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Supporting older adults with mobility disabilities through voice-activated digital assistants and smart home technologies

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Abstract

Background: Older adults aspire to maintain their autonomy in their preferred environments and remain active in their community. However, disabilities or age-related changes can present obstacles to achieving this goal. Voice-activated digital assistants and smart home technologies are potential solutions to support older adults. However, widespread implementation of these technologies has not been explored for older adults with mobility disabilities, who may have unique needs.
Research aim: This study investigated how voice-activated digital assistants and connected smart home technologies can specifically benefit older adults with mobility disabilities, with the provision of facilitating conditions such as instructional support for initial and continued use.
Method: We provided twenty-four community-dwelling older adults with mobility disabilities with an Amazon Echo Show, a smart plug, and a smart light, along with instructional manuals tailored to their needs. Participants were taught to install the technologies and asked to use them for five weeks. We assessed their overall technology readiness and proficiency, feelings of loneliness, and ability to use smart home technologies. We conducted in-depth interviews to gain deeper insights into their experiences and perspectives.
Results: Step-by-step instructional manuals supported their successful installation and utilization of the provided technologies. Participants reported good usability and high confidence in using these technologies. Qualitative analysis showed that these technologies improved functional independence by enabling participants to control their home environment remotely, increase safety, and enable them to access up-to-date information. They had a significant reduction in loneliness after 5 weeks ($p = .003$), attributed to increased social connections and entertainment and viewing the voice-activated digital assistants as companions.
Conclusion: Voice-activated digital assistants and smart home technologies have the potential to support older adults with mobility disabilities, assuming the right resources are provided to facilitate utilization. Healthcare professionals and researchers should recognize the unique benefits of these technologies for this population to promote their adoption and use effectively.

Keywords: digital assistants, loneliness, older adults, smart home, mobility disabilities

Introduction

Using smart home technologies for successful aging in place

Aging in place should be considered broadly as "One's journey to maintain independence in one's place of residence as well as to participate in one's community." (Rogers et al., 2020, p. 1). Older adults live in various places, but in all cases, they aspire to maintain autonomy in their preferred environments and remain active in their community. Maintaining independence and social connections in familiar spaces and communities are primary motivations (Wiles et al., 2012). Reflecting this sentiment, a recent national survey found that more than three-quarters of American adults aged 50 and older preferred aging in place (Binette, 2021). However, older adults may face challenges in their daily lives over time due to disabilities or age-related declines in functioning. These functioning limitations can lead to reduced social participation and quality of life.

Mobility disabilities, defined as "having serious difficulty walking or climbing stairs," are the most prevalent disabilities in the United States (Centers for Disease Control and Prevention, 2023). In 2022, approximately 20.8% of American older

adults reported living with mobility disabilities (U.S. Census Bureau, 2022). Given the crucial role of mobility in maintaining functional independence, older adults with mobility disabilities may have concerns about their capacity to move freely and perform daily tasks and activities they enjoy (National Institute on Aging, 2020). For example, older adults with long-term mobility disabilities reported that they often encounter physical challenges, such as difficulties transitioning from sitting to standing or maintaining balance while walking or standing, and face accessibility challenges in their daily lives, such as reaching for objects or navigating obstacles (Koon, Remillard, et al., 2020). Moreover, age-related changes in physical, neuromuscular, cognitive, and behavioral factors can contribute to further decline in mobility as individuals age (Freiberger et al., 2020). Therefore, it is important to offer older adults with long-term mobility disabilities suitable strategies to maintain and postpone significant declines in functional independence.

In recent years, smart home technologies have been recognized as a promising tool to support independent living for older adults (Arthanat et al., 2020; O'Brien et al., 2020; Tural et al., 2021). These technologies can support automation and remote access to home devices and offer user-friendly interfaces such as smartphones for receiving information and setting preferences (Tural et al., 2021). Smart home technologies include various devices, from voice-activated digital assistants and wearable health monitoring devices to smart hubs to manage the home environment, such as humidity, temperature, and security (Arthanat et al., 2020; Tural et al., 2021). Among these options, voice-activated digital assistants stand out as potentially accessible smart home technology for older adults, as they can interact with these devices using simple verbal commands.

Voice-activated digital assistants are a type of artificial intelligence that utilizes algorithms to enable devices to communicate with humans (Poushneh, 2021). Examples include Amazon Alexa and Google Assistant, which interact with users through smart speakers such as Amazon's Echo and Google's Nest. They can understand questions and respond to diverse formats, including text, visuals, or spoken replies (McGreevey et al., 2020). This feature has led to a noticeable increase in the adoption of voice-activated assistants, with an anticipated 157.1 million users in the U.S. by 2026 (Insider Intelligence, 2022).

Voice-activated digital assistants can benefit older adults, particularly those with mobility disabilities, in their daily lives. For example, by integrating additional smart home technologies such as smart plugs, lights, and robotic vacuum cleaners, their capabilities can improve the functional independence of older adults with mobility disabilities by effectively managing the home environment. Furthermore, these assistants could enhance older adults' quality of life, enabling them to enjoy leisure activities such as music or games, quickly access information such as weather or news, and manage daily tasks such as reminders and timers (Koon, McGlynn, et al., 2020). Therefore, voice-activated digital assistants, combined with other smart home technologies, can enhance functional independence and quality of life of older adults with mobility disabilities, facilitating their successful aging in place.

Accessibility of smart home technologies for older adults

Although voice-activated assistants and connected smart home technologies hold promise in aiding older adults with mobility disabilities, they may not be specifically designed to meet their unique needs and abilities. Moreover, considering the potential lack of digital technology experience in older adults compared to younger generations, targeted strategies are essential for optimizing their user experience (Pradhan et al., 2020). Our previous work addressed this gap by developing instructional manuals tailored for older adults on using these technologies (Blocker, Ramadhani, et al., 2022). These manuals were created through task analysis and iterative user testing in collaboration with older adults, both with and without mobility disabilities, who had no prior experience with such technologies. After the development, we conducted a demonstration study with a small sample to gain insights into the training requirements of older adults using these technologies with our instructional manuals (Blocker, Kadylak, & Rogers, 2023). Participants found our manuals helpful for learning. However, their feedback indicated the necessity of adding additional features, such as instructions on making audio or video calls using the Amazon Echo's Alexa, to meet their need for social connection. Through an iterative development process, we created comprehensive instructional manuals for smart home technologies, including the Amazon Echo Show, smart plug, and smart light. These manuals are available in both paper-based and digital formats, such as PDF files and YouTube videos, providing detailed guidance on basic uses, setup, social communication, environmental control, and health applications (available on the TechSAge website: https://techsage.ahs.illinois.edu/tools/)

Understanding older adults' usage of smart home technologies

Older adults who frequently use technology with multiple features, such as mobile phones, are more likely to utilize user manuals over time

(Tsai et al., 2012). This finding emphasizes the need for manuals that cater to their needs, especially since Tsai et al. (2012) found that older adults often refer back to these manuals to refresh their memory on tasks they may have forgotten. Moreover, even experienced smart home technology users reported that they wished that they had received additional instructions to use their devices and to understand the range of available functions (Koon et al., 2020).

Understanding the specific activities older adults engage in with technology can guide the design of user-centered manuals that offer effective and pertinent information. Furthermore, we can gain insights into older adults' adoption of smart home technologies by analyzing usage patterns. This understanding could provide value for the technologies, allowing researchers and healthcare professionals to improve the product or develop targeted strategies that better meet the needs of older adults.

Purpose of study

The purpose of this study was to explore how AI voice-activated assistants and other smart home technologies (i.e., smart plugs and smart lights) can support older adults with mobility disabilities with everyday activities. Specifically, we explored the following research questions:

(1) Can older adults with mobility disabilities learn to install and use AI voice-activated assistants and connected smart home technologies remotely?
(2) What activities do they engage in using these technologies?
(3) How do these activities influence feelings of loneliness and quality of life?

Based on the research questions, we proposed the following hypotheses:

Hypothesis 1: Older adults with mobility disabilities can successfully learn to install and use voice-activated digital assistants and connected smart home technologies through remote instruction, leading to high levels of usability and confidence.

Hypothesis 2: Older adults with mobility disabilities will use these technologies to engage in a variety of activities, including managing their home environment, participating in leisure activities, and maintaining social interactions, which may otherwise be limited due to mobility challenges.

Hypothesis 3: The use of these technologies will enhance social engagement and reduce feelings of loneliness among older adults with mobility disabilities by providing a means for regular social contact and connectedness.

METHODS

We developed the Digital Assistance in a Box (DAB) technology suite, which included the Amazon Echo Show 8, Philips Hue Smart Lightbulb, and Amazon Smart Plug, along with our instructional manuals (Lim et al., 2023). Participants received the DAB package and were asked to use the technologies for five weeks.

Participant recruitment

Forty-one community-dwelling older adults with mobility disabilities were identified from two registries: the TechSAge Participant Registry and the University of Illinois Disability Resources and Educational Services Research Registry. We sent them recruitment flyers via email, and 38 responded. To ensure eligibility, participants were screened based on the following inclusion criteria: (1) being 60 years of age or older; (2) having self-reported mobility disability for at least 10 years; (3) having minimal experience using smart home technologies; (4) living independently at home; and (5) owning a smartphone or tablet device. Five individuals were excluded due to pre-existing experience with smart home technologies, and one individual did not meet the disability criterion, resulting in 32 participants remaining.

Among the 32 eligible participants, 29 attended the orientation session. However, three participants were subsequently excluded: one due to ineligibility to continue, one due to privacy concerns with the technology, and one who did not show up. This resulted in 26 participants proceeding with the initial setup. Following the initial setup, one additional participant had to be excluded due to their personal technology (i.e., cell phone) being incompatible with the study requirements. Subsequently, 25 participants completed the 1-week interview, though one participant did not attend the 5-week interview. As a result, a total of 24 participants were included in the final data analysis (*Figure 1*).

Materials

The TechSAge Background Questionnaire (TSBQ; Remillard et al., 2020) was used to gather information about demographics and other participant characteristics. The 10-item Technology Readiness Index 2.0 (TRI 2.0; Parasuraman & Colby, 2015) assessed participants' readiness to embrace and utilize new technology, employing a 5-point Likert scale (1 = strongly disagree to 5 = strongly agree). The 16-item Mobile Device Proficiency Questionnaire (MDPQ; Roque & Boot, 2018) and the 10-item Wireless Network Proficiency Questionnaire (WNPQ; Roque & Boot, 2021) evaluated the ability to use mobile devices and wireless networks. The MDPQ uses a 5-point Likert scale (1 = never tried to 5 = very easily) and the WNPQ uses a 6-point Likert scale (0 = don't know the

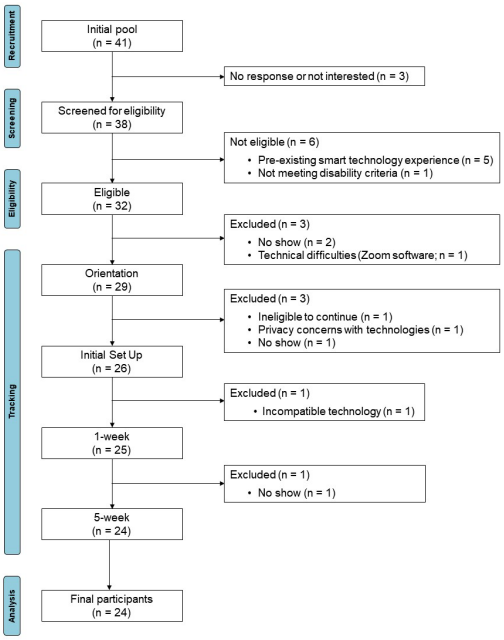

Figure 1. Participant recruitment flowchart

task to 5 = very easily). The 10-item System Usability Scale (SUS; Brooke, 1996) assessed the perceived usability of the provided technologies using a five-point Likert scale (1 = strongly disagree to 5 = strongly agree). The Perceived Competence Scale (PCS; Williams et al., 2006) was modified to evaluate participants' perceived ability to use the technologies. To evaluate subjective feelings of loneliness, the 8-item UCLA Loneliness Scale (Hays & DiMatteo,1987) was used with a modified response scale (1 = never to 5 = always). Additionally, we modified the Echo Show Usage Scale from Koon et al. (2020) to understand what tasks older adults engage in with voice-activated digital assistants. This scale includes 17 activities (e.g., calendar, controlling your smart light, making calls, messaging, setting timers, sports information, and playing music).

Semi-structured interview scripts were developed for this study. Each set of questions was created with a specific purpose tailored to the corresponding phase of the study. Examples of these interview questions will be provided in the following section; the full interview scripts can be found in Blocker et al. (2023).

Procedure

This study included four distinct phases, all of which were conducted remotely via Zoom: Orientation, Initial setup, 1-week follow-up, and 5-week follow-up (*Figure 2*). An optional 10-week phase was available, but those data are not presented here (Lachs, Mitzner, Hussaini, & Rogers, 2024).

Orientation

During the orientation phase, participants provided informed consent. They then completed the TSBQ, TRI 2.0, MDPQ-16, WNPQ, and the UCLA Loneliness Scale.

Initial setup

Upon receiving the DAB package at home, participants participated in an initial setup session remotely led by researchers. During this session, participants unboxed the package under the guidance of the researchers and were directed to user guides developed by the research team for setup and usage instructions. Following the completion of the setup, participants were asked to complete the SUS and PCS to evaluate their perceived usability and competence in using the provided smart home technologies. Additionally, participants engaged in an interview to explore their confidence and ease of use in interacting with the technologies after their initial exposure. Questions included: "How confident do you feel about learning to use these technologies?" and "Do you think the Amazon Echo Show/smart plug/smart light will be easy to use?"

1-week follow-up

After using the digital assistant for 1 week, participants were asked to complete the SUS and PCS

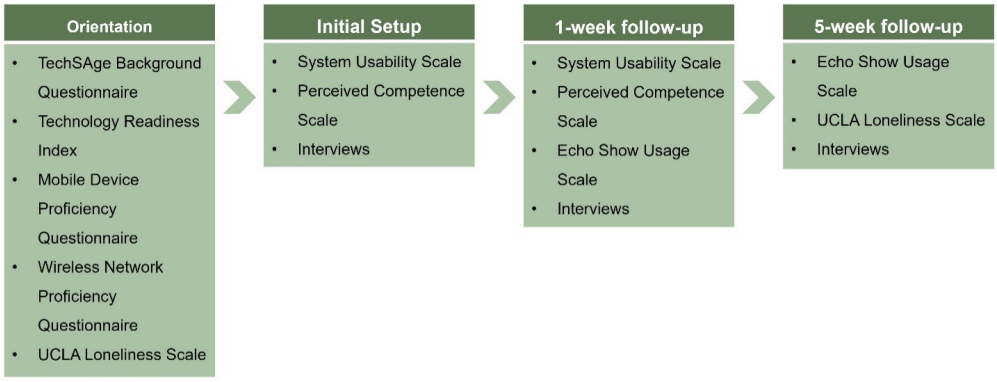

Figure 2. Study procedure and data collection

Table 1. Participant demographics and health conditions (N = 24)

Variables	n	%
Gender		
Male	11	45.83
Female	13	54.17
Marital status		
Married	17	70.83
Divorced	3	12.50
Widowed	4	16.67
Education level		
High school graduate/GED	2	8.33
Bachelor's degree	8	33.33
Master's degree	10	41.67
Doctoral degree	4	16.67
Household income		
$25,000 - $49,000	3	12.50
$50,000 - $74,999	6	25.00
$75,000 or more	9	37.50
Other	6	25.00
Health conditions*		
High blood pressure	10	41.67
High cholesterol	9	37.50
Multiple sclerosis	14	58.33
Osteoporosis	8	33.33
Arthritis	8	33.33
Overall health rating		
Poor	1	4.17
Fair	9	37.50
Good	11	45.83
Very good	3	12.50
Frequency of health problems interfering with desired activities		
Never	1	4.17
Seldom	4	16.67
Sometimes	8	33.33
Often	11	45.83
Having serious difficulty walking or climbing stairs	21	87.50
Using any supportive aids for mobility*		
Grab bars	17	70.83
Grabber or reacher	15	62.50
Cane	11	45.83
Manual wheelchair	10	41.67
Power wheelchair	8	33.33
Scooter	7	29.17
Walker	7	29.17
Unable to walk independently without using a walking aid	20	83.33

*Participants could have multiple health conditions or use multiple aids, so the total percentage may exceed 100%.

again to explore if there were any changes over the past week. Additionally, they completed the Echo Show Usage Scale to understand their usage patterns during the initial week. An interview explored their initial experience with the technologies. Questions included: "Have you found the technologies to be easy to use so far?" and "Have you experienced any challenges or issues when using the technologies over the past week?"

5-week follow-up

After using the digital assistant for an additional 4 weeks (5 weeks total), participants were asked to complete the Echo Show Usage Scale and the UCLA Loneliness Scale to evaluate any changes in usage patterns and loneliness levels over the course of the study. An interview explored their overall experiences and perceptions of using the technologies. Questions included: "Reflecting on the five weeks of using the technologies, what comes to mind?" and "What do you think has been a useful feature to you?"

Data analysis

Descriptive analyses were conducted to analyze quantitative data collected from questionnaires using the R statistical software (R Core Team, 2023). Furthermore, the non-parametric Spearman's correlation coefficient was used to evaluate the relationship between perceptions and proficiency in technology and the competence and usability of the technologies. Significance was determined by considering $p < .05$ to identify meaningful results. Additionally, the Wilcoxon signed rank test was conducted to compare the SUS and PCS scores between the initial setup and the 1-week follow-up. We used the same test to compare the UCLA loneliness scores between the orientation and the 5-week follow-up.

Thematic analysis was conducted to analyze qualitative data from semi-structured interviews (Braun & Clarke, 2006). Three authors (JK, EL, and KH) used a combination of inductive and deductive approaches. The first author (JK) initially generated codes based on the research questions and identified themes. The second and third authors (EL and KH) then reviewed and refined the identified themes. Throughout the analysis process, codes and themes were adjusted, edited, or added as new patterns emerged from repeated readings of the transcripts. Subsequently, all authors engaged in discussions regarding the analysis and its outcomes until a consensus was reached.

RESULTS

Participant characteristics

The 24 participants had a mean age of 71.5 years (SD = 6.6), range 61-91. *Table 1* provides demographic and health characteristics. Participants generally rated their overall health as good or very good, but many indicated facing challenges related to their health conditions, such as multiple sclerosis, osteoporosis, and arthritis. The majority experienced serious difficulties with walking or climbing stairs, needing the use of supportive aids for mobility, and being unable to walk without assistance.

Table 2 presents a comprehensive overview of their technology readiness and proficiency. Par-

Table 2. General technology readiness and proficiency

Measures (total and subscales)	M	SD
Technology Readiness Index 2.0	3.11	0.47
Positive	3.63	0.65
Negative	2.58	0.65
Mobile Device Proficiency Questionnaire	30.56	6.10
Mobile device basics	4.02	0.98
Communication	4.48	0.56
Data and File Storage	2.98	1.39
Internet	4.48	0.65
Calendar	3.98	1.13
Entertainment	3.60	0.07
Privacy	3.44	1.14
Troubleshooting and software management	3.58	1.30
Wireless Network Proficiency Questionnaire	6.91	2.79
PC	2.18	1.09
Mobile	2.17	1.02
Wireless	2.56	1.02

NOTE: Technology Readiness Index 2.0 uses a response scale from 1 (strongly disagree) to 5 (strongly agree). The lowest possible score is 1.0 and the highest is 5.0. A higher score indicates higher readiness; Mobile Device Proficiency Questionnaire uses a response scale from 1 (never tried) to 5 (very easily). The total summed score ranges from 8 to 40, with higher scores reflecting greater proficiency; Wireless Network Proficiency Questionnaire uses a response scale from 0 (don't know task) to 5 (very easily). total score ranges from 3 to 15, with higher scores reflecting greater proficiency.

ticipants held mixed attitudes toward technology, slightly favoring positive perceptions, as reflected in their TRI 2.0 scores. Overall, participants had some proficiency with smartphones or tablets, as measured by the MDPQ, but less with wireless networks to connect their devices, as seen in their WNPQ score.

Seamless integration and confident utilization

All participants successfully installed and used the technologies in the DAB over time, utilizing our comprehensive manuals. Participants reported high levels of ease and competence in using the technologies (*Table 3*). Comments from the interviews revealed that they attributed their success to the user-friendly design of the manuals.

Initial perceptions and adaptation to new technology

After receiving the DAB package, participants were instructed to set up the technologies in their homes following the provided manuals, with remote assistance from research assistants. Following setup, participants reported good usability of the Echo Show (Bangor et al., 2008), as indicated by an average SUS score of 78.75 (SD = 21.25). They reported high competence in its usage, with an average PCS score of 5.77 (SD = 1.28). Spearman's correlation coefficient analysis revealed that participants with higher proficiency in using mobile devices were more likely to demonstrate higher usability and competence with the Echo Show ($p < .05$). Proficiency in connecting wireless networks was not related to usability and competence ($p > .05$; *Table 4*).

Participants found installing the smart light was easy, as it simply replaced the regular light. Similarly, setting up the smart plug was straightforward, requiring the attachment of the original device plug and insertion into the outlet. They anticipated that the smart light and plug would be easy to use after installation, as no further steps were necessary. However, because the Echo Show involves multiple setup steps and learning, some participants initially believed it might not be as easy to use as the smart light and plug. Nevertheless, they were not overly worried because they perceived the Echo Show itself to be intuitive, and the manuals offered detailed instructions and demonstrations on how to use it.

"I feel pretty confident that they appear to be easy to use, at least the plug and light bulb. Take a little more time with the Echo…once I read up on the user guide, find out everything that it can do." [Female, 77 years old]

"I've found my way into some aspects as you were watching and guiding me through [the steps]...I don't know any of the features of Alexa... but they're all pretty straightforward. It looks as though it's intuitive…so I don't anticipate any problems." [Male, 73 years old]

Continued confidence and supportive resources

After one week of usage, we investigated whether participants required additional support or continued to use the voice-activated assistants with ease. There were no significant differences in SUS and PCS scores over time ($p > .05$), maintaining good usability and high competence. Most participants found using the Echo Show straightforward and reported feeling increasingly comfortable with its features. However, some participants reported that the Echo Show's Alexa occasionally failed to understand or respond to them. To ad-

Table 3. Perceived usability and competence in using the Echo Show after initial setup and after 1 week of usage

Variables	Initial setup		1-week follow-up		
	Median	IQR	Median	IQR	p-value
System Usability Scale	78.75	70 – 91.25	80	74.38 – 88.75	>.05
Perceived Competence Scale	6.25	5.19 – 6.81	6.25	5 – 6.5	>.05

NOTE: System Usability Scale uses a response scale from 1 (strongly disagree) to 5 (strongly agree). The lowest possible score is 0 and the highest is 100. In general, a score above 70 is considered good usability; Perceived Competence Scale uses a response scale from 1 (not at all true) to 7 (very true). The lowest possible score is 1.0 and the highest is 7.0. A higher score indicates higher competence.

dress this issue, they noted referring to the manuals to review commands or exhibited self-learning by independently adjusting their commands.

"It's all voice command. If I make a mistake, or if Alexa misunderstands…I'm thinking about it [for] a few seconds [before issuing] another command." [Male, 76 years old]

Similarly, when participants faced technical challenges, they referred to the provided manuals or sought assistance from family members, usually their spouses or children, to address the issue promptly. For example, participants experienced technical issues with connecting music streaming services or medication apps. In most cases, they were able to resolve the issue with the manuals, prompting them to keep the manuals nearby for easy access. However, if they required additional assistance, they reached out to the research team.

"I reached out to you when I had trouble with the smart plug, once. It turned out to be a mistake on our end because my son changed the name of the network. I didn't realize it." [Male, 68 years old]

Usage patterns and enhanced functional independence

During the first week, participants used the voice-activated assistants for an average of 7 out of 17 activities listed on the Echo Show Usage Scale, with individual engagement ranging from 2 to 15 activities. After five weeks, the average increased to 8 out of 17 activities, ranging from 2 to 14 activities. Most participants (n = 15) reported doing more activities over time, whereas only five participants reported doing fewer. The most notable increases were in making to-do lists and setting alarms, each rising for five participants, and setting timers, which increased for four participants. Participants mentioned that becoming more familiar with voice-activated digital assistants encouraged them to explore other features they had not tried before. In contrast, some activities saw a decline. Six participants stopped ordering items (using Amazon), and two participants ceased playing music.

Throughout the five weeks of usage, all participants actively used digital home assistants to control their smart lights (n = 24). Additionally, the majority utilized the assistants to manage devices through smart plugs (n = 20), check the weather (n = 20), play music (n = 20), access news (n = 17), and set alarms (n = 15). These activities showed how participants incorporated smart home technologies into various aspects of their daily lives, such as controlling their environment, managing daily tasks, entertainment, and accessing information. Furthermore, all participants stated they found the provided smart home technologies to be useful, expressing satisfaction and finding them enjoyable and beneficial in their daily lives. Activities related to daily management, such as accessing calendars and setting timers or alarms, showed increased usage over the weeks (see *Figure 3* for usage data).

Convenient remote control and physical energy efficiency

Participants enjoyed their ability to control various aspects of their home environment, such as lights and appliances, using simple voice commands. Given that they have mobility disabilities due to chronic diseases such as stroke or multiple sclerosis, this feature was greatly beneficial for them as it enabled them to control household appliances remotely, eliminating the need for physical movement around the home and thereby enhancing their functional independence.

"I don't need to turn a switch. I don't have to reach a dial. I don't have to do any of those things. So, I love the ability to just do it verbally…[This eliminates] the need for physical movement and use of my arms or hands, which are not functioning as well as they used to do." [Male, 75 years old]

"Being able to ask her to turn it on for me, particularly now that I'm on the walker, I don't have to take my hand off the walker to hit a switch to turn something on. I walk into the room and just ask her to turn it on." [Female, 77 years old]

Enhancing safety and cognitive support

Voice-activated digital assistants can enhance home safety for older adults with mobility disabilities, especially considering the serious safety concerns posed by nighttime falls. Participants noted that through the integration of voice-activated assistants and smart lights and plugs, they experienced an increased feeling of safety.

Table 4. Correlation between perceptions and proficiency in technology and the usability and competence of the Echo Show

Variables	TRI	MDPQ	WNPQ	SUS	PCS
TRI	–				
MDPQ	.25	–			
WNPQ	.02	.72***	–		
SUS	.22	.26*	.21	–	
PCS	.43**	.48**	.36	.43**	–

TRI = Technology Readiness Index 2.0; MDPQ = Mobile Device Proficiency Questionnaire; WNPQ = Wireless Network Proficiency Questionnaire; SUS = System Usability Scale; PCS = Perceived Competence Scale

*p ≤ .05; **p ≤ .01; ***p ≤ .001

"At night, when I'm going from a dark room to a dark room, I continue to have Alexa turn [the lights] on as soon as I walk in…it's such a simple thing, but it saves a lot of walking in the dark and dangerous stuff." [Female, 70 years old]

"Turn on the light in the bedroom before I get up there. So, I don't have to worry about tripping while I'm headed towards the lamp, which is good." [Male, 67 years old]

The assistants offer reminders, not only aiding in daily task management but potentially preventing safety hazards such as forgetting to turn off the stove after cooking, which could lead to a fire. This feature would be particularly beneficial for older adults experiencing age-related memory impairments.

"The main advantage is you can hear [Alexa] throughout the house. Well, I don't need that… but then I realized [an] incident that happened just a couple of days ago. I made chili in a slow cooker downstairs, and then I went out, and I did errands…I should have remembered to turn it off, and I didn't…Five hours later, I went downstairs to get something to drink and looked at it and went, 'Oh my god, I didn't remember that I made chili'… One of my biggest problems is that when I walk away from a task, it's forgotten. I just started to use it a lot, saying, "Alexa, remind me in 20 minutes to turn it off…' Since then, I realized that I could be utilizing it for…the cognition." [Female, 70 years old]

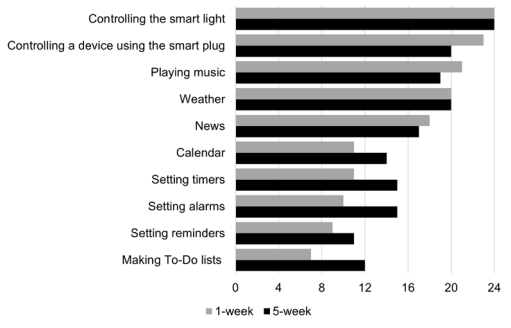

Figure 3. Top 10 activities utilizing the Echo Show (N = 24)

Knowledge access through real-time updates

Voice-activated assistants offer invaluable access to real-time updates, ensuring users keep connected to current events and have access to essential information such as weather, news, traffic updates, and answers to various questions. This accessibility feature can be especially useful for older adults with mobility disabilities as it allows them to stay informed and engaged without needing to move physically. For example, real-time weather updates can benefit older adults with mobility disabilities, particularly those with poor balance or who rely on mobility aids. By providing timely information, these updates can help in planning outdoor activities by avoiding adverse weather conditions that could lead to hazardous situations, such as slipping on wet surfaces.

"Probably the weather [is the most useful] because I spent a lot of time outside. It's the most up-to-date on the weather." [Male, 70 years old]

"Sometimes I just play around with it…ask what is the distance from here to Alaska? I like those questions." [Female, 62 years old]

Reduced loneliness through the use of AI voice-activated assistants

A significant decrease in UCLA Loneliness scores was found between the orientation phase and the end of the five-week usage period, indicating a reduction in loneliness levels (see *Table 5*). Specifically, participants reported feeling less excluded (Item 4 – "I feel left out"), less isolated from others (Item 5 – "I feel isolated from others"), a greater ability to find companionship when desired (Item 6 – "I can find companionship when I want it"), and perceived the presence of people around them (Item 8 – "People are around me but not with me"). Further insights into these changes were obtained from individual in-depth interviews, as elaborated below.

Enhanced social connectivity

The use of voice-activated assistants not only enhances functional independence but plays a crucial role in reducing loneliness among older adults with mobility disabilities. These assistants bridge the gap in social connectivity by allowing them to effortlessly connect with their friends and family members through voice commands. With features such as access to contacts and the ability to recognize desired individuals' names for calls, voice-activated assistants can facilitate

Table 5. Comparison of UCLA Loneliness Scores

Variables	Orientation		5-Week		
	Median	IQR	Median	IQR	p-value
UCLA Loneliness Scale (Summed score)	18	13.75-19.25	14.5	11.75-18.25	.003
I lack companionship	2	1-3	2	1-2.25	.31
There is no one I can turn to	1.5	1-2	1	1-2	.1
I am an outgoing person	2	2-3	2	2-3	.77
I feel left out	2	2-3	2	1-2.25	.04
I feel isolated from others	2	1-3	1.5	1-2	.03
I can find companionship when I want it	2	1-2	1	1-2	.04
I am unhappy being withdrawn	2	1.75-3	2	1-3	.61
People are around me but not with me	2	1.75-3	2	1-2.25	.02

NOTE: The modified UCLA Loneliness Scale uses a response scale from 1 (never) to 5 (always). The lowest possible score is 8 and the highest is 40. A higher score indicates greater loneliness.

meaningful social connections despite mobility disabilities, fostering a sense of belonging and emotional support. Moreover, the inclusion of a screen, as seen in the Echo Show, further strengthens social bonds by enabling face-to-face interactions, which are important for reducing loneliness. This enhanced social connectivity can promote regular and efficient communication with loved ones, which may result in the reduction of loneliness among older adults.

"[The Echo Show] might be a nice alternative… Like a Facebook video call for a Zoom call or anything through that, because sometimes, we're not at the laptop…and the phone is too small." [Female, 70 years old]

"Just with having the picture, there was a little bit more than just having a voice talking back to you." [Female, 77 years old]

Engaging entertainment

Participants found enjoyment in various entertainment activities facilitated by voice-activated digital assistants, such as listening to music, playing games, and watching their favorite shows through connected streaming services. Notably, asking voice-activated assistants to play music was one of the most frequent usages among participants in this study. Listening to familiar songs from their youth can evoke nostalgic memories and positive emotions. These activities can contribute to loneliness reduction by providing emotional fulfillment.

"I want to listen to music, it's really easy, instead of having to turn the radio on or put a CD in or something like that type of thing...I like the background music, while I'm working on something." [Male, 70 years old]

"I have most of my CDs boxed up and there are being able to ask to listen to a particular artist and getting some plays for that artist has been nice." [Male, 67 years old]

Cultivating emotional bonds beyond technology

The voice-activated assistants fostered a sense of companionship among participants, extending beyond their functional roles to create emotional bonds akin to human relationships. Participants often interacted with these assistants by asking questions or jokes. Interestingly, even when the assistants simply responded with information, participants perceived it as conversations with another individual, thus enhancing their feeling of social belonging. Furthermore, most participants referred to these assistants as "she" or "her," personifying them and implying that they view them as human beings rather than mere machines or technology.

"One factor [that I really enjoyed] is that there's a human element where Alexa told me, 'Have a good day' this morning." [Female, 69 years old]

"It gives me somebody to talk to when I'm home alone…I talked to my cat a lot. She doesn't answer me, but Alexa will answer me. So, it's like having another person." [Female, 71 years old]

DISCUSSION

We provided voice-activated digital assistants and other smart home technologies to community-dwelling older adults with mobility disabilities, including those with stroke or multiple sclerosis. Participants could effectively install and use these technologies with the help of manuals specifically designed for older adults. As a result, participants found these smart home technologies useful in their daily lives, contributing to functional independence and psychological well-being.

Instructional manuals tailored to older adults

Despite initially reporting limited proficiency in connecting devices to wireless networks during the orientation phase, all participants could install and use the provided smart home technologies independently by following our comprehensive manuals. This achievement was possible through our human factors approach to the design of

comprehensive, user-friendly, and effective step-by-step instructional support tailored for older adults. We used task analysis to deconstruct goal-oriented behaviors and identify specific tasks and subtasks needed to achieve the goal (Blocker, Mitzner, et al., 2022). We conducted interactive user testing with diverse individuals, including subject matter experts and older adults with varying abilities, providing valuable feedback for enhancing our instructional materials (Blocker, Ramadhani, et al., 2022). As a result, our final manuals offer comprehensive instructions, enabling older adults to install and use the technologies effectively regardless of their prior experience.

In response to current technological trends, we developed digital versions of the manuals, including PDFs and YouTube videos accessible via mobile devices. Yet, recognizing the unique needs or preferences of print materials for our target users, especially those less familiar with digital technology (Gorenko et al., 2021), we provided paper-based manuals. Indeed, participants in our study often kept the paper-based manuals nearby, emphasizing the importance of accommodating diverse user preferences and needs. This seamless integration of digital and traditional formats can ensure accessibility and usability for all older adults, regardless of their technological proficiency or preferences.

Benefits of voice-activated assistants for enhancing safety and independence

We found that participants interacted with the voice-activated digital assistants in various ways, including environmental control, health and life management, entertainment, and social engagement. Through these activities, we identified the potential of such technologies to support individual autonomy, especially for older adults with mobility disabilities. Notably, the ability to remotely control the home environment with simple voice commands is a significant benefit for older adults with mobility disabilities. Mobility, "the ability to move or walk freely and easily," is essential for independent living (National Institute on Aging, 2020). However, mobility disabilities are the most prevalent among older adults (U.S. Census Bureau, 2022), affecting their ability to move freely to conduct daily activities independently. Therefore, voice-activated digital assistants could greatly enhance the functional independence of these older adults by allowing them to engage in daily activities and manage their home environment without physical movements.

All participants used voice-activated assistants to control their smart lights and expressed high satisfaction with this feature. They often asked the assistants to turn on the lights before entering a room, especially at night. This simple action of illuminating a space before entering can greatly reduce the risk of falls. Good lighting, often recommended by healthcare professionals, is a key strategy to prevent falls among older adults (National Institute on Aging, 2022). However, for older adults with mobility disabilities, particularly those who use mobility devices such as walkers or wheelchairs, accessing light switches may pose challenges. Hence, using voice-activated assistants for lighting control could be a crucial fall preventive strategy for this population.

Interestingly, while all participants in our study found the voice-activated digital assistants useful, older adults have reported negative feelings about these assistants. For example, Trajkova and Martin-Hammond (2020) revealed that older adults felt voice-activated assistants could negatively impact their independence. They expressed concerns that simply speaking commands to an assistant might deter them from physically engaging with tasks. Moreover, they used these assistants for fun, believing that if the assistants were taken away, it would be easy to complete tasks using other methods. Consistent with this perspective, many participants in that study chose not to use voice-activated assistants, citing challenges in finding valuable uses (Trajkova & Martin-Hammond, 2020). Another study exploring the perspectives of older adults on smart home technologies found a similar trend, with participants indicating a lack of immediate necessity for such technology (Ghorayeb et al., 2021). This divergence underscores the importance of tailoring technology introductions to understand and meet the specific needs and values of diverse older adult populations.

Improving psychological well-being

After five weeks of using a voice-activated digital assistant, participants reported a significant reduction in feelings of loneliness. With voice commands such as "Call my son," the assistants can access preset contacts, recognize names, and initiate calls. Hearing the voices of loved ones can alleviate loneliness, and the effectiveness can be enhanced through video communication. We selected the Echo Show, which includes a screen feature, from among various types of voice-activated assistants, such as the Echo Dot smart speaker. This decision was influenced by older adults' generally favorable attitudes toward smart speakers with screens (Blocker et al., 2020). The inclusion of a screen allowed participants to make video calls, a feature older adults specifically mentioned in the previous study as desirable during our manual development process (Blocker, Kadylak, & Rogers, 2023). Video calls may positively impact their loneliness levels, helping them stay connected with others (Siniscarco et al., 2017; Zamir et al., 2018).

In addition to social connection, most participants used the voice-activated digital assistant to play their selected music. Participants mentioned they used to rely on CDs or radios to listen to music, which could be inconvenient and limit their song choices. However, with voice-activated digital assistants, they could simply request a desired song by saying its title and artist, allowing them to easily enjoy their favorite tunes. This ease of access to self-selected music may contribute to a reduction in loneliness among participants, given that listening to self-selected music can decrease negative moods such as sadness and anxiety while simultaneously increasing positive moods such as happiness and empathy (Schäfer et al., 2020). Furthermore, self-selected music provides older adults with emotional regulation and companionship as well as serves as a reminder of social relationships in the past (Groarke et al., 2022), which may impact the level of loneliness.

Participants in the study reported engaging in interactions beyond simple one-way voice commands with the voice-activated digital assistant, often referring to it as "she" or "her," personalizing their interactions. This behavior has been observed in previous studies (Blocker, Kadylak, & Rogers, 2023; Pradhan et al., 2020). For instance, older adults exhibited politeness in their speech, using phrases such as "please" when making requests to Alexa, even though this was not explicitly intended by them (Pradhan et al., 2020). Moreover, in another study, older adults viewed Alexa as a close friend, comfortable enough to share personal details they would not tell anyone (Blocker, Kadylak, & Rogers, 2023). Given these observations, where older adults see voice-activated digital assistants as more than just technology, treating them as human-like companions, it is likely that extended interaction fosters a stronger bond. Furthermore, if these assistants could initiate conversations tailored to older adults' interests through AI technology, it could greatly enhance psychological well-being.

Although these findings supported our hypothesis, many older adults with mobility disabilities may not fully benefit from AI voice-activated assistants and smart home technologies. A recent national survey found that although 46% of U.S. older adults are aware of these technologies, 47% are uninterested in adopting them (Kakulla, 2023), often due to a perceived lack of necessity, limited interest, technological skepticism, and privacy concerns (Kakulla, 2023; Tural et al., 2021). Nonetheless, research indicates that with appropriate support and positive experiences, a significant portion of older adults with mobility disabilities are capable of learning and successfully adopting these technologies. For example, when older adults were given the opportunity to try these technologies firsthand, their acceptance increased over time, and they reported fewer concerns compared to those who had not used them (Ghorayeb et al., 2021). Furthermore, positive and enjoyable experiences with these technologies can help older adults feel more comfortable to use smart home devices (Lee & Kim, 2020). Therefore, it is essential for healthcare professionals and researchers to offer hands-on exposure to these technologies for older adults with mobility disabilities, helping them experience the benefits identified in this study.

Limitations and future direction

Although this study provided valuable insights into the use of voice-activated digital assistants and connected smart home technologies among older adults with mobility disabilities, several limitations should be acknowledged. Firstly, the study duration may not have been sufficiently long to fully understand the long-term effects and sustainability of using these technologies. Future research should extend the duration of the study to explore longitudinal changes and assess the long-term impacts on functional independence and loneliness among older adults with mobility disabilities.

Secondly, the participants in this study initially reported low levels of loneliness, with most being married. Although a significant reduction in loneliness was observed after five weeks of usage, it remains unclear how effective these technologies would be among individuals with higher levels of loneliness. Future studies should aim to recruit participants experiencing significant levels of loneliness, such as those living alone, to explore the potential in-depth effects of voice-activated assistants on reducing loneliness. Moreover, the pre-post research design we used did not have a control group, which will be an important next step to verify the source of the decreased loneliness.

Lastly, the sample size was relatively small and consisted solely of older adults with mobility disabilities. To enhance the generalizability and accessibility of voice-activated digital assistants and smart home technologies, future studies should include a more diverse range of participants, encompassing different age groups and disabilities. For instance, younger adults who are more familiar with state-of-the-art technologies may utilize these technologies in more diverse ways and could offer different perspectives compared to older adults. Additionally, individuals with different disabilities, such as cognitive impairments, may require additional training or exhibit different usage patterns, warranting further exploration.

CONCLUSION

This study showed the potential of voice-activated digital assistants and connected smart home technologies in facilitating aging in place for older adults with mobility disabilities. These technologies can not only enhance functional independence but also alleviate feelings of loneliness. Our quantitative and qualitative data analysis revealed that our tailored instructional manuals effectively enabled older adults with mobility disabilities to install and utilize these technologies with confidence. This highlights the importance of considering the unique needs and preferences of different demographics when designing and introducing new technologies. Moreover, our findings revealed that older adults with mobility disabilities perceived the voice-activated assistants and connected smart home technologies as valuable tools in their daily lives, particularly appreciating their ability to control the home environment despite physical limitations. Furthermore, for some participants, these technologies were viewed not just as devices but as companions, positively impacting their psychological well-being. These findings can guide healthcare professionals and researchers in introducing these technologies to older adults with mobility disabilities, emphasizing their potential benefits. By doing so, we can empower older adults to embrace these technologies without hesitation, ultimately fostering autonomy.

Ethical aspects

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Declaration of conflicting interests

The authors declare that there is no conflict of interest.

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