n* (%)	43	32 (74.4)
Among spousal caregivers with children, *n* (%)	14	4 (28.6)
Person with dementia		
Age (years), *M* (SD)	173	78.8 (8.5)
Gender, Female, *n* (%)	173	109 (63.0)
Years of formal education, Mdn (IQR)	97	4 (5)
Marital status, Partnered[†], *n* (%)	97	57 (58.8)
Informal care context factors		
Caregiving duration (months), Mdn (IQR)	94	33 (58)
Hours caring (per week), Mdn (IQR)	96	24 (45.8)
Support for caregiving, Yes, *n* (%)	97	67 (69.1)
Support for caregiving, type of support	67	
Unpaid, *n* (%)		37 (55.2)
Paid, specialized, *n* (%)		11 (16.4)
Paid, non-specialized, *n* (%)		19 (28.4)
Cohabitation with the PwD, Yes, *n* (%)	97	59 (60.8)

N/n, number of participants; M, mean; Mdn, median; SD, standard deviation; IQR, interquartile range.
[a] Includes those who were married or in a de facto union; [b] Includes children and grandchildren.

TABLE 3 Summary of the PwD clinical profile variables and service use.

Variable	*N*	Descriptive statistics
Type of dementia	98	
Alzheimer's disease, *n* (%)		46 (46.9)
Vascular dementia, *n* (%)		17 (17.3)
Frontotemporal dementia, *n* (%)		12 (12.2)
Dementia with Lewy bodies, *n* (%)		8 (8.2)
Other/unknown, *n* (%)		15 (15.3)
Time since diagnosis (months), Mdn (IQR)	97	41 (59.5)
Dependence level, perceived by the carer		
Mild, *n* (%)		16 (16.5)
Moderate, *n* (%)		32 (33.0)
Severe, *n* (%)		25 (25.8)
Total, *n* (%)		24 (24.7)
Functional independence (BI), Mdn (IQR)	78	14 (13)
Total dependence, *n* (%)		21 (26.9)
Severe dependence, *n* (%)		8 (10.3)
Moderate dependence, *n* (%)		35 (44.9)
Independent, *n* (%)		14 (17.9)
Neuropsychiatric symptoms (NPI-Q)	78	
Number of symptoms (NPI-Q), Mdn (IQR)		5 (4.0)
Severity (NPI-Q), Mdn (IQR)		10 (9.0)
Service use by the care recipient	95	
Home care services, uses, *n* (%) [a]		19 (20.0)
Home health services, uses, *n* (%)		13 (13.7)
Day center, uses, *n* (%)		15 (15.8)
Night center, uses, *n* (%)		2 (2.1)
Cognitive or occupational therapy, uses, *n* (%)		11 (11.6)

N/*n*, number of participants; *M*, mean; Mdn, median; SD, standard deviation; IQR, interquartile range; BI, Barthel index; NPI-Q, neuropsychiatric inventory questionnaire.
[a] includes homecare services with or without support for personal care (e.g., personal hygiene).

60.6%; Mdn 33 months, IQR 58) and were spending 20 h or more per week providing care ($n = 96$, 61.5%; Mdn 24 h, IQR 45.8). While most caregivers were supported in their caring responsibilities ($n = 67$, 69.1%), more than half received support from other unpaid caregivers (55.2%).

3.1.3 Clinical profile of PwD and service use

According to caregivers, most care recipients had been diagnosed with Alzheimer's disease ($n = 46$, 46.9%). The median time since diagnosis was 41 months ($n = 97$, IQR 59.5). According to the Barthel Index cut-off scores, almost half of the PwD ($n = 35$, 44.9%) would be classified as moderately dependent ($n = 78$, Mdn 14, IQR 13). However, the sample is diverse, with PwD distributed across all levels of dependence (Barthel Index range: 0 to 20 points). There is a strong negative correlation between the perceived level of dependence of the PwD and the total score on the Barthel Index ($\tau_b = 0.600$, $p < 0.001$). At least one neuropsychiatric symptom was reported by 94.1% ($n = 74$) of caregivers on the NPI-Q, with a median of 5 symptoms (IQR 4, range: 0–12), and a median severity score of 10 (IQR 9.0). The most reported neuropsychiatric symptoms were apathy ($n = 63$, 80.8%), appetite changes ($n = 42$, 53.8%) and depression ($n = 41$, 52.6%), while euphoria was the least reported ($n = 10$, 12.8%). The positive symptoms that scored higher on severity were apathy ($n = 63$, M 2.22, SD 0.66), motor disturbances ($n = 33$, M 2.06, SD 0.75), delusions ($n = 27$, M 2.04, SD 0.71) and agitation ($n = 27$, M 2.04, SD 0.65).

Almost half of the participants ($n = 46$, 48.4%) reported that the PwD did not use any of the services listed in Table 3. Home care services were the most used ($n = 19$, 20.0%).

3.1.4 Psychosocial profile and service utilization of informal caregivers

3.1.4.1 Burden of care, psychological distress, and service use

Significant levels of burden were reported by caregivers ($n = 95$, M 36.0, SD 12.9), with 88.4% ($n = 84$) scoring ≥21 on the ZBI-22 (Zarit et al., 1980). The distress caused by neuropsychiatric symptoms was on average higher for agitation/aggression ($n = 27$, M 2.81, SD 0.97), anxiety ($n = 33$, M 2.79, SD 0.86) and delusions ($n = 27$, M 2.78, SD 0.93). A moderate positive correlation between the ZBI-22 and the NPI-Q distress total scores ($r_s = 0.411$, $p < 0.001$) is observed.

TABLE 4 Summary of psychosocial variables for caregivers.

Variable	*N*	Descriptive statistics
Perceived burden (ZBI-22), *M* (SD)	95	36.0 (12.9)
Caregiver distress, neuropsychiatric symptoms (NPI-Q), Mdn (IQR)	73	11.0 (13.0)
Anxiety symptoms (HADS-A), *M* (SD)	85	10.0 (4.2)
Depression symptoms (HADS-D), *M* (SD)	85	7.5 (4.2)
Quality of life (WHOQOL-BREF)	82	
General, *M* (SD)		6.8 (1.6)
Physical, *M* (SD)		25.5 (5.4)
Psychological, *M* (SD)		21.4 (4.0)
Social relationships, *M* (SD)		9.7 (2.5)
Environment, *M* (SD)		28.2 (5.7)
Positive aspects of caregiving (PAC), *M* (SD)	89	34.2 (10.0)
Desire to institutionalize the PwD (DIS-PT), Mdn (IQR)	88	2 (3)
Service use by the caregiver, uses, *n* (%)	95	
Mental health consultations		25 (26.3)
Psychoeducational, support or mutual aid groups, uses, *n* (%)		9 (9.5)
Holiday center or carer relief services, uses, *n* (%)		0

N/*n*, number of participants; *M*, mean; Mdn, median; SD, standard deviation; IQR, interquartile range; ZBI, Zarit Burden interview; HADS-A, hospital anxiety and depression scale (anxiety subscale); HADS-D, hospital anxiety and depression scale (depression subscale); NPI-Q, neuropsychiatric inventory questionnaire; PAC, scale positive aspects of caregiving positive; DIS-PT, desire to institutionalize scale, European-Portuguese version.
[a] Reports on raw scores for each QoL domain.

According to the HADS cut-off scores, 44.7% ($n = 38$) of caregivers would classify as abnormal and 24.7% ($n = 21$) as borderline abnormal for anxiety. For depression, 20% ($n = 17$) would classify as abnormal and 27.1% ($n = 23$) as borderline.

The number of hours spent on caregiving is positively correlated with the level of burden ($n = 94$, $r_s = 0.312$, $p = 0.002$), anxiety ($n = 85$, $r_s = 0.266$, $p = 0.014$) and depression ($n = 85$, $r_s = 0.336$, $p = 0.002$). Likewise, the severity of neuropsychiatric symptoms is positively correlated with the level of burden ($n = 76$, $r_s = 0.350$, $p = 0.002$), anxiety ($n = 77$, $r_s = 0.306$, $p = 0.007$), and depression ($n = 77$, $r_s = 0.304$, $p = 0.007$). Caregivers who reported no support for caring responsibilities scored higher on burden (M 42.2, SD 12.4 vs. M 33.3 SD 12.1, $t(93) = -3.280$, $p = 0.001$), anxiety (M 11.6, SD 3.6 vs. M 9.3, SD 4.2, $t(83) = -2.390$, $p = 0.019$) and depression (M 8.9, SD 4.1 vs. M 6.9, SD 4.2, $t(83) = -2.132$, $p = 0.036$), than those receiving such support.

Of the caregivers who scored as borderline or abnormal for either anxiety, depression, or both ($n = 65$, 76.5%), only 30.8% ($n = 20$) were seeking mental health counseling. When asked about the use of support services, most participants reported using none ($n = 54$, 56.8%). None of the caregivers were using carer relieve services. Caregivers supporting PwD who were not using community services scored significantly higher on anxiety (M 11.3, SD 3.9 vs. M 8.6, SD 4.1, $t(82) = 3.102$, $p = 0.003$), and depression (M 8.7, SD 4.4 vs. M 6.3, SD 3.7, $t(82) = 2.681$, $p = 0.009$) than those who were.

3.1.4.2 Quality of life

Transformed scores for the WHOQOL-BREF show that the social relationships domain is on average the lowest rated ($n = 82$, M 56.2, SD 21.1) compared to the physical (M 66.1, SD 19.1), psychological (M 64.0, SD 16.8), and environmental (M 63.1, SD 17.8) domains. The average transformed score for general QoL was 60.5 (SD 19.4). Of all three indicators of psychological distress (burden, anxiety, and depression), depression shows the strongest negative correlations with all QoL domains ($n = 82$, general $r_p = -0.577$, $p < 0.001$, physical $r_p = -0.515$, $p < 0.001$, psychological $r_p = -0.744$, $p < 0.001$, social $r_p = -0.613$, $p < 0.001$, and environmental $r_p = -0.577$, $p < 0.001$).

3.1.4.3 Positive aspects of caregiving and desire to institutionalize

Despite high psychological distress, positive aspects of care were moderately rated (M 34.2 points on the PAC). Positive aspects were negatively correlated with the severity of neuropsychiatric symptoms ($n = 77$, $r_s = -0.248$, $p = 0.030$), and with the functional independence of the PwD ($n = 78$, $r_s = -0.356$, $p = 0.001$). Caregivers reported only mild desire to institutionalize ($n = 88$, Mdn 2, IQR 3). The willingness to institutionalize is positively correlated with the level of caregiver burden ($n = 87$, $r_s = 0.415$, $p = 0.001$).

3.2 Qualitative analysis of unmet needs among informal caregivers

Through responses to open-text exercises in iSupport-Portugal, a sub-sample of caregivers ($n = 20$) reported unmet needs, coded as i. practical support (39 references), ii. emotional support (7 references), and iii. information, advice, and training support (5 references). In addition, the need for a better work-life balance has emerged (5 references) (see Figure 4).

The most reported need was for practical support in caring. Extracts within this category highlight caregivers' needs for i. support with daily tasks, including bathing and other personal care tasks, and ii. for time out from caring: e.g. *"I would need at least one afternoon a week to myself"* (IC_414, daughter). The provision of occupational activities and increasing the physical/mental activity of the PwD also emerged as a concern: e.g. *"I would need someone to take my dad for a walk a couple of times a week or to accompany him*

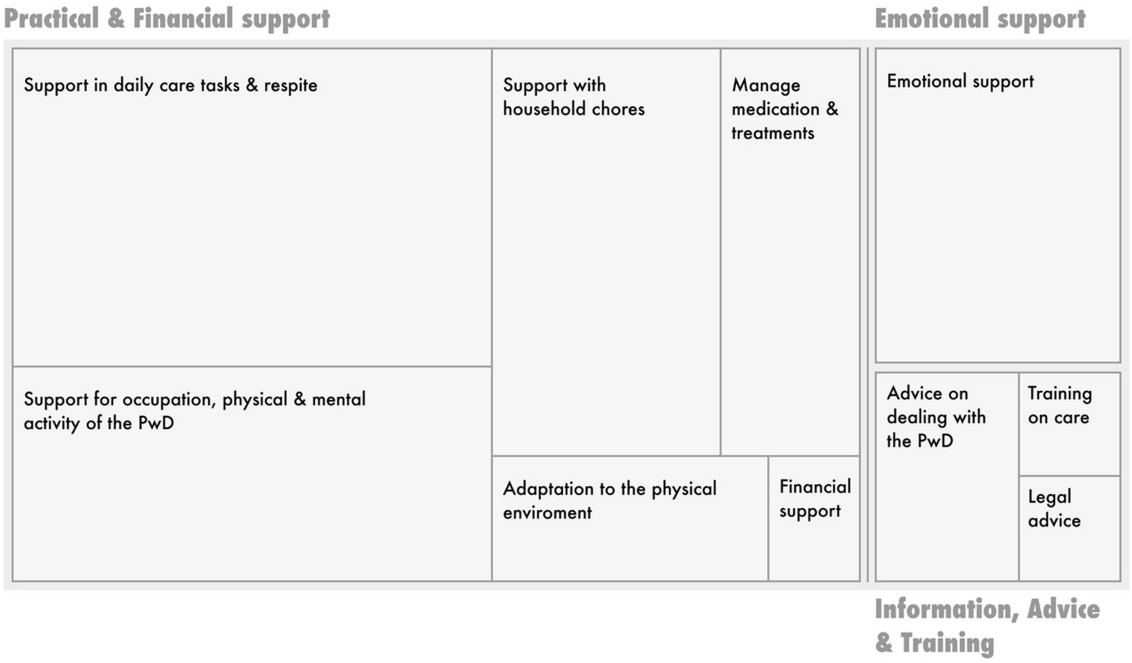

FIGURE 4
Visual representation of the number of items coded per coding category/node. Source: Nvivo 11, edited for improved visualization of category titles.

in the activities he likes best when I'm at work" (IC_781, daughter). Assistance with household tasks, including cleaning, meal preparation and grocery shopping was a common need. Financial support needs were the least expressed, although assistance with household chores or respite care most often depended on the family's financial resources.

Emotional support needs expressed by caregivers included support both from other caregivers – *"I would need to talk to someone who is going through the same difficulties"* (IC_272, granddaughter) and from mental health professionals – *"I would need psychological help, it's extremely difficult to live with a person in this [referring to dementia] situation. I understand and accept the illness, but at the same time I feel exhausted, tired and I've asked myself how much longer I can put up with it"* (IC_824, husband). The need for advice on how to deal and communicate with the PwD, how to provide practical care, and how to activate legal mechanisms such as power of attorney (*Regime do Maior Acompanhado*, e.g., IC_321, daughter), were also expressed.

4 Discussion and conclusion

Most people with dementia are cared for by unpaid caregivers, especially in low-and middle-income countries (Prince et al., 2015), and in regions where a familialistic model of care prevails (del-Pino-Casado et al., 2011) as in Portugal. Cultural and political issues are influential on how the profile of caregivers and their needs varies across countries as well as on the burden they support (Meijer et al., 2022). Understanding the characteristics and needs of informal caregivers and PwD is a national priority reflected in the Portuguese Health Strategy for Dementia (Order n.° 5988/2018, 19th June) and the Informal Caregiver Statute (Law no.100/2019).

This research contributes to this knowledge by providing a comprehensive description of the sociodemographic, clinical, and psychosocial profiles of informal caregivers and PwD, along with insights into service utilization and unmet caregiver needs. The data is drawn from early adopters of iSupport-Portugal, collected upon their registration within the platform. This study differs from previous research in several important ways. First, in contrast to other national research (Movimento cuidar dos cuidadores informais, 2021), it focuses on specifically characterizing informal dementia caregivers, who are thought to be at higher risk of experiencing mental health problems than caregivers of people with other chronic conditions (WHO, 2015; Gilhooly et al., 2016). Second, it stands out for the number of variables collected to characterize the profile of dementia caregiving dyads, including a comprehensive array of sociodemographic, contextual, and psychosocial variables, both modifiable and non-modifiable. Other national studies have made an outstanding contribution in measuring psychosocial variables among informal dementia caregivers [e.g., Gonçalves-Pereira et al. (2019)]. Nevertheless, this study broadens the scope by measuring additional dimensions such as positive aspects of caregiving, caregivers' use of community resources (e.g., psychoeducational groups), or the desire to institutionalize the PwD [a known predictor of actual institutionalization (Luppa et al., 2008)]. In addition, this research innovates in data collection methods by using a remote measurement tool (iSupport-Portugal) to collect nationwide data, thus overcoming the limitations of more circumscribed recruitment contexts (e.g., regional, or clinical recruitment).

Therefore, as a secondary by-product of the data collection through this platform, this research offers an opportunity to discuss the use of iSupport-Portugal as a RMT. Indeed, this study marks the first international exploration of iSupport beyond its original intervention purpose. From the preliminary measures taken to leverage iSupport-Portugal as a remote measurement tool (see Section 2.1, Preliminary Measures), several insights have been gained. Despite thorough preliminary testing of the platform (Teles et al., 2021) to prevent critical technical errors during data collection, the mobile

version of iSupport-Portugal is still undergoing enhancements, impacting the convenience of participants' self-completion of measurements. As illustrated in Tables 2–4, more than half of all eligible caregivers ($N = 173$) left at least one dimension unanswered when completing baseline measurements on iSupport's platform. Preliminary testing of the data collection protocol indicated that completing the measurements took approximately 25 min, which was perceived as time-consuming but feasible. However, when measures are completed remotely and independently, without researcher prompting, caregivers may be more inclined to withdraw or fill in the measurements at different times or on separate days. Altogether, this suggests that improvements are needed regarding the accessibility and conciseness of data collection measures. Furthermore, enhancements are required for the automation of reminder systems to prompt platform users to complete assessment measures.

As for the main results of this study, iSupport-Portugal has attracted considerable attention from both informal caregivers and health/social care professionals. Within just 6 months, there were 365 full registrations, with 52.3% being by informal dementia caregivers. Consistent with national and international research [e.g., Wimo et al. (2018), Gonçalves-Pereira et al. (2019), Paúl et al., (2019), and ADI (2022)] caregivers registering on iSupport-Portugal were predominantly female and middle-aged. A higher representation of children (70.5%) was observed than in other Portuguese studies [e.g., 30.3% in Gonçalves-Pereira et al. (2019); 45.5% in Paúl et al. (2019)]. In line with trends seen in Mediterranean countries, a notable rate of cohabitation with the PwD (Barbosa and Matos, 2014) and the provision of high-intensity care (>20 h/week) (Hirst, 2005) were observed. In this sample, a high level of education is observed and there is a high representation of employed caregivers. Hence, this study distinguishes itself from previous research by examining caregivers' needs in a context where achieving a work-life balance may be more challenging, and the choice to leave a career to provide full-time care may be less appealing (Flinn, 2018) or not be considered out of a necessity. Indeed, work-life balance concerns emerged in this study, as shown by the content analysis of text data (see section 3.2). Also pertinent to considerations on work-life balance is the provision of multigenerational care. As a relevant proportion of iSupport-Portugal users are children of PwD, this study gathered data on the number of offspring caregivers who live with their own children, of which over 70% were found to do so. While no significant association was found between being an offspring caregiver with cohabitating children and symptoms of burden, anxiety, or depression, previous studies have indicated that individuals who manage care responsibilities for both their parents and children - the so-called "sandwich" generation – have higher participation in the workforce and endure increased caregiving-related stress (Lei et al., 2023). Future research endeavors, with a larger user base of iSupport-Portugal, should delve deeper into this issue, given its substantial political implications.

The sociodemographic characteristics of PwD in this sample align with previous research, as does the clinical profile. Alzheimer's disease is the most common subtype of dementia, consistent with most national epidemiological studies (Garcia et al., 1994; Nunes et al., 2010; Santana et al., 2015; Gonçalves-Pereira et al., 2017). Neuropsychiatric symptoms were reported in 94.1% of PwD, consistent with international research indicating a prevalence of 50 to 98% in community-dwelling PwD (Zhao et al., 2016). The severity scores were higher than those reported in a national study (Gonçalves-Pereira et al., 2019). Neuropsychiatric symptoms are increasingly recognized as core features of Alzheimer's disease and other dementias, and a main contributor to caregiver psychological distress (Zhao et al., 2016) and institutionalization (Luppa et al., 2008). Therefore, the higher severity of neuropsychiatric symptoms in the care recipients of this sample may have prompted caregivers to seek online support. Apathy was the most common neuropsychiatric symptom, aligning with most research (Zhao et al., 2016). Appetite changes were more prevalent-than-usual (Zhao et al., 2016) in this study, but those may fall within the same subsyndrome category as apathy (Aalten et al., 2007).

Consistent with previous research, caregivers in this sample reported significant burden. However, for depression and anxiety symptoms, caregivers scored higher than in a recent Portuguese study that used the same measure (HADS M 6.5 and M 6.4 for anxiety and depression, respectively (Gonçalves-Pereira et al., 2019). This difference might be explained by the higher severity of neuropsychiatric symptoms reported in this sample. This is evidenced by the correlation of these symptoms with caregiver anxiety and depression, found in several other studies (Kim et al., 2021). The link between anxiety and employment status may also contribute to these elevated scores. Despite the high psychological distress observed in this sample, there was only a mild desire to institutionalize. The positive correlation found between caregiver burden and such desire highlights the need to intervene on modifiable factors to prevent the early placement of PwD.

This study has highlighted the low utilization of community support services by both PwD and their caregivers. Most of the caregiver support was coming from other informal sources. Less than a third of caregivers experiencing symptoms of depression and/or anxiety sought mental health support. The data does not indicate whether distressed caregivers not using mental health services were identified and referred by a health professional and chose not to use them or faced accessibility barriers. However, these findings may partly stem from underdiagnosis of depression and anxiety among informal dementia caregivers, as observed in other populations of caregivers (Zhang and Li, 2023). Recognizing that these caregivers are at higher risk of psychological distress, implementing routine screening in primary health settings, followed by referrals to mental health services and caregiver-centered interventions, is crucial to reduce the number of caregivers who are unsupported and untreated for their mental health concerns. Various factors contribute to the development of depression among dementia caregivers, including the characteristics and clinical profile of the PwD (Huang, 2022). Formulating individualized treatment plans and providing case management for both the PwD and their caregivers are crucial to address their needs effectively. Caregiver depression is increasingly impacting existing medical care, such as the utilization of emergency department services, underscoring the importance of addressing this issue from a healthcare cost management perspective as well. Upstream, early dementia diagnosis is crucial in helping caregivers adapt to their roles and access timely training and support interventions (de Vugt and Verhey, 2013).

Furthermore, caregivers supporting a PwD who was not utilizing community services tended to report more symptoms of anxiety and depression than those who were. This underscores the significance of enhancing the accessibility of community support services for PwD, including home care services, day, or night centers, cognitive or occupational therapy, and memory cafes, among others. In Portugal,

specialized social responses for PwD are scarce, and the coverage rate for social responses catering to older individuals, including home care services and day centers, was only around 12% in 2021 (GEP - Gabinete de Estratégia e Planeamento, 2021).

Also, despite provisions in the Portuguese Informal Caregiver Statute that emphasize respite care as a fundamental aspect of caregiver support to mitigate burnout and promote physical and mental health, none of the caregivers in this sample used such services. The data do not allow for conclusions to be drawn about whether the caregivers in this sample needed or wanted respite care, and whether they encountered obstacles in obtaining it. However, from a regulatory perspective, to benefit from respite care within the scope of the Informal Caregiver Statute (Law No. 100/2019), individuals must have been formally recognized under this statute as a principal or non-principal caregiver. Since only principal caregivers are entitled to a monthly allowance, and since qualifying as such requires meeting conditions such as not having a job, caregivers who are employed may be unwilling to undergo the bureaucratic hurdle of applying for the statute. More than 60% of the caregivers in this study were employed and therefore would not qualify as primary caregivers. In addition, waiting lists for respite care are typically long, and family co-payments are often a barrier to accessing these services. All these barriers may impact the number of caregivers benefiting from the support measures outlined in the caregiver statute, including respite care (Instituto da Segurança Social IP, Administração Central do Sistema de Saúde I.P, 2021), necessitating additional political attention.

The findings from this research should be considered in light of its specific characteristics or limitations. In this study, several correlation coefficients indicating statistically significant associations demonstrated relatively low values. However, in behavioral sciences, correlation coefficients ranging from 0.3 to 0.5 are typically regarded as indicative of a moderate relationship, consistent with Cohen's guidelines (Cohen, 1988). The relationships observed between the number of hours spent on caregiving and anxiety scores ($r_s = 0.266$), as well as between the positive aspects of caregiving and the severity of neuropsychiatric symptoms ($r_s = -0.248$), demonstrated weaker associations ($r < 0.3$) in this study.

As a potential limitation, the recruitment of caregivers for this research was not random and was conducted through the dissemination of iSupport-Portugal, which may have introduced volunteer bias. While this study may not guarantee national representativeness, convenience sampling aimed to avoid reproducing atypical situations. The dissemination efforts of iSupport-Portugal were extensive. Those involved collaboration with community projects and services, patient associations, communication with Portuguese Regional Health Administrations, and engagement with neurologists and psychiatrists in both private and public practice. Although the results may not generalize to the Portuguese population of informal dementia caregivers, the study sample is diverse and, overall, relatively typical in terms of sociodemographic characteristics, caregiving context, and caregivers' psychological needs. This includes the high rate of women, caregivers in cohabitation with the PwD, and high psychological distress. Nevertheless, caregivers who are children of the PwD, employed, and highly educated may be overrepresented in this sample. This fact is possibly due to the use of digital means for data collection and the program's appeal to newer generations of caregivers. A recent Portuguese study reported a higher-than-usual percentage of highly educated caregivers (Gonçalves-Pereira et al., 2019), although the prevailing description has been of lower education levels. Moreover, participants in caregiving studies are often recruited through community projects that are less accessible to employed, younger, and more educated caregivers, making this study potentially more inclusive in reaching caregivers who are typically underrepresented. As political investments across Europe to close the digital divide begin to yield results and digital natives assume caregiver roles, iSupport-Portugal may be able to reach a more diverse group of caregivers.

In conclusion, the baseline data from early adopters of iSupport-Portugal suggest significant psychological distress and unmet practical, emotional, and informational needs among informal caregivers of PwD. Despite limited utilization of community support services by both caregivers and PwD, caregivers reported higher levels of anxiety and depression when these services were not used. The ability to meet the needs of a growing number of PwD and ensure they can continue to receive quality care at home hinges on multiple factors, including the well-being of informal caregivers. Identifying caregiver needs in a timely manner and providing proactive interventions is therefore essential. iSupport-Portugal can serve as a valuable remote tool for collecting data and informing on the profile, needs, and resources of dementia care dyads. In the short term, this information could lay the groundwork for expanding and enhancing the training and support offered through iSupport-Portugal. This could involve creating new training modules or improving existing ones. Moreover, caregiver profiles could inform a recommendation algorithm within iSupport, directing users to modules and lessons tailored to their specific needs. On a broader scale, the insights gleaned from this study may inform both practice and policy. They underscore the underutilization of support services for caregivers, an area targeted for improvement politically both nationally, as evidenced in the recent Informal Caregiver Statute (Law no.100/2019), and internationally (WHO, 2017).

Upcoming research endeavors with iSupport-Portugal will focus on following up a cohort of caregivers on the desire to institutionalize and the actual institutionalization of PwD. This should allow to examine whether the sociodemographic and psychosocial variables collected at baseline and described in this study can be used to predict these outcomes.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by the Ethics Committee for Health of the Faculty of Medicine of the University of Porto (ref: 76/CEFMUP/2022). The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

ST: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Writing – original draft, Writing – review & editing. SA: Methodology, Writing – review & editing. OR: Methodology, Writing – review & editing. AlF: Methodology, Writing – review & editing. AnF: Methodology, Writing – review & editing. CP: Conceptualization, Funding acquisition, Methodology, Project administration, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Implementation of digital health technologies for older adults: a scoping review

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The critical importance of technological innovation in home care for older adults is indisputable. Less well understood is the question of how to measure its performance and impact on the delivery of healthcare to older adults who are living with chronic illness and disability. Knowing how well digital technologies, such as smartphones, tablets, wearable devices, and Ambient Assisted Living Technologies (AAL) systems "work" should certainly include assessing their impact on older adults' health and ability to function in daily living but that will not guarantee that it will necessarily be adopted by the user or implemented by a healthcare facility or the healthcare system. Technology implementation is a process of planned and guided activities to launch, introduce and support technologies in a certain context to innovate or improve healthcare, which delivers the evidence for adoption and upscaling a technology in healthcare practices. Factors in addition to user acceptance and clinical effectiveness require investigation. Failure to appreciate these factors can result in increased likelihood of technology rejection or protracted procurement decision at the "adoption decision" stage or delayed or incomplete implementation or discontinuance (following initial adoption) during implementation. The aim of our research to analyze research studies on the effectiveness of digital health technologies for older adults to answer the question, "How well do these studies address factors that affect the implementation of technology?" We found common problems with the conceptualization, design, and methodology in studies of digital technology that have contributed to the slow pace of implementation in home care and long-term care. We recommend a framework for improving the quality of research in this critical area.

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KEYWORDS

ambient assisted living, aging, digital health, gerontechnology, technology implementation, scoping review

Introduction

The critical importance of technological innovation in home care for older adults is indisputable (Rogers and Mitzner, 2017; Linskell et al., 2019; Rajer and Bogataj, 2022). Less well understood is the question of how to measure its performance and impact on the delivery of healthcare to older adults who are living with chronic illness and disability (Matthew-et al., 2016). Knowing how well digital technologies, such as smartphones, tablets,

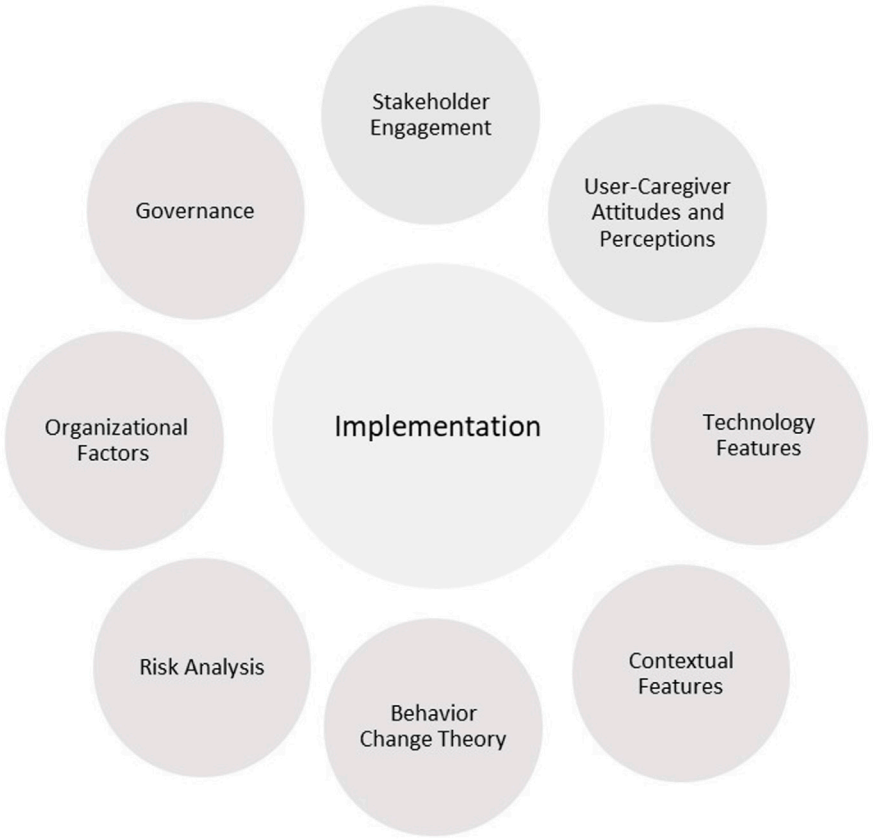

FIGURE 1
Categories of factors affecting implementation of digital technologies.

wearable devices, and Ambient Assisted Living Technologies (AAL) systems "work" should certainly include assessing their impact on older adults' health and ability to function in daily living. However, it should not be assumed that, because a technology produces clinical benefits and is acceptable to the user, it will necessarily work in the sense that it provides solutions for the needs of users and healthcare facilities that will be adopted and implemented.

Technology implementation has been defined as a process of several planned and guided activities to launch, introduce and maintain technologies in a certain context to innovate or improve healthcare, which delivers the evidence for adoption and upscaling a technology in healthcare practices (van Gemert-Pijnen, 2022). For digital technologies to be successfully implemented in delivery of healthcare and social services to older people, factors in addition to their user acceptance and clinical effectiveness require investigation. Failure to appreciate these factors can result in increased likelihood of technology rejection or protracted procurement decision at the 'adoption decision' stage or delayed or incomplete implementation or discontinuance (following initial adoption) during implementation (Kyratsis et al., 2012).

Categories of factors that are proposed to affect the implementation of healthcare technologies have been identified in the literature (Kyratsis et al., 2012; Keyworth et al., 2018; van Gemert-Pijnen, 2022) and are depicted in Figure 1. Some categories, such as Governance, Organizational Factors, and Risk analysis, may be more applicable to some residential settings (e.g., long-term care facilities or retirement communities) than others (e.g., community-dwelling older adults). For example, issues of governance and care facility management would have lesser importance for older adults who consume technologies in their private homes and apartments but significant importance for agencies that purchase and maintain technologies for older adults who are under their care.

Stakeholder engagement is regarded as crucial for ensuring that a technology realizes the values of end users and other stakeholders and identifying issues for implementation (van Gemert-Pijnen, 2022). *Behavior change theory* is recognized as an important ingredient (Keyworth et al., 2018). Types of technology interventions that have been shown to be effective include reminders and alerts and computer-generated feedback. The most targeted behavior is adherence to clinical prescriptions and prescribing behaviors. Behavior change techniques include instruction on how to perform the behavior, feedback on behavior, prompts and cues, demonstration of the behavior, reducing negative emotions, social comparison, and problem solving. *Contextual features* include practice and workload considerations. *Features of the technology* include pilot testing before wide-scale usage, an iterative modification approach, and the ease of use of the technology. The *attitudes and perceptions* of older adult users and their caregivers, who include healthcare providers, are important for adoption and use. *Organizational*

factors are also critical for successful implementation (Kyratsis et al., 2012). Technology researchers and developers should recognize that the key motivator for adoption decisions by healthcare organizations is finding solutions to problems. Among types of knowledge, scientifically produced research evidence has the highest priority for judging technology effectiveness. It is often combined with experiential ("how-to") knowledge to evaluate the appropriateness of technology for a particular setting. *Governance*, by way of establishing vision, leadership, policy, and accountability, is essential for sustaining implementation through appropriate planning, commitment of staff, manageable workload, and positive attitudes (van Gemert-Pijnen, 2022).

There will necessarily be variation in implementation performance since different agencies, whether they be households, healthcare facilities, or healthcare systems, will not respond in these categories in the same way (Goggin, 1986). Technology researchers and developers should be aware of this variation and consider how they might assist potential adopters to do implementation planning within their areas of competence and expertise.

A final set of factors pertains to *risk analysis*, which helps us understand and prepare responses for the potential risks associated with adopting and implementing the new technologies. Brown and Osborne (Brown and Osborne, 2013) identified the key elements for analysis and classified risks as follows. The locus for *consequential* risk is the individual and refers to direct risk to the user of the digital health service. For example, deviation from established approaches to home care for older adults may introduce emotional distress and risks to physical health. The locus for *organizational* risk is the service agency and its staff. The risk here involves vulnerable individuals remaining living independently for longer than they might have been able to and the implications for the organizational or professional reputation and/or legitimacy and sustainability of the service agency. For example, managers and staff tend to be risk averse and may tend toward concealing errors instead of identifying and learning from them. The locus for *behavioral* risk is the community of interest and involves risk to the stakeholders surrounding a service and/or the wider community. For example, digital health technologies, while offering a more appropriate response to the needs of community-dwelling older adults, can lead to risks to other people in the community, such as distress to uncomprehending relatives and neighbors. Implementation is undermined by failure to acknowledge and discuss these risks.

As an important first step toward understanding the state of knowledge on this topic, we performed a scoping review. The aim was to characterize the research available to address the question, "How well have research studies on the effectiveness of digital health technologies for older adults addressed factors that affect the implementation of these technologies?" In our analysis, we looked for evidence that researchers considered the implementation factor categories described above in their studies.

Methods

Study design

We conducted a scoping review of the peer-reviewed literature with an unlimited publishing time limit. As described by Arksey and O'Malley (Arksey and O'Malley, 2005) and Levac et al. (Levac et al., 2010), the use of scoping reviews was determined to be the most appropriate approach to collate a wide range of evidence and identify research gaps in the literature. The findings can be used for mapping a complex area of investigation and informing future research. The population of interest is older adults living with chronic health conditions and disabilities. In this review, we did not restrict the range of digital health technologies and settings for their application, as we were interested to learn if studies addressed factors for digital health technology implementation, whether an older adult was living at home in the community or in long-term care or similar facility. The potential range of devices includes ambient assisted living (AAL) systems, wearable sensors, smart everyday objects, environmental sensors, and social assistive robots that are intended to be used by older adults, their caregivers, and healthcare providers (Cicirelli et al., 2021).

The research question was composed based on a lack of consensus in the research literature on the most appropriate set of indicators for the successful implementation of digital health systems in all settings that matter. It should be noted that we did not evaluate methodological quality of included studies, in accordance with the convention for scoping reviews. A detailed search strategy for peer-reviewed literature was developed prior to conducting any searches. The review protocol was designed and conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) (RRID:SCR_018721) guidelines and was registered with Open Science Framework (RRID:SCR_003238) to increase research transparency and prevent any duplication efforts as per best practice guidelines.

Eligibility criteria

We considered all peer-reviewed journal articles related to technologies for assisted living for older adults (aged 60+ years) and published in English. This age group was selected as the definition of 'older adults' because in most contemporary Western countries, 60 or 65 is the age of eligibility for retirement and old-age social programs (OECD, 2021). We did not consider any grey literature reports. A complete list of the eligibility criteria is shown in Table 1. To be included in this review, the authors of the original papers did not have to explicitly name "implementation" as an outcome or objective of the study. The reviewers included all studies that reported outcome measures relevant to the effectiveness, feasibility, and implementation of digital technologies as noted in the introduction to this article.

Search strategy

The technical information about the search strategy is presented in Appendix. A systematic search of the following five academic databases was conducted to identify relevant peer-reviewed results: Ovid MEDLINE/PubMed, Scopus, Ovid Embase, Ovid PsycINFO and Ovid Cochrane Library (Cochrane Central Register of Trials). The search strings used for the academic databases (available on request from the

TABLE 1 Scoping review search methodology: eligibility criteria.

Eligibility criteria	Exclusion criteria
Unlimited timeframe. Specific timeframe will be concluded once all articles have been found	Newspaper articles, working papers, conference papers, editorials, or book chapters
Worldwide data	N/A
Original research; unpublished trials, any other Reviews	Did not describe original research
Evidence on indicators of successful technology implementation among elderly people	N/A
Available in English	In languages other than English

authors) were developed with guidance from a university librarian with expertise in the health sciences. This search of electronic databases was conducted using only English search terms. All results retrieved by the search were imported into Covidence (RRID:SCR_016484; Veritas Health Innovation, Melbourne, AU, 2020) a web-based software for systematic reviews, and duplicates were automatically removed.

Selection of articles for review

Two reviewers (FH and DB) screened all peer-reviewed results using Covidence. The screening of search results from the electronic academic databases occurred in two phases. First, two reviewers (FH and DW) independently screened the title and abstract of each article using the predefined eligibility criteria; any disagreements were resolved via consensus. Next, both reviewers screened the full texts of potential articles for eligibility by both reviewers. Disagreements were also resolved by discussion and/or consultation with a third reviewer (JJ) when necessary. All articles that remained after full text screening were included in the study. Figure 2 summarizes study selection process for peer-reviewed and grey literature, based on the PRISMA-ScR reporting guidelines.

A total of 150 studies were dropped at the full-text screening phase as "wrong outcomes" and 86 as "wrong intervention". Our selection criteria did not exclude outcome measures and digital health technology interventions based upon lists of examples because we did not want to risk overlooking any promising studies. Studies that were screened out for the reasons listed above included those that described outcome measures and interventions that were irrelevant for implementation, such as bio-signal characteristics and electronic medical records, respectively.

Data extraction and charting

Following the screening of results, three reviewers (FH, DB, MH) extracted from each article. The extracted data included author and publication year, publication type, data collection period, population and key results related to the research question. Four reviewers (FH, DB, MH, JJ) completed validation of the extracted data. We subsequently grouped the results by outcome measure and relevancy.

Data analysis

As scoping reviews typically do not include an assessment of methodological limitations or the potential for evidence bias (Munn et al., 2018), we elected to focus our analysis on the implications for future research design, rather than the practical applications of our findings.

Results

Table 2 presents essential information from the 26 selected articles, which includes the study population, nature of the technology intervention, the outcomes that were assessed, and implications of the study findings for technology implementation. Five of the articles were reviews (scoping or systematic). The populations researched in these articles were overwhelmingly community-dwelling older adults (n = 17), but also long-term care and nursing homes (n = 4), retirement community or village (n = 3), setting not specified (n = 1), and implementation stakeholders (n = 1). The categories of interventions were information and communication technologies (n = 7), wearable sensors (n = 2), ambient assisted living technologies (n = 6), assistive robots (n = 5), interventions to overcome barriers to using technologies for aging in place (n = 1). Some articles discussed several different categories (n = 5). The domains in which outcomes were assessed spanned a wide range at the levels of users (or residents), healthcare providers, and healthcare facilities. Most of the studies used measures of user acceptance and intention to use technology (derived from the Technology Acceptance Model and its variants) (n = 9). Note that only nine of these studies explicitly discussed the relevance of the findings for implementation.

From the list of implementation issues identified in the selected studies, we detected the following themes:

1. *Communication* (technology utilization and functionality poorly communicated to users).
2. *Context sensitivity* (e.g., need to train users in their homes; need to investigate workflow compatibility).
3. *Design* (importance of co-design with users and caregivers).
4. *Economic analysis* (e.g., cost-benefit analysis).
5. *Ethical considerations* (e.g., need for ongoing processes for assent for users with dementia).
6. *Outcome assessment* (inconsistent across studies; not comprehensive with respect to user and caregiver needs, emotional satisfaction, and health benefits).

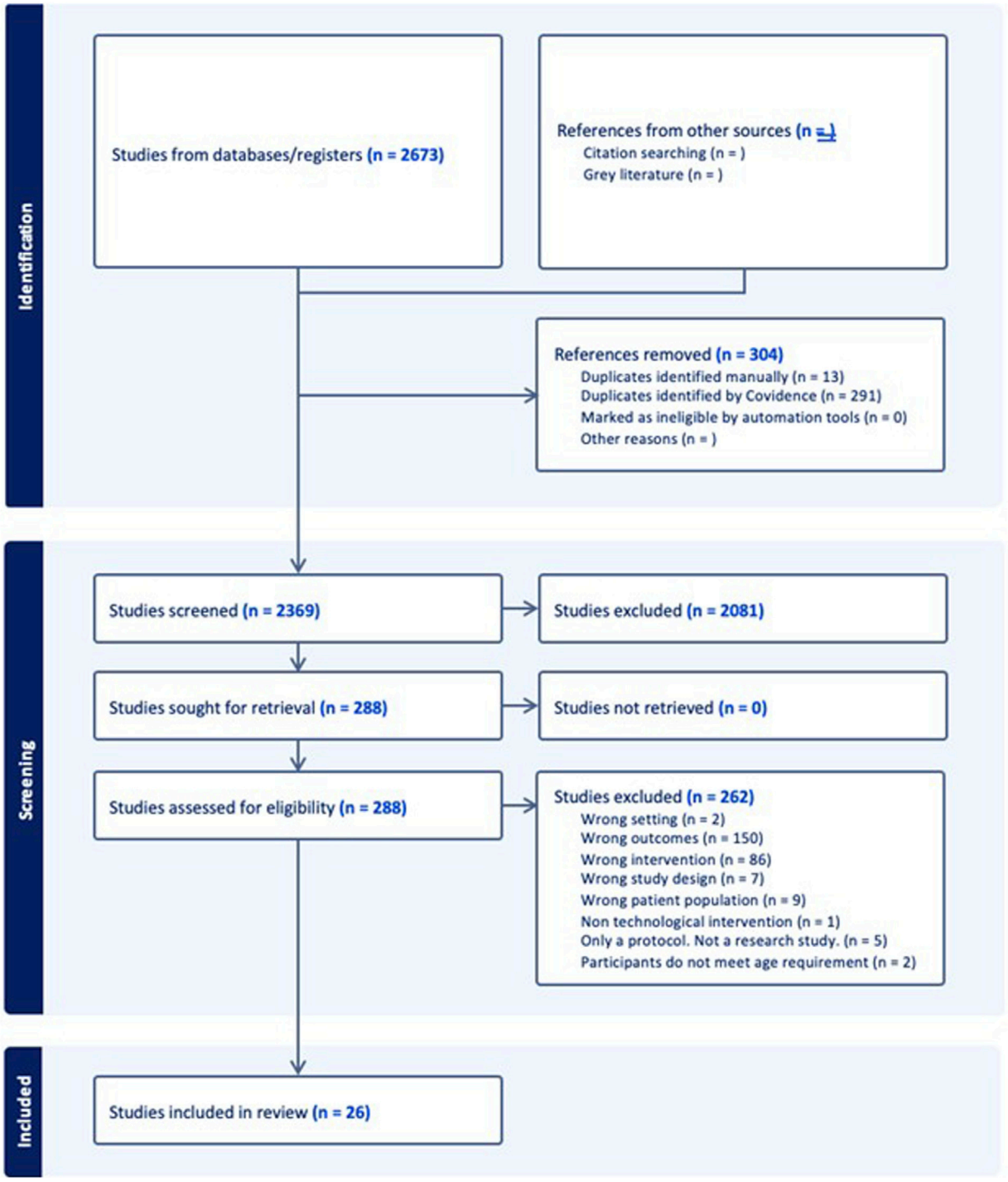

FIGURE 2
PRISMA flow diagram of systematic search of peer-reviewed and grey literature.

7. *Quality of research* (weak evidence basis; poor methodology; lack of theoretical grounding; lack of cross-product comparisons; lack of longitudinal studies to analyze dynamic variations in physical, social, and cultural environments).
8. *Technology maturity and readiness* (unreliability; malfunction and maintenance concerns).
9. Unmet user needs and expectations.
10. *User education and training* (e.g., peer-supported training).

Table 3 presents an analysis of whether the selected articles referred to implementation factors presented in Figure 1. Those marked with an asterisk (*) made explicit reference to the relevance of their research for technology implementation. Most of the articles reviewed made only indirect references to implementation. The overwhelming focus of

TABLE 2 Details from the selected articles.

Article	Population	Intervention	Outcomes assessed	Implementation implications
[a]Bail et al., 2022 (Bail et al., 2022) (systematic review)	older adults in long-term care and nursing homes	health information technologies for electronic health record, medication management, skin management, and communication (e.g., telehealth)	facility-level outcomes, nurse outcomes, and resident outcomes for acceptability, satisfaction user perceptions, worker time, timeliness of care, and quality of care	the probability of implementation success is higher when technology systems are co-designed with residents and staff; most of the studies reported technology problems and maintenance issues; the functionality of the technology was poorly communicated and did not meet user needs and expectations; rarely was the same outcome assessed across studies; studies seldom captured the complexity and relatedness of resident care needs
Berquist et al., 2020 (Bergquist et al., 2020)	community-dwelling older adults	smartphone app–based self-tests of physical function	usability measures	high error rates due to users misunderstanding instructions
*Bieryla et al., 2013 (Bieryla and Dold, 2013)	older adults living independently in a senior living community	Nintendo Wii Fit for improving balance	Berg Balance Scale, Fullerton Advance Balance Scale, Functional Reach test, and Timed Up and Go test	the study did not actually include training in the participants' homes
*Braspenning et al., 2022 (Braspenning et al., 2022)	three stakeholder groups involved in the implementation process of lifestyle monitoring (informal caregivers, healthcare professionals, and healthcare managers)	technology for ambient assisted living	interview guide based on normalization process theory (NPT) constructs (coherence, cognitive participation, collective action, and reflexive monitoring)	barriers to implementation were a perceived inflexibility in how the technology should be used and integrated with organizational workflows; lack of a clear business case for engaging with healthcare managers; and perceived unreliability of the technology
Broadbent et al., 2015 (Broadbent et al., 2015)	older adults residing in a retirement village hospital and rest home setting and care staff	multiple healthcare robots	quality of life, depression, and dependency (mobility, activities of daily living, and behaviour)	no safety concerns; staff were more positive toward robots than residents
*Cavallo et al., 2015 (Cavallo et al., 2014)	community-dwelling older adults with dementia	technology for ambient assisted living	unvalidated 5-point rating scales about the technology's usefulness, obtrusiveness, and acceptability, from a multidisciplinary team of clinicians, engineers, psychologists, and therapists	authors stressed the importance of extensive consultation with stakeholders on technical, ethical, legal, clinical, economic, and organizational implications of technology implementation
Choukou et al., 2021 (Choukou et al., 2021) (scoping review)	community-dwelling older adults	technology for ambient assisted living	perceived usefulness, ease of use, intention to use, and user acceptance	authors concluded that the methodological quality of research in this area was poor (only one study evaluated all four aspects of the Technology Acceptance Model); need for studies that use a comprehensive evaluation framework that considered the needs and preferences of intended users at each stage of technology development
Fan et al., 2017 (Fan et al., 2017)	older adults in long-term care and nursing homes	socially assistive robots (SARs)	user's acceptance and intention to use new technology based on performance expectancy, effort expectancy, attitude toward using technology, and self-efficacy; level of enjoyment and interest	Authors recommended studies of long-term effect of SARs, including misuse of robots, decreased human contact, loss of control, loss of privacy, and feelings of objectification
Fiorini et al., 2021 (Fiorini et al., 2021)	older adults living in long-term care and nursing homes	robots that provide functional assistance (ASTRO robot)	attitudes and beliefs in the ability of the robot to address primary needs; concerns about stigma and replacement of human care	Implementation challenges included the capability of robots to navigate dynamic variation in the physical and social/cultural environments in the longer term, to detect and manipulate a wide variety of objects in different contexts, to act autonomously, and to interpret human emotions and react appropriately in social situations

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TABLE 2 (*Continued*) Details from the selected articles.

Article	Population	Intervention	Outcomes assessed	Implementation implications
Gettel et al., 2021 (Gettel et al., 2021) (scoping review)	community-dwelling older adults	software apps, augmented and virtual reality, care robots, home monitoring systems, intelligent cognitive assistants, and wearable activity monitors and cameras	measures of behavior, working memory and physical activity	barriers to adoption and implementation included lack of experience with technology, difficulties learning to use technology, privacy concerns, and fears that technology (e.g., social robots) would lead to social isolation; potential users need education and training; implementation studies are badly needed
Law et al., 2019 (Law et al., 2019)	community-dwelling older adults with mild cognitive impairment (MCI) or early dementia	home-based healthcare robot	perceived usefulness	implementation challenges included technical problems with the robot and lack of research studies with longitudinal designs and comparison of different robots
Lesauskaitė et al., 2019 (Lesauskaitė et al., 2019)	community-dwelling older adults and geriatric in-patients	computers, the internet, smartphones, and fall detectors	self-report questionnaire on the knowledge, readiness to use, and use of technologies	smartphones were less stigmatizing than non-digital technologies; privacy concerns about smart home technology were inversely correlated with user health needs
McMahon et al., 2016 (McMahon et al., 2016)	community-dwelling older adults	wearable physical activity monitors (Fitbit One)	questionnaire based on the Technology Acceptance Model (TAM)	the technology was found to be easy to use, useful and acceptable; authors recommended that studies compare several types of monitors, and measure emotional satisfaction and health benefits
Moyle et al., 2018 (Moyle et al., 2018)	dementia patients in long-term care	PARO robotic seal	motor activity and sleep patterns (SenseWear® armband)	participants did not tolerate wearing the armbands; devices were often unreliable in their recording; care staff should monitor adherence and remind residents about wearing devices appropriately
*Moyle et al., 2021 (Moyle et al., 2021) (scoping review)	community-dwelling older adults with dementia	technology for ambient assisted living	various measures of technology effectiveness	authors recommended that evaluation of the technology should occur only when it is at a level of sufficient development, to avoid ongoing and disruptive technical issues
Neal et al., 2021 (Neal et al., 2021) (systematic review)	community-dwelling adults with a diagnosis of dementia or with MCI	digital technology (if it was inherently dependent on any electronic device that comprised, or interfaced with, any kind of computer)	self-management and social participation	study authors made surprisingly few statements about implementation; identified implementation factors were enjoyment from technology use and complexity or limited functionality of technology; the availability of high-quality evidence in this field does not seem to have significantly progressed from previous reviews
Orellano-Colón et al., 2016 (Orellano et al., 2016)	community-dwelling older adults	a wide variety of technology devices for aging in place, including digital health technologies	user-perceived challenges, barriers or obstacles for using technology devices	lack of awareness and information about technology, cost, limited coverage of technology by healthcare plans, and perceived complexity of technology
Orellano-Colón et al., 2020 (Orellano et al., 2020)	community-dwelling older adults	intervention to overcome barriers to using technologies for aging in place	acceptability, effectiveness, physical and mental health, psychosocial impact, and self-efficacy	self-management and behavioural change techniques for technology users can facilitate implementation
*Peek et al., 2017 (Peek et al., 2017)	community-dwelling older adults	a wide variety of technology devices for aging in place, including digital health technologies	reasons for device ownership and frequency of use, and attitudes and perceptions about these devices	factors affecting implementation included: favorable or unfavorable beliefs concerning the reliability, lifespan, power consumption, and costs of purchase and maintenance of technology; positive and negative consequences of using technology for users and caregivers; self-efficacy for using technology; user's social network, social agencies, and compatibility of the technology with the user's physical environment

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TABLE 2 (*Continued*) Details from the selected articles.

Article	Population	Intervention	Outcomes assessed	Implementation implications
*Reeder et al., 2013 (Reeder et al., 2013)	older adults living in a retirement community	technology for ambient assisted living	self-report standardized measures of physical mobility, psychosocial health, and cognitive health, and fall tracking	authors reported significant implementation challenges with the sensor-based monitoring system; recommended that study designs use mature and reliable technology, provide adequate resources for installations, and ensure that participants are informed in advance that there may be technical problems
Sánchez et al., 2019 (Sánchez et al., 2019)	community-dwelling older adults	technology for ambient assisted living	attitudes and perceptions	implementation challenges included costs, loss of autonomy and personal dignity, and a preference for human care; participants were not concerned about privacy
*Sautter et al., 2021 (Sautter et al., 2021)	older adult with mild and advanced dementia	touch-screen computer applications to enhance social connection, facilitate entertainment, and implement cognitive training	frequency counts of challenging behaviors and cognition (attention, concentration, executive functions, memory, language, conceptual thinking, calculations, and orientation)	authors recommended that studies with participants who have dementia should use ongoing processes for assent and building rapport between study personnel and participants (both older adults and caregivers)
Schoon et al., 2020 (Schoon et al., 2018)	community-dwelling older adults	self-management fall prevention program using a wearable gait-speed feedback device	compliance (number of weekly gait speed measurements and reasons for not having a measurement), falls (via telephone), mobility (Timed Up and Go), and disability (Katz-15 scale)	the intervention had good technical feasibility and compliance, but it did not produce overall positive outcomes; authors recommended that future research examine all constructs of the TAM
*Selye et al., 2020 (Seelye et al., 2020)	community-dwelling older adults	sensors and software to monitor pill-taking, steps taken, time spent sleeping, and computer use in a real-world assessment of digital health technology in the homes	standardized neuropsychological test, health assessments, and daily function questionnaires	feasibility issues included technical problems with installation and in-home technology maintenance
Wang et al., 2020 (Wang et al., 2020)	community-dwelling older adults	an integrated, personalized telehealth monitoring system (steps and sleep data using a Fitbit, and gait and balance status using wearable sensors)	users' acceptance of the system with respect to attitude, self-efficacy, perceived usefulness, perceived ease of use and behavioural intention	users found the system easy and comfortable to use and useful for improving their health, and intended to use the system in their future health management
Wu et al., 2015 (Wu et al., 2015)	community-dwelling older adults	information and communication technologies (ICTs)	attitudes toward ICTs	authors recommended that older adults get appropriate training and support in ICT use through peer-supported training, to improve their technology skills and their attitudes toward technology

[a]Denotes that the authors made explicit reference to the relevance of their research for technology implementation.

studies has been on implementation issues related to features of the technology under investigation and the attitudes and perceptions of technology users and caregivers. As previously noted the methodological rigour of these studies was weak. Very few studies used a theory-driven approach and validated methods for assessing attitudes and perceptions. We were unable to find any studies of the impact of governance and risk analysis on the implementation of digital health technologies for older adults.

Discussion

We found that understandings about factors affecting implementation across research studies of digital health technologies for older adults varied significantly and was reflected by a wide variety of methods for technology evaluation and uneven quality of research. Most of the research studies were either focused on the smart home technology development phase or were laboratory-based evaluation studies that narrowly defined implementation in terms of technical feasibility, clinical effectiveness, and user acceptance. None of these articles examined the full range of implementation factors depicted in Figure 1 for either community-dwelling older adults or those residing in long-term care facilities.

Areas where high-quality research is particularly needed include managing risks of discontinuous, potentially disruptive innovations by health and social services (Brown and Osborne, 2013), developing culturally and linguistically appropriate technology-delivered interventions for ethnic minority older adults (Chung et al., 2016), evaluating the impacts of technology implementation on service delivery (Cucciniello and Nasi, 2013), and adoption and long-term use of technologies for health self-management (Courtney, 2008; Lee and Coughlin, 2015). In each setting in which digital health technologies may be deployed, we need to understand how they should be developed alongside the networked social relations that make them 'work' and

TABLE 3 Analysis of implementation factors for the selected studies.

	Category of implementation factor								
Article	Behavior change theory	Contextual features	Stakeholder engagement	Technology features	User-caregiver attitudes and perceptions	Governance	Organizational factors	Risk analysis	No. of categories assessed
[a]Bail et al., 2022		√	√	√	√		√		5
Berquist et al., 2020				√					1
[a]Bieryla et al., 2013				√					1
[a]Braspenning et al., 2022		√	√	√	√		√		5
Broadbent et al., 2016		√		√	√				3
[a]Cavallo et al., 2015			√	√			√		3
Choukou et al., 2021					√				1
Fan et al., 2017				√					1
Fiorini et al., 2021				√	√				2
Gettel et al., 2021	√			√	√				3
Law et al., 2019				√	√				2
Lesauskaitė et al., 2019					√				1
McMahon et al., 2016					√				1
Moyle et al., 2018		√		√	√				3
[a]Moyle et al., 2021				√					1
Neal et al., 2021	√			√					2
Orellano-Colón et al., 2016				√	√				2
Orellano-Colón et al., 2020					√				1

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TABLE 3 (*Continued*) Analysis of implementation factors for the selected studies.

Category of implementation factor									
Article	Behavior change theory	Contextual features	Stakeholder engagement	Technology features	User-caregiver attitudes and perceptions	Governance	Organizational factors	Risk analysis	No. of categories assessed
[a]Peek et al., 2017		√			√				2
[a]Reeder et al., 2013				√	√				2
Sánchez et al., 2019					√				1
[a]Sautter et al., 2021	√		√						2
Schoon et al., 2020				√	√				2
[a]Selye et al., 2020				√					1
Wang et al., 2020					√				1
Wu et al., 2015		√			√				2
Category Total	3	6	4	17	18	0	3	0	

[a]Denotes that the authors made explicit reference to the relevance of their research for technology implementation.

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pragmatically customized to meet older adults' unique and changing medical, personal, social, and cultural needs" (Greenhalgh et al., 2015; Sánchez et al., 2015; Jutai et al., 2022).

It is unreasonable to expect that a single research study should investigate in all eight of the categories of implementation factors that we identified. We argue, though, that the quality of research in this area would be markedly improved if researchers would subscribe to a more comprehensive program logic for their studies. For example, investigations of the technical feasibility, clinical effectiveness, or user acceptance of a new technology should show how they have anticipated the most pressing concerns that might arise from the domains of behavior change, governance, organizational factors, risk analysis, and stakeholder engagement. Adherence to an accepted conceptual framework should improve the likelihood of successful technology implementation. Several published frameworks, such as NASSS (Greenhalgh and Abimbola, 2019), CeHREs (van et al., 2011), and SCIROCCO (Grooten et al., 2020) offer excellent, detailed guidance, and we encourage researchers to consider them. We recommend their use because they can inform the design of a new technology, identify technological solutions that have a limited chance of achieving large-scale, sustained adoption, help to plan the implementation of technology, and help explain and learn from implementation failures (Greenhalgh et al., 2017). These frameworks are underutilized at present, due in part to their recent development, but probably also due to a need for them to be adequately contextualized for individual technologies (Abell et al., 2023).

Limitations

Our study did not include stakeholder consultation on the scoping review but we plan to conduct stakeholder evaluations of the provisional framework, to identify opportunities for its application across the broadest possible range of digital health technologies for older adults.

Future directions

Our findings reinforce the view that implementation is often planned and executed only after the design of a technology has been completed. Future studies of technology development should include consideration of the eight categories of factors that can affect implementation. They should acknowledge the implications of the technology not only for individual users, but the healthcare system and society at large (van Gemert-Pijnen, 2022). We recognize that it is challenging for a single study to address all these factors, but if indeed the goal for the research is to achieve successful implementation of the technology, then researchers should be expected at least to demonstrate their awareness of the issues.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

Author contributions

JJ: Conceptualization, Funding acquisition, Project administration, Writing–original draft, Writing–review and editing. FH: Data curation, Methodology, Software, Writing–review and editing. DB: Data curation, Formal Analysis, Methodology, Writing–review and editing. MH: Data curation, Formal Analysis, Methodology, Writing–review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fragi.2024.1349520/full#supplementary-material

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The evaluation of a decision support system integrating assistive technology for people with dementia at home

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Introduction: With a decreasing workforce of carers and a transition from care homes to home care, people with dementia (PwD) increasingly rely on informal caregivers (ICs) and assistive technologies (ATs). There is growing evidence that ATs in the home environment can reduce workload for formal carers (FCs) and ICs, reduce care costs, and can have a positive influence on quality of life (QoL) for PwD and their caregivers. In practice, using multiple ATs still often implies using different separate point solutions and applications. However, the integral, combined use of the data generated using various applications can potentially enhance the insight into the health and wellbeing status of PwD and can provide decision support for carers. The purpose of the current study was to evaluate the use of a DSS that integrated multiple ATs into one dashboard through a small-scale field study.

Methods: The current study presents the formative evaluation of a Decision Support System (DSS) connected to multiple ATs. This DSS has been developed by means of co-creation during an international project. The DSS provides an insight into the physical and cognitive status of a PwD, as well as an insight into sleep activity and general wellbeing. Semi-structured interview sessions were held in three countries (Netherlands, Italy, and Taiwan) with 41 participants to gain insight into the experiences of formal and informal carers and PwD with both the ATs and the DSS Alpha prototype dashboard.

Results: The results showed that participants using the DSS were satisfied and perceived added value and a fit with certain care demands from the PwD. In general, ICs and FCs have limited insight into the status of PwD living independently at home, and in these moments, the DSS dashboard and AT bundle can provide valuable insights. Participants experienced the DSS dashboard as well-organized and easy to navigate. The accuracy of the data displayed in the dashboard is important, the context, and (perceived) privacy issues should be tackled according to all users. Furthermore, based in the insight gained during the evaluation a set of design improvements was composed which can be used to further improve the DSS for the Beta evaluation.

Discussion and conclusion: The current paper evaluates a possible solution for excess AT usage and how the use of a DSS which integrated multiple AT into one single technology could support caregivers in providing care for PwD. The formative evaluation scrutinized the integration of the developed DSS and the composed bundle of ATs across diverse cultural contexts. Insights from multi-center observations shed light on user experiences, encompassing overall usability, navigational efficacy, and attitudes toward the system. FCs and ICs expressed positivity toward the DSS dashboard's design and functionalities, highlighting its utility in remote monitoring, tracking changes in the person's abilities, and managing urgent situations. There is a need for personalized solutions and the findings contribute to a nuanced understanding of DSS and AT integration, providing insights for future developments and research in the field of DSS for the care of PwD.

KEYWORDS

assistive technology, gerontechnologies, home support, decision support system, AI, people with dementia, formal carers, informal carers people with dementia

1 Introduction

In 2015, the total estimated worldwide cost of dementia care had reached $818 billion and it is expected that dementia will become a trillion-dollar disease (Prince et al., 2015). This financial burden is a significant concern, especially considering aging populations and a shrinking workforce of formal carers (FCs). In response, there has been a shift toward stimulating older persons, including PwD, to live in their own residences for as long as possible, which is also an increasing desire by many older adults themselves (Rogers and Mitzner, 2017). However, living at home for as long as possible also requires additional support for a PwD. This support can come from informal caregivers (ICs) as well as supportive technologies that can alleviate the care burden and at the same time improve the safety and quality of life (QoL) of PwD. When the transition to a care home becomes inevitable, the limited nursing workforce underscores the importance of employing technologies that can reduce the care burden.

Given the growing reliance on ICs at home, it becomes essential to examine the challenges that accompany their role. Studies have shown that supporting a PwD takes a heavy toll on ICs (van der Lee et al., 2014; Lindt et al., 2020), both in terms of economic and social costs. These costs become even higher as dementia progresses (Brodaty and Donkin, 2009). On the positive side, caring for a loved one can result in a sense of meaning, companionship, and improved QoL (Yu et al., 2018).

The long-term healthcare sector is already facing a recruitment challenge of FCs, which has further been exacerbated by the COVID-19 pandemic leading. This has led to increased labor shortages across the world (Denny-Brown et al., 2020). One contributing factor to this challenge is the demanding working conditions in the sector (Causa et al., 2021). Nevertheless, there is growing evidence that assistive technologies (ATs) in the home environment can reduce workload for FCs and ICs, reduce costs, and can have a positive influence on QoL for PwD and their carers (Madara Marasinghe, 2016; Neal et al., 2020). Examples of ATs are lifestyle monitoring systems to detect changes in life patterns (Zwierenberg et al., 2018), social robotics to support day structure (Casaccia et al., 2019; Ciuffreda et al., 2019) or senior tablets for communication and self-management (Suijkerbuijk et al., 2020). Current research and developments are predominantly focused on the design and implementation of individual ATs and their accompanying user interface (UI). In practice, however, both PwD and their (in)formal caregivers use several ATs at the same time, each with their own UI. A practical challenge that arises when multiple ATs are implemented is that different applications and technologies are needed—sometimes even only accessible via multiple different mobile operating systems—to access the collected information. This challenge underscores the practical value of integrating multiple ATs into a single and comprehensive technology, with a uniform UI, for example, a dashboard. Moreover, in the context of increasing amounts of pertinent data that may be difficult to oversee and process, FCs also seem to value the translation of data into information that supports them in their decision-making (Moreira et al., 2019). FCs may prefer using multiple ATs connected to a decision support system (DSS) to complement their clinical reasoning and strive toward a holistic view on the health status of the PwD and assess corresponding care needs (Horsky et al., 2017).

The term DSS refers to information systems. The functions of a DSS can include gathering data (i.e., sensor or manually registered data) for example, data about care needs or processes, presenting data to users (such as nurses) via, for example, a dashboard, analyzing data to generate new insights and alerts (e.g., risk calculations), selecting and providing recommendations about possible decisions and actions, and the actual implementation of decisions and actions (Parasuraman et al., 2000; Lee, 2013; Akbar et al., 2021). As Akbar et al. (2021) argue, DSSs thus far largely support the steps of analyzing data and selecting possible decisions and actions, while they could also be enabled to gather and utilize data from other sources (e.g., medical records or patient input). In long-term care, PwD and their caregivers use and interact with a

variety of ATs such as tablets and monitoring systems. The use of ATs generates data about e.g., vital signs, physical activity, eating and sleeping patterns, cognitive functioning, mood, social activity, and medication intake. Feeding or integrating such data into DSSs enables these systems and their users (e.g., FCs and ICs) to utilize more varied data about a person's needs, behavior and environment to arrive at decisions about person-centered care. Moreover, these data could be utilized—whether or not in combination—by *pre-programmed, rule-based* algorithms and *data-driven, self-learning* algorithms rooted in machine learning (i.e., artificial intelligence, AI) to extract patterns and new insights from datasets that may be challenging for humans to analyze. Contemporary DSSs have already shown to support caregivers in specific aspects of the care process, such as identifying frailty, assessing dementia-related problems and suggesting suitable interventions. They may also be used for triage of health deteriorations before eventually sending a PwD to an emergency department (Iliffe et al., 2002; Lindgren and Lindgren, 2011; Kihlgren et al., 2016; Thoma-Lürken et al., 2018; Dubuc et al., 2021). Anticipated progress in AI suggests a growing role of DSSs in the proactive support of caregivers and other stakeholders in (shared) decision-making about person-centered care strategies by harnessing relevant data to provide descriptive, diagnostic, predictive and prescriptive insights (El Morr and Ali-Hassan, 2019; Mosavi and Santos, 2020).

So far, several initiatives have started with the development of DSSs and the implementation of integrated AT platforms for older people and people with disabilities, aiming for increased wellbeing, safety, independence, and confidence in their home environment. In the Vital Assistance for The Elderly (VITAL) project, a platform was developed for older people to improve personal independence and social connectivity (Hamdi et al., 2014). The project focused on using technology that could be managed by older people themselves. In the evaluation of the VITAL prototypes, users considered the applications particularly useful and reported that they could lead to improved QoL and social relationships. Another project that has aimed to support older people living alone at home is the NETCARITY project (a NETworked multisensor system for elderly people: healthCARe, safety and securITY in the home environment). The project used a monitoring system with cameras and sensors in the house to timely alert the contact persons of the elderly about abnormal activities and movements. In a study by Nap et al. (2014), the use of ATs like ReAAL was analyzed using focus group discussions with care givers, service providers as well as older adults in Spain and the Netherlands. Participants acknowledged the benefits of the technologies in improving self-management, social engagement and reducing loneliness. However, there were also some concerns regarding privacy, particularly with regard to video recordings. Usability issues were also noted, with a need for simpler interfaces. While opinions on cost varied, some participants thought the benefits outweighed the costs. In the Netherlands, the visual communication and medication reminders were particularly valued (Nap et al., 2014).

The concept of integrating several ATs in one system has been proven successful in an earlier International Active and Assisted Living (AAL) project called eWare (Casaccia et al., 2019). Combining a social robot (i.e., Tinybots Tessa) and a lifestyle monitoring system (i.e., Sensara) in the eWare project demonstrated the complementarity of different ATs and the potential of such ecosystems. While lifestyle monitoring enabled caregivers to monitor the behavior of older adults and recognize relevant patterns and unusual situations, without necessarily being at home with them (Amabili et al., 2022), the integration with the social robot enabled caregivers using the ecosystem to set more context-relevant suggestions and daily reminders by the social robot (Nap et al., 2018; Casaccia et al., 2019). Hence, integrating several ATs has the potential to strengthen the outcomes of those ATs. Furthermore, integrating multiple ATs—or at least the data resulting from their use—can be a basis for a DSS that can enable FCs and ICs to devise more person-centered care strategies. Additionally, there is a need for DSSs in dementia care as it can be burdensome for carers to use multiple technologies, applications, and UIs, and particularly in care—where workload is high—bandwidth is limited to use multiple technologies. Therefore, this paper presents the field evaluation of, a newly developed (Alpha) prototype of a DSS, which integrates data from several ATs for people living with dementia.

1.1 The HAAL project

To develop a new DSS, a multidisciplinary consortium was set up in the international HAAL (HeAlthy Aging eco-system for peopLe with dementia) project (Nap et al., 2022) within the AAL programme.[1] With the HAAL project, ten organizations from the Netherlands, Italy, and Taiwan combine their expertise and experiences in the iterative development, co-design and evaluation of an AI-supported DSS for carers to gain insight into the health and wellbeing of PwD. The DSS is linked to a state-of-the-art AT bundle of products and services for PwD in various stages (see, Reisberg et al., 1982; Ipakchian Askari et al., 2024) and their (in)formal carers. The aim of the DSS is to reduce the caregivers' workload, increase the quality of care, and support independent living and QoL of PwD (Koowattanataworn et al., 2022). The developed DSS comprises a dashboard that integrates several types of data collected from PwD: their physical activity, eating and sleeping patterns, cognitive functioning, social contact, and medication intake. FCs and ICs select suitable ATs together with the people they support, based on their individual care and support needs. The ATs that can be selected are a set of AAL products and services (henceforth "HAAL technologies"), that can be employed throughout different stages of dementia and assigned according to the person's needs. HAAL technologies for example include lifestyle monitoring, daytime structure, medical dispensers, GPS trackers and serious gaming (for a complete overview, see Table 1). In addition to the integration of data from the HAAL technologies into a single dashboard, opportunities are explored to provide caregivers with only the most relevant data and to deploy AI to detect changes in patterns over time, such as changes in physical activity or medication intake. Potentially useful types of data visualization are summary overviews, alerts, predictions, and recommendations based on changes in the beforementioned data.

1 https://www.aal-europe.eu/

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TABLE 1 HAAL technologies available and used in the formative Alpha evaluation phase, by name, GDS scale, product group and functionalities and type of support.

Image	Name HAAL technology	GDS scale	Product group	Functionalities and type of support
	Tipr	2–4	Exergame	A user-centered exergaming system (palm-size, portable product) aimed to improve brain function and fine motor skills for rehabilitation. Provides precision, personal training based on strength and visual feedback to improve hand dexterity and cognitive function.
	Compaan	2–4	Senior Tablet	A tablet with software designed for older adults. Main features are functionality management from a distance for the ICs and FCs, video calls and messaging to encourage social connection.
	Medido	2–4	Medicine dispenser	An automated medication dispenser (table-top dispenser) that gives reminders for a set of prescribed medication, at the preprogrammed time. Users must confirm medication intake by pressing a button. In addition, it monitors and reports user's responses to their caregivers.
	Kompy Pico	2–5	GPS tracker	A GPS tracker (pendant or watch). Tracks the GPS location of the PwD, ICs and FCs can build a geofence in the accompanying web application, and PwD can use an emergency button. For indoor and outdoor use.
	WhizToys	3–5	Exergame	An exergame that consists of nine portable tiles with sensors that are connected to a screen. The game combines physical activity and cognitive training, and games can be personalized. This game aims to prevent or slow down cognitive function.
	Tinybot Tessa	3–5	Social robot	A care robot for daytime structure, which provides verbal guidance to older adults on daily activities. The robot reads aloud written text, for example daily tasks or activities. FCs and ICs can schedule tasks and personalize spoken messages and instructions.
	Sensara	3–7	Lifestyle monitoring	Movement sensors attached to walls and doors in the home of a PwD. The algorithm in the Sensara aims to detect unusual behavior. Notifications of emergencies and deviations are sent to FC of ICs.
	WhizPad	3–7	Smart mattress	A smart sensor mattress combined with transmission system. WhizPad can detect lying monitoring data on sleep, for example predict quality of sleep or help prevent bedsores.
	CogvisAI	3–7	Fall detection	A medium-size 3D smart sensor installed on a wall of a nursing home or assisted living facility. Alarms can be set for falls and other functions, for example fall prevention. Falls are recorded for further examination.

The information provided by the dashboard can be used for early detection and prevention of health and wellbeing related issues. The targeted primary end-users of the HAAL dashboard are FCs—at the time of writing—, care professionals such as (home care) nurses, dementia care coordinators, practitioners, and alarm centralists. The use of the HAAL DSS can potentially reduce their workload.

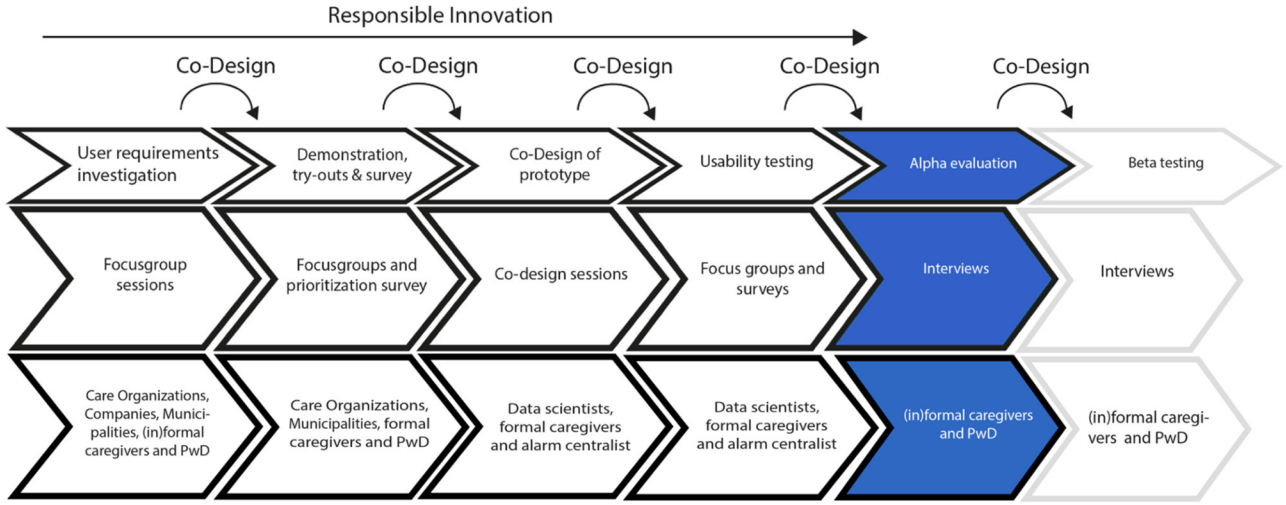

FIGURE 1
Overview of the various research activities conducted during the HAAL project.

Future primary end-users of the DSS will be informal carers and likely PwD themselves.

The HAAL project prioritizes Responsible Innovation (RI), centering on ethical acceptability, societal desirability, and the sustainability of the innovation process and its outcomes, as emphasized by Owen et al. (2013) and Von Schomberg (2013). Therefore, end-users have been actively and iteratively engaged in co-design activities, playing a crucial role in identifying user needs for the DSS dashboard (see Figure 1 for an overview of the different research activities). The RI-process was led by the coordinating HAAL partner, involving multiple collective workshops and individual activities conducted among all project partners, comprising three distinctive cultural backgrounds and care systems (i.e., Northern Europe, Southern Europe, and East Asia). These initiatives aimed to increase awareness of RI and foster its integration into the research and development (R&D) of the HAAL dashboard. The reflective exercises facilitated discussions on the relevance of RI to the HAAL project, prompting considerations in the design process regarding decisions that could address societal needs and values such as privacy, autonomy, and transparency (Lukkien et al., 2023).

The HAAL project has focused on the co-design of the HAAL DSS dashboard (see Figure 2), and this article reports on the findings of the formative evaluation (i.e., Alpha evaluation), where the first high-fidelity prototype with integrated dummy data has been used and evaluated in Dutch, Italian, and Taiwanese care organizations. The formative Alpha evaluation investigated the overall experience, usability, acceptability, and attitude over time toward the HAAL DSS system by PwD and their in(formal) caregivers. Next to the DSS dashboard, the experiences with the ATs themselves were also evaluated. The number and type of HAAL technologies selected by the participating care organization were based on their experience during meaningful try-out sessions (Cornelisse, 2024), which were conducted earlier on in the project. Additionally, based on the Global Deterioration Scale (GDS) score per technology it was listed for which need and stage it could be applicable as presented in Table 1. This information was also provided to care organizations to support them in the selection of the HAAL technologies. For more information on the HAAL project, such as deliverables and progress, see www.haal-aal.com.

1.2 Research aim

Based on several co-design steps, a data driven dashboard was developed. Although the prototype has been tested and evaluated during usability testing, this was in a controlled setting. Moreover, the usability testing focused solely on the evaluation of the HAAL dashboard and not on the implementation and use of the HAAL technologies. Therefore, the purpose of the current study was to evaluate the use of the HAAL platform and the HAAL technologies through a small-scale field study. The insights gained during this evaluation could then be used to further improve the HAAL dashboard for a Beta evaluation. A qualitative approach by means of interviews with (in)formal caregivers and PwD was used to answer the following research questions:

RQ1: How do formal caregivers perceive the usability of the HAAL technologies and the HAAL DSS by?
RQ2: What are formal caregivers' opinions about the accuracy and transparency of the HAAL technologies and the HAAL DSS.
RQ3: What is the perceived user satisfaction and perceived added value of the HAAL DSS for (in)formal caregivers and PwD?

To ensure that the implementation of the HAAL technologies was driven by user needs and not a technology push, PwD could, in consultation with (in)formal caregivers, decide for themselves which HAAL technologies they would like to use during their participation. In addition, the HAAL DSS was studied in a fitting setting for the care context in the three different countries.

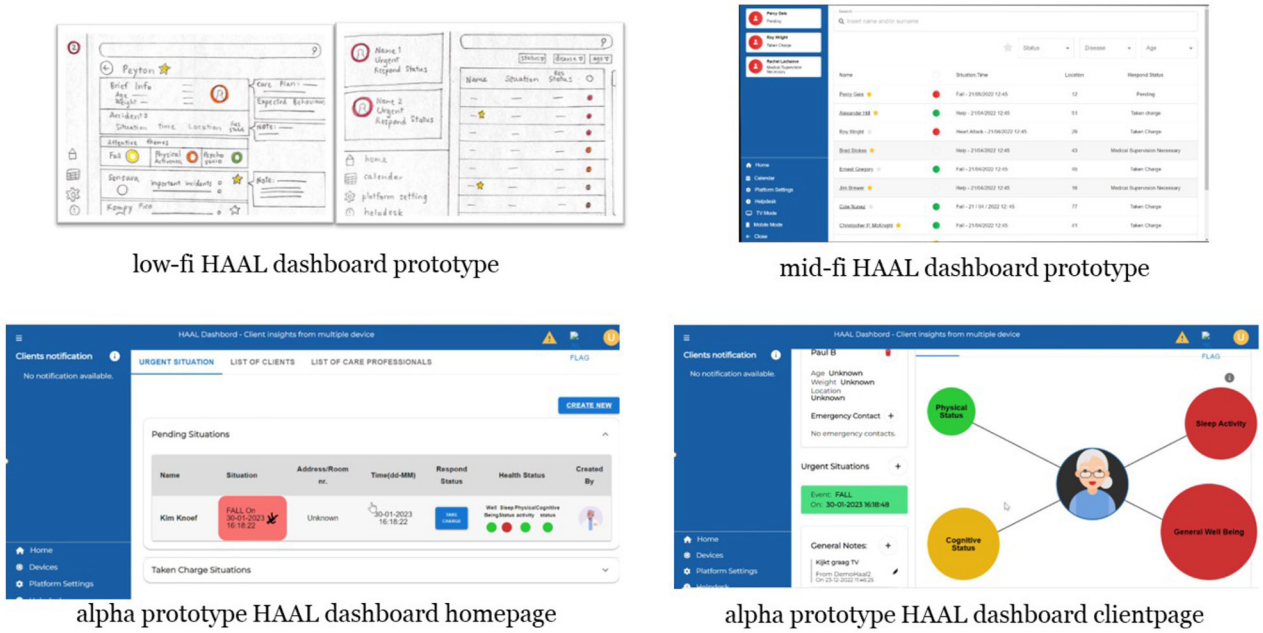

FIGURE 2
Iterative designs of the HAAL DSS dashboard, from low-fidelity **(top left)** to mid-fidelity **(top right)** to high-fidelity Alpha prototypes used in the current study **(bottom left and right)**.

2 Methods

2.1 Participants

In total, 41 elderly people with cognitive impairment or dementia participated in the formative Alpha evaluation. Inclusion criteria for participation were PwD aged 65 years or older who were able to give their consent for participation, had a healthy sight and hearing and were supported in the main daily activities by an informal/formal caregiver were included in the study. PwD were excluded from participation when failed to meet the inclusion criteria, or were concomitant participating to other studies. Each of the participating persons with dementia formed a triad together with one of their informal caregivers and one of their formal caregivers. Formal caregivers were nurses, district nurses, health care assistants, specialists and one case manager (in the Netherlands). The HAAL project consortium involves several care and support organizations with FCs taking care of PwD's (potential end-users of the HAAL dashboard). In the Netherlands, participants were recruited via the care organization Livio (Enschede region). In Italy, the end-users were recruited from the Neurology Unit and Alzheimer Assessment Unit (Memory Clinic) of the IRCCS INRCA. In Taiwan, Yuan Ze University (YZU) recruited participants at Bianciao Veteran Dementia Nursing Home. Via National Cheng Kung University (NCKU, Taiwan), the end-users were mainly recruited from daycare centers established by Schuhe Social Welfare Foundation. Project members in participating care organizations recruited participants using flyers, word of mouth, and demonstrations of the HAAL technologies during information markets. Before the start of the Alpha evaluation, the participating care organizations selected a subset of HAAL technologies through HAAL technology demonstrations and try-outs (Cornelisse, 2024). HAAL project members informed FC's on the functionality of the subset of selected HAAL technologies and the research process. FC's identified PwD with care and support needs that fit with the functionalities of two or more HAAL technologies. These people and their ICs were invited for the research. For information on the age and gender, Table 2 can be consulted.

One participant in the Netherlands dropped out of the study because this participant moved to a care home.

The Italian participants with dementia had a Global Deterioration Scale (GDS) ranging from five to seven, while those in Taiwan fell within the two to four range. In the Netherlands, participants were situated in the early to mid-stages of dementia as assessed by the participating FCs in the care organization. Specific GDS scores were unavailable about the Dutch participants because this organization did not apply this type of scale and did not want to adopt it for the purpose of the study. As for living arrangements, the individuals with dementia in Italy and Taiwan resided alongside their children or spouses while in the Netherlands, all participants lived independently in their own homes.

2.2 Materials

The HAAL bundle of ATs that was configured to the needs of the PwD was installed and implemented in a real-life setting in their homes/apartments of PwD. The HAAL technologies differed across triads. Each participant received a personalized bundle of HAAL

TABLE 2 Gender and age of the participating PwD, ICs and FCs per country.

		Gender (number of participants)		Age range in years	Total
		Male	Female		
Italy	PwD	0	3	77–93	3
	IC	1	2	55–65	3
	FC	2	3	23–57	5
The Netherlands	PwD	2	3	74–89	5
	IC	1	4	unknown	5
	FC	0	5	24–48	5
Taiwan	PwD	0	5	75–91	5
	IC	3	2	37–63	5
	FC	1	4	20–42	5

FIGURE 3
Overview of the steps taken during the study.

technologies based on their specific wishes and care needs. Despite this variation, at least one complete HAAL bundle was present to supply all ATs for the triads at all three test sites. In the Netherlands, the adopted HAAL technologies comprised Kompy Pico, Sensara, WhizToys, WhizPad, Tinybot, and Compaan. Conversely, in Italy, the HAAL bundle included Kompy Pico, Sensara, CogvisAI, and WhizToys, while in Taiwan, the bundle featured WhizPad, WhizToys, Compaan, and Tipr. Additionally, a user manual was created and distributed to all participants involved in the triads. The FCs and ICs had access to the HAAL DSS Alpha prototype dashboard. The dashboard consisted of several online screens with fictional data. In addition to these technologies, the ICs and FCs were provided with a tablet from which they could navigate within the system's dashboard.

The interview questions were developed to examine the goals for the HAAL DSS during the field study. The interview protocol included questions regarding experiences using the individual HAAL technologies and the HAAL DSS. The interview topics covered potential risks and added value of using the HAAL technologies and HAAL DSS in the care process for the PwD.

2.3 Procedure

In this paper we report on the findings of the formative evaluations during the Alpha evaluation in 2023. The procedure for the formative Alpha evaluation was similar for all three participating countries. After inclusion and exclusion criteria were verified, participants were informed about the study and FCs and ICs signed an informed consent form. PwD were supported by their ICs and FCs to provide consent. All participants were asked to complete a socio-demographic questionnaire at T0. Information was gathered such as age, gender, living situation, use of technologies and the amount and type of care the PwD received. After the introduction phase, the treatment visit took place (baseline T1). The HAAL technologies (ATs) were installed in the homes of the PwD and the functionalities and usage were explained to them. The use of the HAAL DSS dashboard was explained to the FCs and ICs. In Taiwan, the technologies were installed in the training and rehabilitation room of the Veteran Hospital. In Italy and the Netherlands, the bundle of technologies chosen by the participants was installed in their home. In the Netherlands, follow-up measurements took place every 2 months for 6 months total, in Italy and Taiwan this was done three times in 1 month (T2, T3, T4). During the follow-up visits, semi-structured interviews were conducted with the participants, their FCs and ICs. Figure 3 shows an overview of the steps taken during the study. In addition, information was collected through the ATs' databases. In the Netherlands, some participants dropped out, because they were deceased or moved to an intramural care home. During the Alpha evaluation participants were offered the possibility to ask questions and switch in HAAL technologies. As an exit strategy, participants could keep using the HAAL technologies after the Alpha evaluation.

2.4 Measurements and analyses

A qualitative approach was used by means of conducting semi-structured interviews with FCs and ICs during several time intervals. Additionally, interviews were conducted with the PwD using creative methods such as conversation cards. These cards and the physical technologies served as a conversation aid to discuss their experience during the Alpha evaluation. PwD were invited to reflect on how they felt during the use of the HAAL bundle, the ease of use, trust, independence and privacy. When requested the interviews were conducted together with the IC. The interviews with FC's and IC's focused—among others—on usability, barriers, frequency of use, privacy and possible improvements of the HAAL bundle and DSS dashboard. Methods, materials and questionnaires were adapted to refer to the HAAL prototype and to match the cognitive level of the participants. Data analyses were descriptive. The interviews were analyzed by means of a thematic analysis (Braun and Clarke, 2006, 2019). A first structuring mechanism for the analysis was formed by the topic of interest: the HAAL technologies or the HAAL dashboard. As sub categories, usability and data accuracy, privacy issues and points of improvement were coded. The inductive approach of the thematic analysis also allowed for the creation of additional themes. All the interviews, across the three countries were coded iteratively by a researcher. Additionally, two fellow researchers validated the codes.

2.5 Ethics

The study was approved by the Ethic Committees in the individual countries and the pilot sites (Netherlands, NW2023-13; Italy, INRCA n. 3750/2023; NCKU B-ER-112-026). The principles of the Declaration of Helsinki and Good Clinical Practice guidelines were adhered to. Personal data collected during the trial was handled and stored in accordance with the General Data Protection Regulation (GDPR) 2018 (Protection, 2018).

3 Results

Results from the semi-structured interviews are presented per theme. The interviews were held in the native language of the participant and within the (care) context of the PwD. The quotes have been translated into English for the purpose of this article. To enhance readability, the quotes have been enriched by clarifications above the quotes and between brackets within the quotes. The information in parentheses informs about the type of participant and country, and a number is added to identify individual participants.

3.1 HAAL technologies

3.1.1 Usability of HAAL technologies (ATs)

The section below reports on the usability experiences with the bundle of HAAL technologies (ATs) from FCs, ICs and the PwD in the three countries. We also report on the technical problems that end-users experienced with the HAAL technologies.

Tipr (exergame)—Both the PwD and their caregivers in Taiwan used the Tipr for finger force control training. The Tipr was found to be interesting to play with and the participants' skills improved with playing the games over 1 month of play 2-—3 times a week. However, it was unfortunate that the ICs could not perceive the improvements (yet) from the HAAL Alpha dashboard. For the Beta prototype dashboard (real-time) data needs to be integrated.

> *"As clients play Tipr, we see their progress." (Formal Carer, Taiwan, participant number 03; FC TW 03)*

Compaan (senior tablet)—In the Netherlands and Taiwan. Overall, the Compaan was experienced positively by the formal caregivers. In practice they often had to answer the wellbeing questionnaire. In the Netherlands most participants did not interact with the Compaan. The caregivers responded to the messages and reminders on the tablet but they reported that it was unlikely for PwD to respond to these messages. However, there was one participant who was able to use the Compaan independently. According to the FC of the PwD, this person found the Compaan clear and easy to use, even though it was not used before:

> *"When the question was asked [on the Compaan], the client pressed the button [on the screen] and answered the question" (FC NL 03).*

One IC reported to experience the added value of the Compaan as an "additional" moment to chat with the PwD, alongside the regular visits. In Taiwan, FCs reported that the Compaan could serve well to have more (social) contact with the family of PwD.

Kompy Pico (GPS)—In the Netherlands and Italy. Overall, the feedback from the ICs in Italy on the GPS device Kompy Pico was positive. Its use was perceived as supportive for safe mobility. Caregivers from the Netherlands and Italy did share that the Kompy Pico was not used to its full potential and could have been used more often by the PwD. The main common usability problem of the Kompy Pico was the size and portability of the device. One participant did not use the device because it was too large to fit in pocket pants. An FC from the Netherlands shared that it would be better to (permanently) attach the Kompy Pico to an object that the PwD always brings along with them, for example a set of keys or a belt. ICs from Italy also reported that the device might be forgotten by the PwD, and one IC stated that a device whose shape was more relatable to something familiar would be preferred.

> *"I'm always afraid Mom will run away [without the GPS Kompy Pico]. The problem is that if her intention is to run away, she will definitely not take that [GPS] device, so I think the idea is good but poorly implemented"* (IC IT 02)

WhizToys (exergame)—In Taiwan and Italy. The participants enjoyed playing the games and the WhizToys was used for lower extremity training. In Italy, two participants also had fun playing the games offered by the WhizToys platform. One IC was happy

that the participant had something stimulating to engage with and keep her mentally and physically involved. However, some technical problems were met.

> *"My mother had a lot of fun with the WhizToys, although it had several technical problems."* (IC IT 02)

WhizPad (smart mattress)—In Taiwan and the Netherlands. There was a high demand for gaining insight into the sleeping behavior during the night. However, some participants found the WhizPad mattress slippery or thought it raised the bed too much to get into bed safely. Multiple participants mentioned that the battery of the WhizPad indicated being low while there still was battery life. Also, there were some concerns whether the data was valid because other people present in the house might have generated them, for example when the bed was in the living room.

> *"When the visitors are sitting on the bed [which is in the living room], it seems as if sir is sitting on the bed himself" (FC NL 02)*

CogvisAI (fall sensor)—In Italy. One IC reported that the CogvisAI was one of the most useful technologies in the bundle. However, a limitation of the technology was the small coverage radius of the technology, which should be wider to ensure more safety. Also, it would be necessary to have one technology in every room of the house to maximize the utility.

> *"The fall detection system [CogvisAI] was useful, however, should have a wider range [to detect falls]"* (IC IT 01)

MEDIDO (medicine dispenser)—in Netherlands. Regarding the medicine dispenser Medido, FCs and ICs in the Netherlands were positive about the technology. One participant reported to be satisfied with using the Medido because it provided tangible evidence of its effectiveness, unlike the other HAAL technologies that monitored him. One IC indicated that even though the PwD was correctly reminded of the medication intake, it was difficult to validate if they actually took the medication. It could still be possible that the medication was taken out of the Medido, but placed on a table or other location and that the concerning PwD had forgotten to take this medication.

Regarding all technologies—A number of participants from the Netherlands conveyed instances where the charging of HAAL technologies was inadvertently overlooked, often attributable to misplacement or inadvertent disconnection of the technologies. In Italy, users occasionally encountered disruptions in data acquisition due to inadvertent disconnection of power to the internet modem.

3.1.2 Difficulties and accuracy of HAAL technology data

During the user trials, we encountered several implementation challenges. First, regarding the lifestyle monitoring system, several FCs indicated the importance of knowing the position of the different sensors. FCs shared that it was sometimes challenging to find the appropriate position of the sensor as it is important to maximize the space that can be monitored by the sensors, in order to minimize errors and/or blind spots. Another challenge was related to the presence of more than one person in the home of the participant. Although all PwD lived alone, there were frequent visits from ICs or FCs. In such situations, the system could temporarily be turned off. However, in practice the system mostly remained on, which resulted in misinformation in the dashboard. It was mentioned by an IC that other FCs would also open the refrigerator door. This resulted in incorrect information regarding the frequency of the refrigerator being opened by the PwD. Concerns were expressed by users from the Netherlands and Italy that if a someone would receive many visitors or over a longer period, important data on their movements could be lost. The technology cannot distinguish the intended user from other people in the house. In addition, the presence of pets could alter the correct recording of data.

> *"If the sensor detects any movement of any person, we will not be able to actually understand how much movement my mother makes in the house"* (IC IT 03)

A similar limitation was observed with the WhizPad. The WhizPad lacks the capability to discern whether one or two individuals are seated on the smart mattress, consequently leading to the dissemination of inaccurate information. Moreover, challenges surfaced during the integration of Tinybots Tessa, with a formal caregiver from the Netherlands elucidating an instance where a participant's ability to hear messages delivered by Tinybots Tessa was compromised when they were outside their room or living area.

3.1.3 Overall satisfaction with the HAAL technologies

In the Netherlands, both IC6 and IC3 were positive that the HAAL technologies could support them in their care responsibilities. They explained that the HAAL DSS dashboard could provide additional insight into situations that they would normally have no information about because they would not be present in the home of the PwD. The ICs reported that the use of the HAAL technologies, such as lifestyle monitoring, could support in the early detection of a bladder infection/pneumonia or provide a notification of fall incidents. Moreover, it was mentioned by IC6 that the collected data could provide a more accurate perspective on the behavioral pattern of the PwD, which is desired when it comes to monitoring food patterns. However, it was also reported that some technologies were not easy to use. In Italy, ICs experienced some obstacles when using the WhizToys. One of the problems was caused by the frequent disconnection from the internet. Nevertheless, ICs indicated that the WhizToys had a number of interactive games that were interesting. An FC in Italy emphasized the usefulness of the GPS Kompy Pico in nursing homes that have an outdoor space where people are free to move around. Another FC stressed the usefulness of WhizToys as a physical-cognitive rehabilitation game if the activities are conducted in the presence of a supervisor.

> *"In the nursing home where I work there is a garden and patients can go there freely, so a tracking system like Kompy Pico is useful" (FC IT 04)*

The participants from both the Netherlands and Italy appreciated the HAAL technologies, yet their satisfaction was lower than that of the people taking care of them. Overall, the participants seemed to prefer the HAAL technologies that had a small impact on their home environment and daily life, for example passive sensors. However, there were also some technologies that had some impact on the home environment of the participants, for example, the Compaan (senior tablet) has a shining bright light in the bedroom, and Tinybots Tessa produces sounds. The perceptions of the Kompy Pico (GPS) were mixed. On the one hand, results showed that carrying the GPS tracker brought feelings of comfort. On the other hand, it was reported that the need of the GPS tracker might be unnecessary because the participant was well enough to take their usual stroll. One participant expressed an overall neutral attitude toward the technologies and did not adjust his lifestyle to the technologies. In Italy, some of the participants were satisfied that their family members could be more relaxed about their situation, yet the technologies in the home created some concerns for two of the participants. For example, they were bothered by the (high) number of technologies scattered around the house, and they feared inadvertently breaking something.

> *"There are too many wires, too many things in the house"* (PwD IT 01)

In contrast, ICs and FCs from the Netherlands assumed that most PwD would not be aware of the presence of the technologies. In Taiwan, the participants in the daycare center indeed positively and happily used Tipr. The gamified interface made them feel like they were playing games.

> *"Is it my turn to play Tipr?"* (PwD TW 01)

One FC at the day care center explained that for some persons with dementia their physical condition improved by using Tipr and WhizToys.

> "*Client's physical condition improved after training with Tipr and WhizToys. This will help reduce the care burden on caregivers in the daycare center."* (FC TW 03)

3.2 HAAL DSS dashboard

3.2.1 Usability of the HAAL dashboard

Overall, participants were positive regarding the usability of the HAAL DSS dashboard. ICs and FCs in both the Netherlands and Italy experienced the HAAL dashboard and its functionalities as clear and intuitive to use, with smooth navigation. Specifically, three FCs from the Netherlands mentioned the layout of the user page to be pleasant and intuitive.

> *"Also clear, it is self-explanatory, if you work with it more often you will know where to click"* (FC NL 04)

Even though the dashboard did not (yet) display the accurate data collected by the installed technologies, most FCs in Taiwan were positive regarding the placement of the sensor data in the HAAL dashboard.

> *"The dashboard is comprehensive. It [the dashboard] is very clear."* (FC NL 06)
>
> *"The platform is simple and easy to use. Using the HAAL platform helps me understand the client better, thus increasing my empathy for him."* (IC TW 04)

Italian caregivers were also positive about the current user interface that was used to describe the status of the PwD. They expressed that the graphics and the "circle" format provided clarity and allowed the caregiver to have an immediate overview of the person's wellbeing, making monitoring more efficient and effective.

> *"The colored circles are very useful, because they give an immediate general idea of the patients"* (FC IT 01)

Moreover, most ICs and FCs suggested that they found it logical and clear how they could navigate through the dashboard. However, one IC from the Netherlands mentioned that it was not fully clear how to interpret the red color of the "circle" regarding the sleep. Another IC pointed out that the dashboard still had some spelling and translation errors. Moreover, it was confusing that all participants were visible in the user list, as this reduced the clarity of the dashboard.

3.2.2 Frequency of use of the HAAL dashboard

ICs and FCs in Italy reported that they checked the dashboard almost every day. Two Italian FCs used the dashboard for just a couple of min while three other FCs used it between 30 and 60 min. In Taiwan, the HAAL dashboard was used 2–3 times a week, whenever (rehabilitation) training sessions took place with the Tipr and WhizToys.

> *"I checked the [HAAL] app about once every two days"* (IC IT 02)
>
> *"30 min a day, at the beginning and end of my work shift"* (FC IT 03)
>
> *"Since the technologies used in the daycare center are not yet fully integrated, I rarely check the HAAL dashboard."* (FC TW 03)

In the Netherlands, the frequency of use of the HAAL dashboard was relatively low. Some caregivers explained that they did not use the dashboard that often because it showed fictional data. Nevertheless, some of them logged into the dashboard a couple of times and easily navigated through it. They reported that if this system was fully developed with real-time data, the dashboard would be checked on a regular basis.

3.2.3 Accuracy of the HAAL dashboard data

Regarding data accuracy and user trust in the HAAL dashboard, Italian FCs affirmed the data's accuracy and expressed intent to integrate the data into their clinical practice. Conversely, several Dutch FCs noted inconsistencies in the logical sequencing of activities within the lifestyle monitoring section of the dashboard. Specifically, they highlighted instances where notifications of activities appeared illogically ordered, underscoring the need for data annotation before analysis and presentation. They proposed to implement a manual button enabling caregivers to confirm or discard specific situations, enhancing data accuracy and trustworthiness through user annotation or 'human-in-the-loop' involvement. FCs from Italy considered the dashboard as a means of *supporting* their clinical decisions, and they reported that their professional judgment was decisive.

> *"Yes, they [dashboard data] are suggestions, obviously then my judgment as a professional will be more important"* (FC IT 02)

As for the Italian ICs, all agreed to consult the dashboard and follow its advise. However, they stressed that it is essential to recognize that the DSS primarily serves as a supportive tool providing a general check on the person's wellbeing.

3.2.4 Overall satisfaction and perceived added value HAAL dashboard

The overall satisfaction and added value of the HAAL dashboard for Dutch and Italian FCs and ICs was high. FCs and ICs indicated to have limited knowledge on the health status of the PwD in their home context. They wanted more insights into the moments that they were not physically present in the person's house. Two FCs from the Netherlands reported an interest in the GPS data. One specifically wanted to know if the person they were taking care of went to the appointments that were added to the agenda. Another FC was especially interested in the lifestyle monitoring data on the dashboard.

> *"Yes, I find it especially interesting to see how often she gets out of bed and what her night rhythm is exactly."* (FC NL 04)

FCs and ICs noted that gaining insights could enable more appropriate actions. In one case, lifestyle monitoring data (specifically toileting) informed multidisciplinary consultations, leading to interventions such as urine sample collection. According to a Dutch FC, a more functional benefit of the DSS dashboard was that without it you would need to separately log into several webapps and applications where as the HAAL dashboard provides a direct overview of the data from different technologies.

> *"If you use healthcare technology on different websites, you have to use a different login each time. A while ago I wanted to log in to Sensara but first I spent an hour looking at how to log-in to see which apps I needed. So, if you have everything on one dashboard, it is more clear and easier for ourselves"* (FC NL 04)

In respect to the added value, Italian ICs shared that the use of the dashboard could reduce both their workload and that of the professional. In addition, FCs shared that the dashboard could be useful as a comprehensive monitoring tool, allowing them to focus first on those people that need immediate support, i.e., triage of a PwD. The DSS could support in managing people and simplify the work dynamics of FCs, especially because of time savings, a greater peace of mind and an overall sense of security. The results of the research underscored the vision of the dashboard as supporting the daily monitoring by carers.

> *"I could immediately get an idea of how all the clients are doing, so that I could arrange rounds of visits according to priority"* (FC IT 03)
>
> *"I believe that the work commitment can be reduced, and that time saved can be used in other work needs"* (FC IT 04)

However, one Italian IC highlighted the need for technical robustness to ensure user satisfaction and effective use of the system.

> *"I didn't find it [dashboard] very useful, the basic idea is good, but there were too many technical errors"* (IC IT 02)

In Taiwan, FCs reported that the communication with the families of the PwD improved. In the Netherlands, a FC valued the dashboard as a communication tool.

> "*The factors [data and recommendations] from the dashboard could be used as a conversation guide for example with family. It could be an easy approach to start a conversation"* (FC NL 03).

Moreover, it was expected that by selecting technologies that could facilitate physical and cognitive training, the health status of the PwD could also be improved. Furthermore, this could prevent health issues and, as a result, reduce the workload of caregivers. Both the PwD and the FCs expected improvements in the hand and lower extremity after the training period of 1 month. During testing, most PwD found Tipr and WhizToys interesting to play with. One formal caregiver noted: *"It is seen that the skill of playing with Tipr and WhizToys improved noticeably in the clients; however, it is unfortunate that their family (informal caregivers) cannot perceive it from the dashboard""* (FC TW 01).

3.2.5 Clarity and applicability of the HAAL dashboard functions

The main finding regarding the HAAL dashboard highlighted its applicability for gaining insights into a person's behavioral patterns. FCs and ICs from the Netherlands and Taiwan expressed a desire for systematic recording of the overall condition of the PwD, with potential benefits for caregivers. Dutch caregivers sought separate access to data collected by individual technologies. FCs and ICs mentioned the potential benefits of utilizing the HAAL technologies' data to predict and stimulate future behavior to enhance the QoL. Specifically, being able to monitor bathroom

visits or wandering, was deemed beneficial for early detection of issues like bladder infections.

> *"Once all technologies are integrated, I hope families will be able to see how clients are doing at the daycare center. We expect the HAAL dashboard to enhance communication between families and formal caregivers." (FC TW 01)*

According to the FCs, caregivers primarily communicate through direct messages or phone calls, rendering the dashboard's internal messaging function potentially redundant. FCs suggested that having essential contact information, such as phone numbers displayed on the dashboard, would suffice.

3.2.6 Points of improvement for future development of the HAAL DSS dashboard

While considering the points of improvement as mentioned before, there were additional improvement points reported by Dutch and Italian FCs and ICs, specifically regarding the implementation and end goals of the HAAL dashboard.

First, based on the remarks made by two FCs and one IC regarding their anticipated frequency of use and ultimate responsibility, it is important to decide if the HAAL dashboard will be used as a notification system or a consultation platform. Moreover, it is important to determine which parties and how many individuals will get access to the dashboard. Secondly, two FCs and one IC were concerned that caregivers and PwD might not have the proper knowledge on how to operate the HAAL technologies or experience difficulty interpreting the information on the dashboard. This would make it difficult to integrate the HAAL technologies and the dashboard into actual health care practice. They argued that training and support should be provided for implementation and usage.

> *"If we are to work with this technology [Compaan], there must be a clear policy. So, everyone can be on the same page and knows what to do. Some guidance is needed there."—(FC NL 03)*

Similarly, the need for training and support would also be applicable for the expected actions that need to be taken by the people who are responsible (e.g., FCs and ICs) when receiving certain alarms/messages from the HAAL dashboard.

Additionally, one FC mentioned that the dashboard should not interfere with the professional and logical knowledge of healthcare workers. On the contrary, it was explained that FCs should be able to judge circumstances according to their professional knowledge instead of blindly trusting the dashboard and its technologies.

FCs from the Netherlands reported that it would be more efficient to link the electronic health record (EHR) of the PwD to the HAAL dashboard directly. This way formal caregivers could report directly to the EHR.

Dutch, Italian and Taiwanese FCs and ICs suggested that the usefulness and usability of the HAAL dashboard could be improved by making some practical design changes to the dashboard. The design suggestions per country are presented in Table 3 below.

3.3 Privacy issues regarding the HAAL technologies and HAAL dashboard

In the Netherlands, the PwD primarily raised privacy concerns. Regarding lifestyle monitoring, some people perceived that using the system would be an infringement of their privacy. One participant expressed having the feeling of being monitored by the sensor at the door, which caused a feeling of unease. Similarly, in Italy several PwD raised concerns about being monitored in their daily activities. However, some formal carers valued having control via a dashboard above privacy.

> *"No worries about' privacy, it is worth having your data in a system if it means you have more control"* (FC IT 01)

One PwD from the Netherlands did not experience any privacy issues, as the HAAL technologies did not make use of cameras for the monitoring activities.

> *"You are just being monitored. I don't mind. In the beginning I found it a bit difficult that I was being watched. Now I don't feel that way anymore. Why not? The technologies are just there now, and I just leave them alone."—(S NL 03).*

One Dutch FC wondered whether caregivers should continuously be aware of the whereabouts of the people they take care of.

> *"As a healthcare professional and case manager, it is an invasion of privacy to keep an eye on where your clients hanging out. When I'm that age, and I have a technology that tracks my movements, I'd rather have only my children seeing that. For me as a case'manager I don't think there is any added value to it."—(FC NL 03).*

4 Discussion

The formative multi-center and multi-cultural evaluation of a DSS (decision support system) and connected bundle of Assistive Technologies (ATs) for (PwD) in the home setting offered relevant insights on the stakeholders' (PwD, ICs and FCs) experiences. Insights were gained over time, encompassing the overall user experience, the navigational efficacy of the DSS dashboard, as well as considerations of acceptability and attitudes toward the DSS dashboard and ATs. In the following sections, we will first discuss the experiences with the DSS followed by the ATs. Thereafter, we will discuss limitations and provide suggestions for further research.

4.1 Experiences with the decision support system: usability, accuracy and transparency of data

The results showed that both FCs and ICs from all three countries were positive about the design and functionalities

TABLE 3 Overview of suggested design improvements for the HAAL DSS dashboard per section, made by FCs and ICs (Netherlands, Italy and Taiwan).

	Netherlands	Italy	Taiwan
General	***Linguistics & terminology*** • Use the correct medical terminology when describing situations, conditions or other descriptions. (FC) • Allow the user to change the language of the dashboard to their preferred language and enhance spelling. (FC & IC) ***(Transmission of) information*** • Send alarm notifications through an (phone) application (IC) • Connect the EHR to the HAAL dashboard directly. This way the FCs can report directly to the EHR. (FC) • Add an explanation about why a certain message pops up on the dashboard. It is desired to know how the dashboard (i.e., algorithms) came up with certain statistics. (IC)	***(Transmission of) information*** • Add a page that lists all the technologies and their features. This supports FCs in finding the most suitable technologies for PwD. ***User interface*** • Make the user interface of the dashboard more accessible.	***(Transmission of) information*** • Create a dashboard that would be compatible with a mobile phone. For FCs in the daycare center, it will be more practical to check the status of PwD through their mobile phones. ***User interface*** • For the login process, it would be helpful if users could view or change their passwords.
Homepage	• Add a button to give the caregiver a manual option to discard (or confirm) a certain situation (FC)	• Improve the management of urgent situations. It was suggested to add the option to delete a resolved situation.	• Provide a function to view the instruction manual on the dashboard for users who are less tech savvy.
PwD page	• Add the PwD's medical condition on the dashboard to provide context of the health status (for example when a PwD has diabetes). (FC) • Allow adding notes to the PwD's overview in the dashboard, for example small personal traits. (FC, IC) • Add a section to present the data collected by each technology separately. (FC)	• Allow FCs to choose which health information is displayed for a particular patient. For example, add information such as the diagnosis. • Add a section where primary caregivers can insert which therapy a patient is following. • The profile picture should be of the PwD, instead of an avatar.	• Offer the possibility to record notable events (e.g., medical treatments) and provide notifications to caregivers.
'List of care professional' page	• Remove the function of the dashboard that allows caregivers to contact each other through the HAAL platform. Having the required contact information, such as the phone number presented on the dashboard would be sufficient. (FC)	• Allow professionals to manually add additional information about the caregiver, such as phone contact, profession, days of reception. This information could be added in a separate tab. • Add a search tool, where one can search for caregivers based on their name.	

of the DSS dashboard. They appreciated a single dashboard for remote monitoring, the ability to show gradual changes in the PwDs' physical and cognitive abilities They also liked to receive indication alerts of urgent situations and information to predict and prevent health issues. The design of the DSS dashboard was considered usable, clear and intuitive by FCs. The organization of functions within the dashboard was perceived as logically structured, easing seamless navigation and operation. Despite positive experiences, improvements were needed for the DSS dashboard, such as precise terminology, real-time data, the provision of a comprehensive instructional manual, and clear information about responsibilities (e.g., who should follow up on an alarm). Next to these improvements, both accuracy- and confidentiality of data were principles that FCs and ICs found important in the design and use of a DSS. It was stressed that information provided by the DSS dashboard should not lead to any faulty judgements made by caregivers, and that both the data and the algorithms processing data should therefore be accurate, without biases and without being too directive. This resonates with principles for ethical and responsible AI, such as accuracy and fairness, as promoted by organizations such as the European Commission (2019) and the World Health Organization (2021). Also, this implies that some transparency should be provided about the underlying functioning and algorithms of DSS to ensure that users can properly understand how specific insights are generated. This helps them to assess the applicability and relevance of these insights in the context of individual PwDs.

Besides the need for transparency of the algorithms, the data in the DSS should be accurate in order to be used in health care decision making. Only accurate data would help to choose proper interventions for e.g., training cognition, physical activity and monitoring mobility and sleep quality. The care- and client's context should also be accounted for in the DSS to enhance decision making. Contextual information could involve PwD characteristics such as their cultural and socio-economic background, as well as caregivers' own observations or interpretations. Such information could provide a broader perspective on the relevance of DSS insights, and could be supportive for caregivers to develop a nuanced understanding of a PwD's situation, and care and support needs. In the forthcoming iteration of the DSS, enhancements will include the integration of data visualization features to ensure a

more detailed insights to users. FCs from all three countries were already positive regarding the clarity and placement of the sensor data in the DSS. In order to validate the data in the DSS and increase the accuracy of the data, feedback options in the DSS need to be added e.g., functionality to annotate or rate the data via the DSS dashboard. Leveraging these feedback options, users can relay insights and observations to developers, thereby facilitating iterative improvements to the underlying algorithms. Such iterative refinements hold promise in minimizing instances of erroneous data interpretations, consequently mitigating the occurrence of false alarms or data omissions, as posited by Swets et al. (1961).

4.2 Experiences with the assistive technology bundle: benefits, cultural, and contextual differences

Multiple different ATs are connected to the Alpha DSS prototype providing support to PwD in both physical and cognitive domains, facilitating activities such as training, medication management, and fostering remote social interactions with FCs and ICs. In respect to the experiences with the bundle of ATs, it was found that overall, the experiences were positive. FCs and ICs felt supported by the ATs, particularly in localization of the PwD and monitoring their lifestyle, such as eating and sleeping patterns, as also found by Zwierenberg et al. (2018). Central to this support felt during the use of the HAAL AT bundle was the flexibility inherent in selecting ATs tailored to individual needs, desires, and capabilities, i.e., a technology pull rather than a technology push. Nevertheless, the introduction of certain ATs was met with reservations among the PwDs in the Netherlands and Italy, who perceived them as intrusive. According to the PwDs, the ATs had an impact on the physical context of the home environment, such as the large amount of equipment with wires, the bright light from the senior tablet and replacing a regular mattress by a smart one. Moreover, ATs can stigmatize people by age or disease (Parette and Scherer, 2004), which might also have influenced the PwDs' experience and acceptance of the ATs. For ATs in general, it is therefore advised to embrace the "Warm Technology" design process, which is sensitive to the possibilities and unique qualities of old age—personal, affective, social, contextualized, and embodied (IJsselsteijn et al., 2020). Warm Technology aims at improving (or remaining) QoL by supporting and enhancing human potential, dignity, social connectedness, and self-reliance.

As discussed before, the accuracy of data is crucial in health care decision making. The study shows that the individual AT data and the aggregated processed data by AI algorithms presented in the DSS dashboard are highly dependent on the data from the ATs in context. Misplacement of lifestyle monitoring sensors, as well as the presence of animals or multiple people in the house, can cause false alarms or misses. Similar reductions of accuracy in data were present with the smart mattress, which cannot differentiate (yet) between multiple people sitting on the bed (e.g., a formal carer and the PwD). Reduced accuracy can also be caused by users that do not perceive messages from the social robot or medicine dispenser, possibly because they are not present in the room, have hearing problems, and/or because of sound disturbance or interference. There is a delicate balance between monitoring a PwD for safety, and their need for autonomy and privacy. Privacy concerns among the PwDs underscored this delicate balance, particularly in relation to the lifestyle monitoring sensors. Therefore, we reflected on whether continuous monitoring is worth the privacy infringement. The findings show that opinions on this matter differ among various stakeholders and that it is dependent on whether one sees the application of the AT as infringement of privacy. It seems that for now it needs be decided per individual case whether the PwD would experience the AT as infringement and offer them the opportunity to decide if the technology can be installed in their home. Moreover, it is essential that an AT is only applied when there's a clear need, for example, in the case of a identified safety risk. It is noteworthy that the PwDs from Italy were satisfied with the idea that family members are supported by the DSS and Ats. We speculate that is possibly due to the remote care- and monitoring possibilities. This finding underscores the nuanced interplay between technological intrusion and the broader socio-cultural context within which these assistive technologies are integrated.

Different users valued and experienced the ATs differently, both between countries and between distinct contextual settings. For instance, in Taiwan the utilization of the exergame to train fine motor skills was valued since it improved the skills of PwD, yet there was a need for actual integration in the DSS dashboard. Both in Taiwan and Italy, the exergame WhizToys stimulated physical activity and the PwD thought it was fun to play. However, some technical issues still need to be improved. The senior tablet was also experienced positively both in the Netherlands and Taiwan and could serve to support mediated social contacts. However, most PwD in the Netherlands were not able to interact with the tablet. This was likely due to the (later) stage of dementia they were in. It should be noted that such an AT is specifically targeted at PwD in the early- to mid-phases of dementia (Ipakchian Askari et al., 2024). In the Netherlands and Italy, the deployment of the GPS AT was perceived as instrumental in fostering safe mobility among PwD, thus aligning with broader initiatives aimed at promoting autonomy and mobility within care settings, as elucidated by Buimer et al. (2020) and Sayeh et al. (2022). However, the size and limited portability of the technology posed practical barriers within care practices, prompting suggestions for embedding GPS functionalities within inconspicuous objects to mitigate the risk of misplacement or forgetfulness. However, disguising a GPS as another object raises an ethical dilemma. Depending on the possible health and safety risks, recommending a GPS for a PwD might outweigh the privacy concerns. Therefore, it is of importance to balance the pros and cons and to involve the PwD in the decision process, considering their needs and preferences when designing technology.

Both FCs and ICs valued the use of lifestyle monitoring to support in the early detection of a bladder infection or notification of fall incidents. The 3D fall sensor was used in Italy and was highly valued. A constraint was that the technology could only monitor falls in a limited area. Therefore, multiple technologies were needed to cover a whole house. Finally, the medicine dispenser was valued by all users in the Netherlands, also because it directly

supported the PwD instead of just monitoring them. The medicine dispenser could not be used in Italy and Taiwan, since there was no supporting process by pharmacies that could provide medication rolls for the medicine dispenser.

The formative Alpha evaluation study of the DSS and ATs was conducted in three different countries, cultures and care contexts, involving different care professionals and PwD with different GDS cognitive dementia stages (see, Reisberg et al., 1982). The results show that for a DSS to have an added value in the care process, its functionalities and design should be tailored to these different contexts and users. For instance, there should be customization regarding the specific care technologies to be used and data to be collected (see Berridge et al., 2021). Other aspects that should be customized are the data processing by AI, the granting of access to the data and AI-based insights, the way that AI-based insights are explained to the users (see Du et al., 2022), and the extent in which AI-DSSs proactively advise caregivers about care needs and strategies. Carers from all three countries expressed their interest in the DSS and wanted to gain insights into the behavior of PwD for prevention purposes. However, the type of information they were interested in differed. Dutch FCs were mainly interested in monitoring daily behavior such as sleep and eating patterns, while carers from Italy and Taiwan were mainly interested in monitoring the progress that PwDs made in terms of physical activity. The difference was likely related to the intramural care context in Italy and Taiwan and the extramural care context in the Netherlands where PwDs live independently at home. In the Netherlands, the current policy theme in long-term care is "self if possible", "home if possible", and "digital if possible" (Rijksoverheid, 2022). Care will be provided increasingly- and mostly at the homes of people, possibly supported by ATs. This transition from intramural care to extramural (home) care was also reflected by the perceptions of FCs from the Netherlands. In particular, they perceived remote monitoring as valuable because the DSS could provide insights that could be collected even when they were not physically present in the house. In the Netherlands, FCs also specifically valued an integration between the DSS and the Electronic Health Record (EHR), as this contextual information is necessary to make useful interpretations of the data shown in the DSS. In the Netherlands, all hospitals and most care organizations use an EHR. An integration between the DSS, the data from and to the ATs and the EHR is in line with the goals of the iterative DSS developments and results presented in this paper. However, interoperability between the DSS and the EHR was not specifically emphasized in the other countries. In Italy this was possibly because of the limited general use of an EHR (HIMSS Italian Community, 2021). Although Taiwan has achieved high adoption of the EHR, it is still a challenge for meaningful use of EHRs among hospitals and clinics (Wen et al., 2019).

Overall, the results illustrate the importance of offering the possibility to customize the DSS depending on the context of use and specific needs of the users within this context. This customization could for example be by varying between functionalities and certain (health) information in the dashboard between an intramural- and extramural care context. As advocated by Cahill et al. (2017), in an intramural care context, technology has a role in terms of supporting the wellbeing of both PwDs and staff alike. This could enable life/job satisfaction and social participation, and foster an environment that provides a sense of purpose for all (i.e., residents, staff and families). The usability of the DSS dashboard differed for each type of caregiver in terms of the details provided by the dashboard and in terms of frequency of use. From the interviews it can be concluded that ICs might not need the level of detail that is currently (meant to be) provided by the dashboard. It is important to determine which data should be shared with the ICs, especially when taking into account who is responsible for monitoring the dashboard. Then there is also a distinction to be made between FCs and case managers dementia. From the qualitative results, it is seen that professional carers—in particular, case managers dementia from the Netherlands—are reluctant to use the DSS dashboard as currently intended. Checking the dashboard regularly and having to act on it on a frequent basis, could be overwhelming and too demanding on top of their existing responsibilities. For this reason, it would make sense to consider developing different versions of the DSS dashboard to fit each caregiver's profile. It would also be beneficial to look at the options to create a separate dashboard for FCs, ICs, and case managers. In contrast, it is important to keep in mind which collaboration is necessary to intervene based on information gathered in the DSS dashboard. There should be a clear division in the responsibilities and the DSS dashboard should support this. For example, by showing notifications to the person who is expected to respond to specific insights. Nevertheless, full customization up to the level of individual users might be at odds with the need to offer somewhat standardized solutions that are universally applicable and foster scalability (Peine and Moors, 2015).

In summary, although the overall experiences were positive, some improvements could be made, thereby optimizing the usability and effectiveness of the DSS system. ICs and FCs did not raise problems related to usability, although they did not use the DSS often and had not explored all the functions. Future Beta developments and a (longitudinal) summative evaluation will provide more insights into the expected outcomes when using the DSS dashboard in context with real-time data from a variety of ATs.

4.3 Limitations

No study comes without limitations. The main limitations of the present study were the relatively small sample size, an unbalanced study design, and most importantly, the current development stage of the protype of the DSS. To give participants an impression of the possibilities of the DSS and gather their views at this stage, the DSS used dummy data and working AI algorithms were not yet integrated. The DSS dashboard that was tested had some usability issues. In addition, several ATs were not yet connected to the cloud-based server and the stability of the software also needed to be improved.

In the current study, few explicit questions were asked regarding the broader social and ethical implications of using the DSS. Due to the impact that the use of AI-based technologies may have on people's lives and caregivers' work, such implications need

to be assessed and addressed at an early stage of their development. Otherwise, resistance might emerge during implementation. Future studies could examine more systematically and in more depth how different users and other stakeholders perceive and experience both the positive and potentially unintended effects of using DSSs on values such as autonomy, privacy, transparency, and equality. Furthermore, it should be investigated how the ways in which these DSSs support the care process and interact with users can be flexibly refined "in context" (Lukkien et al., 2023). Moreover, within long-term care, an increasing number of caregiving responsibilities might transition to informal care networks. When ICs have access to a DSS, such as the one used in this study, they get more knowledge of the person they are caring for. This knowledge could help them to co-create the care together with formal caregivers. The DSS could serve as a conversational guide during this co-creation process.

Anticipated progress in AI suggests a growing role of DSSs in proactively supporting caregivers and PwD in shared decision-making about person-centered care strategies by harnessing relevant data through machine learning. In this sense, data collected from various ATs which is made available centrally in a dashboard, can be increasingly utilized to, e.g., perform predictive analyses on risk factors or to perform prescriptive analyses regarding the mitigation of risks and person-centered care strategies (El Morr and Ali-Hassan, 2019; Mosavi and Santos, 2020). Moreover, it is important that in the development of a DSS, the data is validated in order to ensure that the DSS can provide accurate and reliable data.

4.4 Future research

As discussed before, further development of the DSS entails integration of actual data from the ATs and running further evaluations aimed at refining and optimizing the design(s). After the Alpha evaluation, about all participants were willing to continue using the HAAL technologies and dashboard and were enrolled for the follow-up summative evaluation (Beta evaluation) of the HAAL project. For future research it would be beneficial to extend the evaluation period with a larger sample size, as this could enhance the generalizability of the findings and provide more in-depth insight into the long-term effectiveness and sustainability of the use of the DSS. Additionally, in such a follow-up study it is also needed to gain more insights into the perceptions, opinions, beliefs and attitudes of PwD regarding a DDS designed to monitor their behavioral patterns and predict their health situation. Questions can be raised about what is needed to ensure a good balance between values as privacy, autonomy, and care and support needs by ICs and FCs for monitoring and health prevention. Furthermore, ICs and PwD are prospective end-users of the DSS, in particular with increasing self-care and home-care practices. This entails further developments and design refinements of the DSS with genuine iterative involvement of these intended user groups. It is also relevant to study which ATs and which data PwD and their carers prefer to get access to in a DSS. Moreover, it would be beneficial to explore opportunities to integrate the DSS and AT bundle with telehealth services to enable remote monitoring, consultation, and intervention delivery. This could enhance access to care for PwD living in remote or underserved areas and improve care coordination among healthcare providers. Finally, future studies should also focus on cost-effectiveness. Cost-benefit analyses are highly needed in a time with increasing health care costs and a decreasing workforce of FCs.

5 Conclusion

In general, carers and PwD expressed a positive and hopeful attitude toward the DSS dashboard and AT bundle. Despite the fact that the dashboard currently represents an initial Alpha prototype, its potential is seen in efficiently presenting the overall wellbeing of PwD to both FCs and ICs. This, in turn, holds promise for augmenting caregivers' understanding of people's care needs, ultimately benefiting their journey. In the paper we reflected on the formative evaluation results on the usability and acceptability of the prototype by carers and PwD. The insights are used to further improve the dashboard. Furthermore, the findings contribute to the existing body of knowledge surrounding DSS deployment within care contexts, shedding light on the potential impact of DSS utilization on acceptability and perceived workload among both FCs and ICs. The insights garnered from this study can support the effective and responsible development of such DSS solutions, ultimately reducing the workload of carers and supporting the autonomy and QoL of PwD.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The study was approved by the Ethic Committees in the individual countries and the pilot sites (Netherlands, NW2023-13; Italy, INRCA n. 3750/2023; NCKU B-ER-112-026). The principles of the Declaration of Helsinki and Good Clinical Practice guidelines were adhered to. Personal data collected during the trial was handled and stored in accordance with the General Data Protection Regulation (GDPR) 2018 (Protection, 2018). The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

HN: Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. NS: Formal analysis, Investigation, Supervision, Validation, Writing – original draft. SI: Data curation,

Formal analysis, Investigation, Methodology, Supervision, Visualization, Writing – original draft, Writing – review & editing. DL: Data curation, Formal analysis, Investigation, Supervision, Writing – original draft, Writing – review & editing. BH: Formal analysis, Investigation, Supervision, Writing – original draft, Writing – review & editing. NM: Methodology, Resources, Software, Validation, Writing – original draft. SC: Data curation, Software, Supervision, Writing – original draft. GA: Methodology, Validation, Writing – original draft. RB: Methodology, Writing – original draft. AM: Methodology, Writing – original draft. FB: Investigation, Methodology, Writing – original draft. C-JL: Methodology, Validation, Writing – original draft. H-FC: Methodology, Supervision, Validation, Writing – original draft. F-CS: Supervision, Writing – original draft. GR: Writing – review & editing. ET: Writing – review & editing. DB: Investigation, Validation, Writing – original draft. CW: Investigation, Validation, Writing – original draft. Y-LH: Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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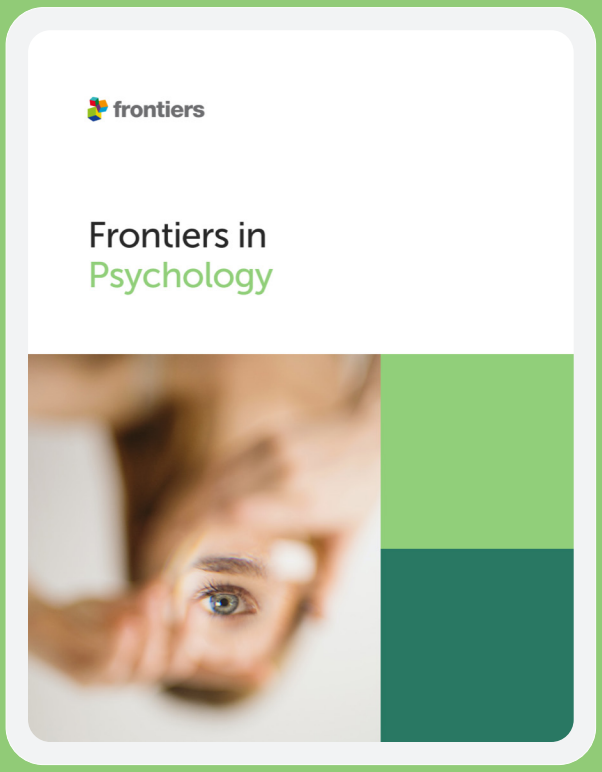

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