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The Intersection of Smart Home Technology and the Disabled Population

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Chapter 1: Introduction

1.1 Background

In the United States, over one in four adults deal with some type of disability, including issues with mobility, cognition, hearing, vision, or other limitations to their self-care. The Center for Disease Control and Prevention (CDC) estimates that approximately 27% of all adults in the United States are dealing with some sort of disability, which includes issues with mobility, cognition, hearing, vision, and self-care [1]. One barrier to independent living faced by people with disabilities is the struggle to complete activities of daily living (ADL). Those dealing with issues of physical limitations are sometimes unable to complete ADLs without the assistance of a helper or caregiver.

One way that people with disabilities can live more autonomously is to incorporate smart home technology into their homes. Smart home assistive technology can be defined as "any item, piece of equipment or product system, whether acquired commercially, off-the-shelf, modified, or customized, that is used to increase, maintain, or improve the functional capabilities of individuals with disabilities [2]." Smart home technology is sometimes incorporated into existing devices, such as laptops, tablets, or smart phones. Apps are easily accessible for download that can address a wide range of issues. AIRA and Be My Eyes are two examples of apps available for download that can connect visually impaired users with someone who can see their surroundings via the phone's camera and answer any question the user might have.

There are other smart home devices that, while not specifically targeted to disabled users, can be leveraged to great effect by those needing extra assistance in their homes. Voice-activated devices such as Alexa and Google Home can serve as a valuable source of information and entertainment for people who have difficulty seeing or using a standard keyboard. Smart outlets can allow remote access to appliances or lights, making it easier for those with mobility issues to interact with their environment without needing to walk all the way through their house. Ring doorbells and internal cameras can also help those with mobility issues, and they can also benefit caregivers who need to occasionally be able to see and interact remotely with those in their care.

A third category of smart home devices are specifically designed to meet the needs of a particular section of the disabled community. Power wheelchairs can help those with severe mobility issues regain the ability to navigate through their environment. Assistive robots, both those that perform assistive tasks or those that primarily offer social and intellectual interaction, can help those with either mobility or cognitive issues.

Regardless of the category in which smart home devices fall, they should ideally meet the requirements set out by the Information Society and Technology Advisory Group: very unobtrusive hardware, a seamless web-based communications infrastructure, dynamic and massively distributed device networks, a natural feeling human interface, dependable, and secure [3]. The more a device meets these requirements, the better it can be incorporated into a smart home setting. One important caveat to bear in mind with this or any study looking at people with disabilities is that every person experiences their disability in their own unique way. Although similar disabilities have been grouped together for convenience in this study under headings such as "visual impairments" and "hearing impairments," that is not an indication that all people included in those categories are a monolithic group with common experiences. All smart home devices aimed to a specific group of people cannot and will not meet the needs of everyone in that group, simply because no two people in any group are exactly the same.

1.2 Objective

The objective of this study is to increase awareness of the smart home technology solutions currently being developed and to give those in the disabled community a voice in what they would like to see developed in the future, as an aid to those developing new technology. It will also include a comparison of the results of both the systematic literature review and the survey, to identify areas where they are similar and where they differ. The differences between the two results are of particular interest because ideally there should not be a disconnect between users' needs and what is being worked on. If there are needs identified in the survey that are not appearing in the current literature, that could potentially signify a direction for new research.

1.3 Organization

This study will begin with a systematic review of existing literature in Chapter 2 regarding smart home technology and its application for those who are disabled or elderly. Specifically, the literature review will look at how proposed technology could help with issues faced by people with hearing, vision, speech, or cognitive impairments, those dealing with concerns about balance and falling, and those hoping to live more autonomously in their own home no matter what issues they may be dealing with. The existing literature on smart home use by people with disabilities focuses almost exclusively on adults, although one study looked at capturing gait information from children with cerebral palsy by embedding sensors in their shoes [4]. Chapter 3 will look at a survey of people from these population groups (n = 22) to see what technology solutions they are currently using, what their concerns are regarding smart home solutions, and what issues they face in their daily lives that they would like to see addressed by future technology-based devices. Chapter 4 will review insights gleaned from the survey and compare them to some key points addressed in the systematic literature review. Chapter 5 will conclude this study and give thoughts about potential future works.

Chapter 2: Systematic Literature Review

2.1 Methodology

The articles reviewed for this study were found in IEEE, Association for Computing Machinery, and ScienceDirect, using the search phrases “smart home” and either “disabled,” “disability,” or “disabilities.” Given the rapid progress that is being made in the area of smart home technology, only articles from 2018 to current were reviewed. This search yielded 1043 articles for review, with one duplicate that was removed immediately. Upon performing a review on the titles and abstracts on those articles, 850 were removed from consideration because they were not pertinent to the issue of how smart home technology can benefit those with disabilities. Out of the remaining 192 articles, a further 46 were deemed not relevant to this research. Five of those were in a foreign language, two were not able to be opened and read, and the other 39 were not applicable to this research.

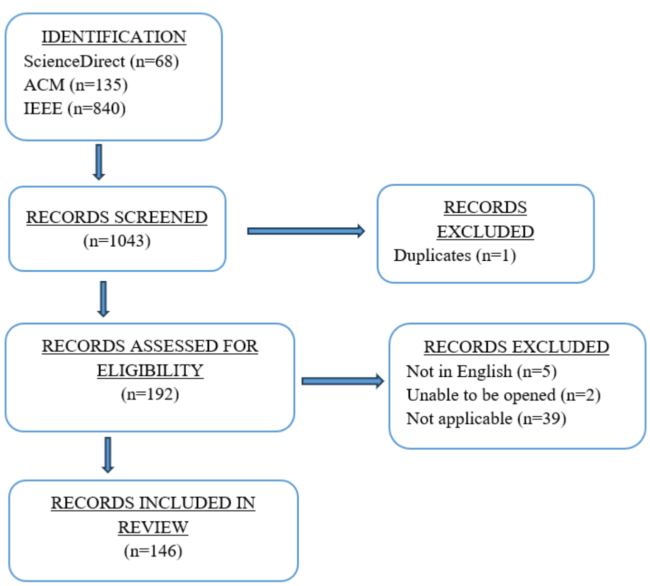

Figure 1: Reference Selection Process

2.2 Visual impairment

As of 2017 in the United States, there were over seven million people with vision issues, ranging from approximately 1.3 million people experiencing blindness and a further six million people with visual impairments even with their vision corrected as much as possible with glasses or other devices [5], [6]. This number is increasing by approximately 75,000 people each year [6]. Assistive technology can greatly assist those with visual impairments in ADLs that cannot be navigated through the other senses. Smart home adaptations designed to assist those with visual impairments fall into two main categories, ambient assistance and active assistance. Ambient assistance technology passively monitors the user's environment and adds information or guidance when needed. Active assistance devices, on the other hand, are those that are explicitly activated by the user to perform a specific task and are subsequently turned off again.

Ambient assistive technology has the benefit of always being on, so it can fit seamlessly into the user's environment. An example of this type of assistive technology was tested by Gowda, Hajare, and Pavan [7] in which a body camera took continuous pictures of the environment in front of a visually impaired walker and alerted the walker through an earpiece if specified objects were detected in their path. This technology was designed to work in conjunction with a cane; the cane would provide information about objects or obstacles directly in the walker's path while the camera's feedback could alert the walker to problematic objects not yet in the immediate vicinity.

Not all devices can be continuously active, though. Devices that draw a lot of power or that require a great deal of computing power can be a drain on resources or can be expensive to always keep in an active state. Voice assistants (VA) such as Siri and Alexa are good examples of active assistance devices, which are engaged by an explicit command from the user. According to a study performed by Vieira, Leite, and Volochtchuk [2], the participants that were visually impaired used VA devices most consistently to carry out commands and answer questions that would otherwise require them to look something up. Some blind participants expressed a wish for the VAs to incorporate tactile outputs such as vibrations or Braille instead of solely audio outputs. Another survey [8] indicated that blind VA users appreciate these devices for their low cost and ease of use, but they wish improvements could be made with precision in voice recognition, more customization options, and the ability to carry out stacked commands or longer, more complex requests. They expressed a desire to increase the speed of the audio response for VA devices as well, to make interactions more efficient, since there is no way to skim through an audio response as one could with a text-based response.

As part of the survey in [2], something visually impaired users mentioned was a desire for VA devices to be connected with cameras. This would give some of the same real-world immediate feedback as tested in [7], but it would be used in an active assistance capacity instead of an ambient assistive mode. Lee, Shrivastava, and Kacorri [9] worked on a prototype for this functionality, wherein a user would take a picture of an object and they would receive a verbal description of the object. Since one of the most difficult obstacles to overcome was identifying which item was being referenced when the picture was cluttered or the desired item was not centered in the photograph, their prototype process included human interaction, with the user pointing to or otherwise indicating the object being investigated.

2.3 Mobility concerns

Mobility issues span a great variety of concerns. Some people rely on canes or walkers to navigate their environment, so while they are able to walk unassisted, they may experience significant fatigue in the process. Others use manual wheelchairs that require either upper arm strength or the assistance of a caregiver to push. Power wheelchairs are another option for those that experience issues with their upper limb muscles as well as their lower limb muscles. Overall, the percentage of the United States population facing mobility issues with serious difficulties walking or climbing stairs is approximately 12.1% [1]. This population also includes a substantial number of temporarily handicapped people who are recovering from surgery or injury, who may be using scooters or crutches in their recovery period.

One area in which assistive technology can benefit those with mobility issues is automation. Instead of having to physically travel around the home to perform tasks or check on the status of items in the home, automation can allow users to initiate those tasks from anywhere in the house. Yang and Zheng [10] looked at optimizing voice assistants (VA) such as Alexa in conjunction with smart outlets and other internet-connected devices. Specifically, they conducted an experiment to see if a simple two microphone array was sufficient to estimate the direction a person was facing when they spoke a command to a VA device. Being able to accurately estimate the direction a person is facing could allow spoken commands to a VA to be applied to a specific target smart device and not to all devices in the room. For example, if a person faces the light they wish to have turned on when they give the command to have the light activated, that light solely could be activated instead of turning on all smart lights in the vicinity. Using only two microphones allows for a less expensive setup, easier installation, and less complicated training.

Smart home technology also encompasses robotic assistants. These devices can be stand-alone entities that can be programmed to fetch or carry items, or run small errands throughout the house. Bajones et al. conducted a set of field trials for a mobile service robot, called a Hobbit, in private residences [11]. The robot was designed to be a companion and assistant for elderly people with either mobility issues or some sort of physical impairment that made the presence of an assistant useful. The Hobbit was designed to pick up, fetch, and transport objects, give reminders, provide companionship, and watch for falls or other emergencies that might need to be reported immediately to someone outside the home. The purpose of the trial was to gauge the efficacy of the robot as well as evaluate how people actually interacted with the robot in a prolonged, unscripted environment. The study found that being able to test the use of the robots in actual homes versus in a laboratory setting gave useful feedback, both in areas that need improvement and in what ways people really used the robots to assist with their ADL.

For those people with lower-limb mobility issues that use power wheelchairs, one issue facing that needs to be addressed is charging the wheelchairs' batteries. This activity sometimes requires manual dexterity that the disabled person does not have. Work has been done to create a wireless power transfer pad that a wheelchair could simply be parked on to charge it, rather than requiring the wheelchair to be plugged in. This technology would increase the self-reliance of powered wheelchair users and make it easier for them to live independently [12], [13].

People with mobility issues in both upper and lower extremities often need assistance with ADLs. Ajani and Assal attempted to create a toothbrush interface for a robotic arm so that people with severe mobility issues could still brush their teeth autonomously [14]. The interface would use sensors to detect the user's mouth and the orientation of the mouth, insert a full-mouth toothbrush into the user's mouth, and clean their teeth, which would be done without any external help needed by either the user or a caregiver. The biggest difficulties that needed to be overcome were sensing the exact position of the user's mouth and determining the appropriate amount of force needed for the toothbrushing activity. Robotic activities around a person's face need to be extremely delicate so as not to injure the person, so there hasn't been a lot of experimentation in this area to date when compared with other robot-assisted activities.

Upper-arm mobility issues can also cause difficulty when interfacing with a computer, since a combination of a keyboard and a mouse is the standard interfacing mechanism. A decrease of stamina or dexterity in a user's arm, hand, or fingers can make the keyboard and mouse set-up hard to use accurately or for an extended period of time. Wang et al. proposed and tested a human-computer interface (HCI) device called an AirMouse that can be attached to a pair of glasses [15]. The built-in gyroscopes can detect motion of the user's head around different axes of movement, such as turning side to side, up and down, and tilting to each side, and translate them into cursor movements on a laptop screen. The AirMouse worked accurately with very little lag. One good feature of this device is that it does not require continual movement of the user's head for continued movement of the mouse; once left-ward movement is detected, for example, the cursor will continue to move to the left without any further head movement until the head movement is detected to stop the movement. This will cause less fatigue in users and make the device easier to use over longer periods of time.

Robotic assistants can also be used to complete certain ADL tasks that are beyond the current capabilities of someone with upper-arm mobility issues, such as getting dressed. Zhang and Demiris [16] worked on incorporating both tactile and visual inputs for a robot to be able to pick up a garment and unfold it in preparation for dressing a person, typically someone who is elderly or with upper-arm mobility issues that needs such assistance. Zhang, Cully, and Demiris also examined the difficulties encountered when a robotic assistant attempts to help dress a disabled person by running an experiment with a Baxter robot dressing participants simulating upper-body mobility issues. [17]. While robotic assistants have successfully dressed stationary mannequins, dressing people means that there may be unexpected movement by the user that will need to be accounted for. The highest priority goal for the robot in these cases is that they do not harm the user, so the robot's software needs to be able to detect and account for unexpected movement in real time.

2.4 Hearing impairment

Hearing loss affects over 5% of the world's population severe enough to require some sort of rehabilitation or intervention, which equates to over 430 million people [19]. The World Health Organization predicts that by 2050 that number will climb to over 700 million people, which is almost 1 out of every 10 people [19]. Some smart home technology such as voice assistant devices can be difficult for those with hearing loss to use effectively, since those devices rely on audio input and do not always have screens for visual output. To counteract that,

Some members of the deaf community have cochlear implants, which allow for hearing in those that are deaf or hard of hearing (DHH). While this opens the door for the use of VA devices, these users face some unique challenges. Blair and Abdullah [20] found in their survey that DHH users expressed a desire to be able to modify the audio output from their VA devices, particularly the pitch and speed of the voice. Higher-pitched voices were more difficult to hear for most participants in the survey, and the standard voices used for VAs are primarily higher-pitched female voices. Also, the processing time for audio input with cochlear implants is on average slower than the standard speed of VA outputs, requiring users to either miss information or ask the same question multiple times, leading to a slower and more frustrating interaction. Visually-impaired users also showed a desire for adjusting the speed of VA voice outputs [8], but wanted to speed up the voice instead of slowing it down. The ability to adjust that parameter in multiple ways would benefit a wide variety of needs.

Gestures can also be used to interface with devices, in the form of ASL, fingerspelling, or other designated gestures. Melo et al. created and tested an experimental ultrasound sensor grid to detect and analyze pre-set hand/arm gestures to control a media player [21]. Participants were given eight distinct arm movements that corresponded to different controls for a media device, such as mute, volume up/down, and play/stop. They also had each participant complete a questionnaire showing their opinions on the interface. Most felt that the interface was relatively easy to use and a good design, and the accuracy was fairly good for a first attempt, although some of the gestures were similar enough to each other that the proposed interface had some confusion in correctly classifying the gestures.

One way that smart home technology can assist DHH people is to act as a bridge for communication with non-DHH people. Communication between one person using ASL and another person who cannot understand that language can be extremely challenging, so Fu et al. [22] tested a prototype device that could serve as a translator between gesture-based and audio-based languages. The hard-of-hearing person would sign while wearing motion-sensing gloves, then the signals from the gloves would be translated into speech for the non-DHH person. To reverse the communication process, the non-DHH person would speak into a voice-capture device, and the speech would then be translated into a gesture animation that the DHH person could watch.

2.5 Fall concerns

Falls are a great concern for the elderly population or anyone dealing with balance or mobility issues. Globally, approximately 684,000 people die from falls each year, making falls the second leading cause of unintentional injury deaths behind road traffic fatalities [23]. Approximately 37.3 million falls necessitate medical attention each year [23], and while the majority of these falls are not fatal, they increase the risk for broken bones and traumatic head injuries. The risk of falling and not receiving timely assistance is also a real threat to the health of people who live on their own, since they could possibly go several days without interacting with someone else who could assist them. Indeed, not being able to get up from the floor promptly after a fall but instead lying on the floor for a significant period of time has been shown to nearly double the risk of death from the fall [24]. Therefore, a system that can alert family members, health care providers, or a third-party monitoring group when falls happen is of tremendous help to the overall health and safety of the disabled and the elderly.

Wearable alert devices such as Life Alert necklaces or bracelets are readily available and can send an alert when help is needed with the push of a button. The advantage of these devices is they can be set up to be used anywhere, whether in the house or out in the community. They are also lightweight and can be used to signal for any type of emergency, including falls or sudden medical distress. Qian et al. [25] constructed and tested one such wearable fall-detection sensor pack that users could wear on their wrist to detect falls and send appropriate alerts for help. The goal was to construct a device that would be low cost and not consume a lot of battery power, but would be accurate in detecting falls in the midst of daily activities.

The downside of these devices, though, is that they require activation from the person who falls; if a fall renders someone unconscious they will be unable to activate the device and call for help. Having a backup fall detection system that does not require user interaction would be extremely helpful in those cases. Another consideration is that these wearable devices need to be worn or carried at all times. Some people are resistant to this because they don't feel like they need the device, or they simply do not always remember to wear or carry the device. Hanifi and Karsligil tested a Doppler radar set-up in a simulated bedroom to detect fall activity as participants were walking around, getting into and out of bed, and lying in bed [26]. Radar was used because it does not rely on lighting, which is important for bed-related falls when the lighting may be dim or off altogether. The radar captured not only fall activity but subsequent activity; if normal activity was able to continue after the fall, then the fall may not have been too serious. The radar system also detected respiration and heartbeat information, to help classify the seriousness of the fall.

Voice assistant devices may be a good alternative to wearable devices in obtaining help for people who fall in their homes, because VA devices are always passively scanning their surroundings and are available for use to anyone within voice detection distance. Vacher et al. conducted an experiment to see if a voice assistant could be used to understand calls for help and carry out the appropriate action based on the vocal command [27]. While the results of the experiment were promising, there are some difficulties that will need to be overcome before VA devices can be considered a good solution. Difficulties were encountered when the device attempted to parse out commands from background noise and conversation. It can also be challenging to correctly understand vocal patterns for elderly or disabled participants, particularly when the vocal patterns are heavily influenced by pain or emotion as is typically the case in the event of a fall. Another consideration for any solution that incorporates VA technology is that some users are hesitant to use those devices due to security concerns. The passive scanning that makes VA devices useful in this scenario means that they are always on and analyzing speech, and some people do not want that technology in their homes.

2.6 Cognitive issues

Cognitive issues can arise from a variety of reasons, including medication side-effects, disease, age-related memory lapses, and dementia onset. Over 55 million people world-wide are living with dementia, with Alzheimer disease making up approximately 60-70% of that number [28]. People experiencing cognitive issues face unique challenges in autonomous living as they perform ADL. Their issues are not necessarily physical limitation, although depending on the cause of the cognitive decline there could be physical issues as well that need to be considered. Rather, the issues are often tied to memory, forgetting if a task has already been accomplished and either doing it multiple times or neglecting to do the task at all. The impact of such memory lapses can range from mild, such as checking multiple times if a light is on or off, to dangerous consequences such as not taking the proper dose of medication to leaving the stovetop on unattended.

Some smart home technology that can help with memory loss is automation, where tasks are scheduled to run at specific times or under specified circumstances, which means the user does not have to remember them. Bellucci et al. developed and tested a do-it-yourself kit for adding sensors to everyday objects and programming events or alerts based on those sensors [29]. Although this was small scale experiment, it showed promise in allowing people to customize the sensor technology to their specific issues. The simple graphical interface helped participants program the sensors without needing a great deal of outside assistance. The hope was that this project would provide a less expensive approach to navigating through daily life, since this type of technology can be prohibitively expensive for many people, and can require more technological knowledge than many people possess.

The way in which those facing cognitive issues interact with technology can be different than the general population, so some special accommodations may need to be made [30]. Visual interaction with technology can be challenging for this population, which can manifest as difficulties with color perception or finding relevant objects and text in a busy screen. Small text can be difficult to read which often leads to users only using larger tablets with bigger screens. While they could also enlarge the text on their current screen, having only limited information showing at once on the screen easily leads to confusion and losing the big picture of whatever they were trying to accomplish. Using speech-to-text capabilities can be a useful interaction tool, but some forms of dementia result in speech impediments or difficulty processing auditory information, so this work-around is not an option for everyone facing cognitive issues.

2.7 Independent living

For many seniors, living at home as they age is preferred over moving to an assisted living facility or moving in with other family members. The American Association of Retired Persons (AARP) claims that 77% of seniors over the age of 50 have indicated a preference for aging-in-place for as long as possible [31]. To that end, smart home technology can be leveraged by seniors to increase the length of time that they can live autonomously in their own homes. Indeed, 48% of the seniors surveyed by AARP indicated that they anticipated needing at least some smart home devices to be able to successfully age in place [31]. Technology that can simplify or assist with daily tasks can be crucial for this segment of the population, and it can also give peace of mind to family members of those seniors.

Continuing to perform ADLs for as long as possible is vital to maintain cognitive and physical abilities. Basic ADLs include ambulating, feeding, dressing, personal hygiene, continence, and toileting, while instrumental ADLS also include transportation, shopping, managing finances, meal preparation, house cleaning and other home maintenance, managing communication, and managing medications. Therefore, any assistive technology that can be used for tasks in one of these areas can be of great benefit to people wanting to live autonomously in their homes. Roberge et al. [32] focused on meal preparation ADLs, examining the possibility that sensors, including triaxial accelerometers and a gyroscope, embedded in a wristband could identify specific motions used in cooking. The hope behind a successful identification of cooking activities is that the user's activities could be passively monitored, with suggestions, help, or direct intervention offered only when issues are noted. This is better for the user's cognitive functions than relying solely on an automated system. The basis of this article was a trial run of the smart wristband, tracking to make the model as robust as possible. Alahmari and Salem [33] also looked food-related tasks, testing a system to recognize the state of food as it is being prepared – for example, whole, peeled, dices, julienned, or juiced. Identifying types of food and the state it is in can be helpful for monitoring food intake or for making sure food is prepared correctly when using robotic assistants.

Another way to remotely check in on individuals living alone is through a monitoring system that determines what activities that individual is engaged in and alerts when an anomaly is detected. Viard et al. [34] worked on a human activity recognition (HAR) system for user actions and attempted to create an algorithm to predict the activity that the user was performing. By monitoring key actions, a decision could be made as to what activity was being undertaken. This experiment looked at inputs from door sensors, water flow detectors, and smart outlets. By analyzing actions for underlying patters, remote caregivers can monitor how their patient or family member is doing; if there is a change to regular behaviors or certain needed behaviors are not happening, caregivers can be alerted.

Chapter 3: Survey

3.1 Population included

When analyzing the effectiveness of new technology, it is important to examine not only what has been created but also what is actually being used by the target population. To that end, we conducted a survey of twenty-two people from a variety of the target populations examined in the literature review to gauge their opinions on current technology and what they would like to see in the future. This survey is not intended to be fully representative of the entire disabled population and may be subject to sampling bias since the participant selection process was not random. By intentionally selecting participants with different disabilities, though, the intention is that some insight into each type of disability will be included in the survey results.

The breakdown of the survey participants includes both male and female (male = 10, female = 12), as well as a mixture of target populations (elderly = 5, mobility issues = 8, vision impairment = 3, fall concerns = 3, caregivers = 8). The target population numbers total to more than the number of people in the survey population because some participants fit into more than one category. Ages for the survey participants range from 27 to 80, with a mean age of 60.3 and a standard deviation of 14.8. Each participant is identified in this study by a participant ID number instead of by name, for privacy, as shown in Table 1. For the purposes of this study, elderly was defined as 75 years of age or older. The ages for the survey participants identified as elderly range from 77 to 80, with a mean age of 78.2 and a standard deviation of 1.6.

Table 1: Survey participants' demographic information

ID	Gender	Age	Vision	Mobility	Elderly	Fall Issues	Caregiver
P1	Male	80			X		
P2	Female	77			X		
P3	Female	63					X
P4	Female	67	X	X		X	
P5	Male	68					X
P6	Male	52	X				
P7	Female	64					X
P8	Female	66		X		X	
P9	Female	45		X			
P10	Male	80			X		
P11	Female	77			X		
P12	Female	77			X		X
P13	Female	54					X
P14	Male	54		X			
P15	Male	27					X
P16	Female	60					X
P17	Male	32		X			
P18	Male	63		X		X	
P19	Male	63	X				
P20	Male	38		X			
P21	Female	55					X
P22	Female	65		X			

3.2 Survey results

3.2.1 Question 1 - What types of technology do you currently use in your home to assist in your daily activities? Why did you select it? How does it help you?

Survey participants started by discussing the technology that they actually use on a daily basis in their home. Some caregivers focused primarily on devices that were used by the people they care for, while others also included devices that they use themselves on a regular basis. These responses were not selected from a pre-compiled list, and every participant listed more than one technological device that they used regularly. As shown in Figure 2, the responses fell into eight primary categories: computers, smart phones, voice assistant devices, tablets and other small personal devices, medical devices, non-medical wearable devices, applications, and smart devices. Many participants also listed low-tech devices they use regularly; while they are not the focus of this survey, those results are included here to give a broader representation of how the participants navigate through their ADLs and what they consider to be important aids to their everyday activities.

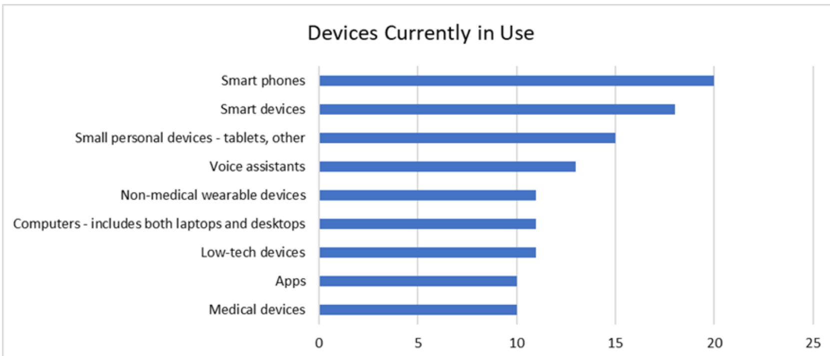

Figure 2: Types of devices currently used by participants

All of the participants in this survey indicated that they use at least one screen-based internet-connected personal device regularly, including computers, tablets, and smart phones; most participants indicated that they regularly use more than one such device. This includes fourteen participants who use devices in two of these categories and five participants who listed devices from all three categories. Participants use these devices for a variety of reasons, including information retrieval, entertainment, creating art, communication, task reminders, and financial handling. Some participants also mentioned that they used the parental control features on these devices to control some of the data that can be accessed by users.

The use of voice assistants, either stand-alone devices such as Alexa or something built into smart phones such as Siri, was a polarizing issue for most of the participants. Thirteen participants have VAs installed in their homes and use them regularly, expressing satisfaction with how well they worked. Five of the remaining nine participants that did not use VAs were quite adamant that they did not use them and were not planning to do so, citing privacy concerns of installing passive monitoring devices in their homes.

A wide variety of smart devices were mentioned by participants. The most common device, mentioned by twelve participants, was smart outlets that were used primarily to remotely control Christmas lights, regular lights, and fans. Seven participants discussed security-related smart devices such as Ring doorbells, motion-activated outdoor cameras and lights, and indoor lights on programmable timers for both convenience and to project the illusion of an occupied house when no one is home. Smart appliances that were mentioned include smart beds that can be adjusted via a phone app, programmable smart speakers, voice-activated automated vacuums, smart televisions connected to VA devices, video baby monitors, heated floors that that can be activated from a remote, and smart keypads to control access to certain areas of the house. A visually-impaired participant mentioned a smart pointer that uses RF tags to identify an item and then plays a pre-recorded audio clip with a description of the item. The same participant uses audio descriptions with movies and television shows played on television or through Netflix.

Ten participants use at least one medical device regularly that either currently is, or has the capability to be, connected via internet to their health care providers or their insurance providers. The two most common devices are CPAP machines and blood sugar monitors, both of which were used by five participants. Four other machines that were each mentioned by a participant are a pacemaker, a monitor for blood oxygen and blood pressure, a continuous pump for spinal medication, and a neuromodulator. All participants who discussed medical devices were pleased with these devices' capabilities and were glad for the level of control that these devices gave them over their health. It should be noted, though, that they did not feel that these devices were a substitute for in-person doctor visits, but instead were a good supplement to regular in-person care. Additionally, one participant uses a power wheelchair, although it does not collect or transmit any health data.

Eleven participants discussed non-medical, wearable smart devices. Five participants use smart watches that allow them to track their steps, daytime activity, sleep activity, and information related to their diagnosis of atrial fibrillation. The watches are also used as timers and stop watches. At this point, none of these participants have watches that automatically send data to third parties such as health care providers. Two caregivers mentioned that someone in their care uses a Life Alert device that is connected to a monitoring service in the event of a fall. Four participants discussed wearable GPS tags that can be worn by children or others that might need to request help while out on their own. These tags allow the wearer to call for help if activated, and the GPS information collected can be sent on an ongoing basis to a designated phone so the wearer can be located even if they do not actively call for assistance.

Some participants listed specific smart phone applications that they rely on as they perform ADLs. The most common application, mentioned by six participants, was a healthcare app that allowed them to access their health information, deal with prescriptions, and stay in touch with their healthcare providers between in-person visits. Two other participants mentioned that they had a smart bed that could be controlled through a phone app. One visually-impaired participant listed several apps that he uses specifically related to his disability. To assist with reading screen-based text, he uses Job Access with Speech (JAWS) to read what is on a computer screen, and he also uses Spectrum's assistive description function to read menus on the television screen. For non-screen related assistance, he uses the apps AIRA and Be My Eyes, both of which capture video through the phone's camera; that video is then relayed to either a living person or an AI system that can answer questions about items in that video feed.

3.3.2 Question 2 - What concerns do you have about assistive technology?

When discussing concerns regarding assistive technology, twenty-one of the twenty-two participants showed concern with at least one aspect of the technology. The most common responses centered on security and privacy concerns, followed by issues they encountered when a technological solution they tried was more difficult to use or not as effective as other solutions they had tried in the past. These responses were freely generated by the participants and did not involve them selecting from a pre-compiled list. Figure 7 shows the number of responses for each concern; the total number is greater than twenty-two since some participants listed more than one type of concern in their response.

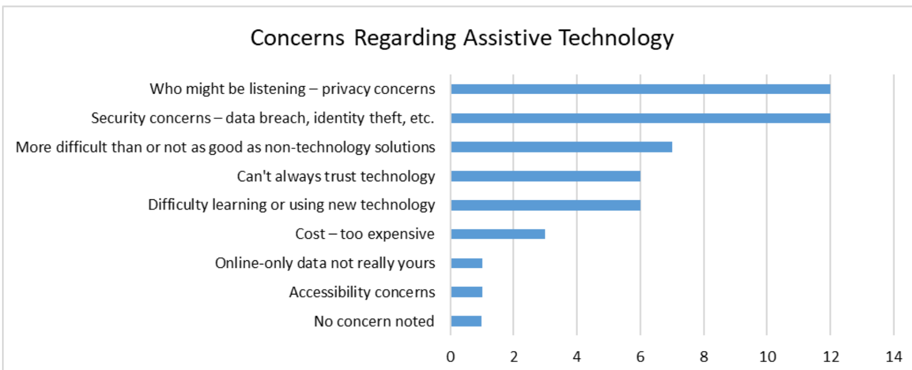

Figure 3: Perceived concerns with assistive technology

The issue of privacy was of great concern to more than half of the participants, and in all but one case it was the first concern mentioned. The response given in almost every case was the question, "Who's listening?" The possibility that a passive listening VA device such as Alexa or Siri could be monitoring, recording, or broadcasting a private conversation in their home was troubling to many of the participants. The same concern was raised regarding built-in cameras in devices such as phones, laptops, desktop computers, and baby monitors. Most of the participants that listed privacy as one of their concerns shared anecdotal evidence that their conversation was being monitored when internet applications gave suggestions or recommendations that closely matched recent conversations that were held in proximity to VA devices. With this level of concern regarding privacy from eavesdropping within the home, it really does not matter if that eavesdropping is occurring or not; the perception will need to be addressed and users will need to be convinced that their privacy is intact before some of these devices will receive wide-spread acceptance.

Of equal concern to the participants was the issue of security, including the threat of identity theft and data breaches. This was particularly true for two participants whose identity had previously been stolen in the past. Medical and financial information was perceived as particularly sensitive, and over half the participants felt that possibility of data breaches involving their personal data was significant enough that it induced caution when using assistive technology. Additionally, one participant raised a concern about adopting new technology that could access and transmit sensitive personal data unless that new technology could be confirmed as legitimate by someone she knew.

The third most common concern raised by participants is that technological solutions are sometimes simply not as effective or easy to use as non-technological solutions. While technology can supplement human interaction or substitute for it in cases where it is difficult to meet in person with medical personnel or other people in remote locations, the ideal interaction is still seen as face-to-face meetings. Virtual communication was perceived by the survey participants as acceptable but certainly not ideal. Other participants made the comment that more devices in the home are just more things that can break or need maintenance or replacement, which adds to the cost and hassle of using smart home technology. This also includes replacing batteries, whether that is in the form of disposable batteries or rechargeable batteries that start to lose their charge at a faster and faster pace over the life of the device. One participant said that technology should save on either time or labor, and many new smart home technology solutions feel like they are labor enhancers rather than labor saving devices, which does not appeal to him. Two different participants, one with vision impairment and one with mobility issues, also mentioned that they enjoy the tactile feel of interacting with the world around them while they work on a task, and they miss that when a task is delegated to an outside device. They would prefer in some cases to manually complete a task even if a smart home device could complete the task more quickly or efficiently.

One participant did not have any concerns regarding assistive technology. It is important to note, though, that this does not mean that the participant did not think there were security or privacy issues with assistive technology. Rather, she felt that all internet-connected devices are by nature non-private and non-secure, to the extent that in her mind, using any smart device including a phone or computer means that you have accepted the inevitability of your information being accessed without your knowledge. She indicated that she has knowingly accepted that risk and so does not feel any further concern about the technology. That feeling of inevitability regarding data breaches and loss of privacy was shared by many of the participants in this survey, but only this one participant was so accepting of it; the rest expressed serious concerns.

3.3.3 Question 3 - Is there any challenge you face currently that would benefit from a technology solution that you haven’t seen available? If so, what is that challenge?

With only one exception, every participant, no matter how much or how little technology they used in their daily lives, had opinions about technology they wished was available for them to use. Most of the desires that were expressed for new technological solutions were unique to that participant's situation, although some desires were shared by multiple participants. Table 2 contains a sample of the responses to this question that were gathered in this survey; any desired technology that was mentioned by more than one participant is followed by a number in parentheses showing how many participants mentioned that particular technology.

Table 2: Participants' desires for new technology

Category	**Desired technology**
Alert devices	Something that would automatically alert family in the event of a fall (5)
	Motion-activated cameras in shared living spaces that could alert for falls
	Sleep walking alert
Cleaning assistance	A system to remotely prepare a bathroom for a bath. It would warm the room and fill the bathtub to the proper level with the correct temperature water.
	Automated window cleaning (2)
	A sensor for undesirable odors such as urine, natural gas, or something burning, for people with a diminished sense of smell
	A germ sensor for surfaces like kitchen counters, sinks, and the bathroom
	Automated cleaning assistant (4)
	A washing machine with a life cycle as good as a standard washer that can be accessed from a wheelchair; front-loader washing machines have a shorter lifecycle than standard machines.
	A way to sweep and mop easily from a wheelchair
	Something that can assist with hanging things on the wall or holding items such as a fan or light fixture steady while they are being installed,
Cognitive assist devices	Reminder messages for medication or daily tasks that would play at appropriate times throughout the day, preferably using the voice of a caregiver or family member (4)
	Locks for refrigerators, stove, microwave, toaster, and other household appliances
Communication assistance	Video communication that is simple to access and use by someone with cognitive issues. It should not require the user to operate a computer, navigate to a certain website, and enter username or password information.
	Hearing assistance that is easy to use for people with dexterity issues that struggle using hearing aids (2)
Cooking assistance	Automatically heat a meal. Ideally, a shelf-stable meal could be put into the microwave or other heating device, then a command given at a later time would cause the meal to be cooked to a pre-set temperature (2)

	An easy way to differentiate spices in a spice rack without having to open each jar
	Mold detector for people who cannot easily see or smell the mold (2)
	A way to get food into and out of the oven safely from a wheelchair when the open oven door gets in the way of the wheelchair
	A way to access high cabinets from a wheelchair
	A knife grip to help people with arthritis still be able to use a knife without fear of losing control of the knife and cutting themselves
Healthcare assistance	Some way to remotely screen for diseases or health issues such as UTIs, perhaps a breathalyzer-style test
	A fitness app that is designed to record wheelchair rotations and other wheelchair movements as part of its fitness stats
	Flat charging stations for glucose monitors, hearing aids, or other devices
Improvements to existing technology	More consistent and reliable fingerprint and facial recognition software
	Larger buttons on remotes, to assist with hand tremors and other dexterity issues (2)
	Better temperature regulation in showers, including the ability to set a specific temperature and hold that temperature consistently
	The ability to personalize voice assistant devices, perhaps programming in certain responses to specific questions
	Accommodations for people with disabilities being integrated into homes instead of retrofitted later, beyond just the bare minimum as required by law (2)
	Transcription phones that are more accurate
	The ability to personalize wearable alerts such as Life Alert, by making them louder so people with hearing impairment can still use them
	A reliable glucose monitoring system that doesn't require finger sticks
Visual assistance	A way to easily track colors of items
	A way to track monetary denominations for bills
	A binocular-type device, but one that gives a wider field of vision than the small circle provided by binoculars.

Many of the participants showed an interest in new technology that would help with ADLs, particularly cleaning, cooking, communication, healthcare, and outdoor tasks around the house. Participants wanted the ability to perform ADLs safely and autonomously; most expressed a desire to be able to perform the tasks themselves with technological support rather than turning the task over entirely to some sort of robotic assistant. Many of the recommendations involved one specific aspect of the ADL that was difficult for a specific participant. Participants with visual impairment mentioned wanting assistance with identifying colors, monetary denominations, and moldy food. They also expressed an interest in devices that could magnify a field of vision that was bigger than the small window provided by binoculars. People with mobility issues discussed better ways to access household spaces and appliances from a wheelchair, along with ways to make exterior home doors easier to navigate through. For people with arthritis or who have limited finger dexterity, devices that could assist with fine motor skill tasks could help them independently pick up or manipulate small objects. Another issue mentioned by several participants was a lack of smell, either by them or by someone they were caring for; devices that could detect and alert for unwanted or unsafe odors such as natural gas, burning, urine, or mold would help greatly with this condition.

Caregivers had a second grouping of desired technology, including a variety of alerts, cognitive assistant devices, and safety devices. Alerting for falls was the most common situation mentioned, although one participant mentioned that a way to prevent or help counteract falls before they occur would be far better than an alert after the fact. Cognitive assistant devices that would give reminders would be extremely beneficial to the caregivers from this survey, particularly if the reminders could be delivered with the voice of someone like the caregiver or a family member. Caregivers were more likely than other participants to mention fully automated solutions to ADL concerns, such as automated cleaning systems, cooking devices, and automated bath preparation. They also mentioned several safety devices, such as ways to prevent people with dementia for accessing dangerous household appliances. A specific safety need that was mentioned was the desire for a device that could assist someone who has fallen but is unable to get off the floor by themselves. This would give tremendous help to people who live alone that are prone to falls, and would provide peace of mind for caregivers as well.

Several participants mentioned a desire, not for new technology, but for improvements to existing technology that they already use. Small buttons on remotes and other controllers can be difficult to use for people with hand tremors or other dexterity issues. Also, facial recognition and fingerprints, both ways to increase the security of personal devices, do not always work well and sometimes cause enough frustration that participants do not want to use them. Participants mentioned wanting more control over devices they use every day, including better temperature regulation for showers and personalized VA devices. Finally, they would like to see the ideals of universal design incorporated into the home building process, so the default home design would already have accessibility built into it from the start and less time and effort would be required to retrofit homes to meet various needs of disabled people.

Chapter 4: Insights from survey

One area which was covered in both the systematic review and the survey centers on the concerns raised by survey participants that are keeping them from using new technology. Cost was a concern for several participants, and the literature review found several groups working on new or existing technology with a stated goal of reducing the overall cost for the technology.

Another area where the literature reflects real needs of the survey participants is in fall alerts. This was a need expressed by several participants, with more looking ahead to that being a potential need in the future. Falls were particularly of concern to those participants that live alone or are caregivers to others, and they expressed a desire for a device that would recognize a fall with very few false positives and automatically alert a family member or caregiver. The current literature includes several experimental devices towards this end, including the goal of fewer false positives so that the device is not a nuisance to use.

Since a large percentage of the survey population uses a VA device such as Alexa or Siri on a regular basis, that fits well with those groups that are working to improve the functionality of these devices. These improvements include personalizing the output from the VA devices and making commands more precise and more easily understandable.

Some desires expressed by the survey participants, though, were not mentioned in the literature reviewed for this study. One such area is the need for sensors that will help with specific ADLs. This includes sensors that would indicate the presence of undesirable things like bad odors, germs, or mold. Both cooking and cleaning tasks would benefit from this type of sensory input. Sensors for specific tasks to aid visually impaired people would also be useful way to distinguish between items that feel the same, such as currency, spices, or differently colored items.

Another type of device that was only mentioned in the survey and not in the literature review were devices mentioned by caregivers that could help people with cognitive or sensory concerns. Devices such as smart locks for dangerous household appliances such as ovens, microwaves, or toasters would improve safety at home and give peace of mind to caregivers. Also mentioned was the desire for soundproofing that could be turned on and off as needed. For people who become overwhelmed with sensory information, the ability to create a temporarily soundproof environment would be an extremely useful way for them to restore their equilibrium; the ability to turn off the soundproofing once it is not needed anymore would help with overall communication with others around the house. Caregivers also mentioned in the survey that it would be beneficial to have a way to remotely screen for diseases or health issues such as UTIs. This type of device was not mentioned in the current literature and might be an idea for future research and development.

One issue noted throughout the survey is that participants were not always sure what technology was available or how to obtain and install desired technology. Many participants used commonly available technology such as tablets, VA devices, and smart outlets to meet any needs they had because those devices were easy to obtain and were not too expensive. Any future technology that is not widely available or is only targeting a niche demographic may not be used, not because it is not effective but because the target population may not know of its existence.

Chapter 5: Conclusion and future work

Even though some participants self-identified as not technologically savvy, most were surprised by the level of technology they actually when they started focusing on it. They were using technology to assist with such diverse areas of their lives as communication, healthcare, ADLs, information retrieval, and entertainment. All participants had ideas as to how technology could enhance their lives and help with safety and autonomy in their personal spaces. It is important to include representatives from a wide variety of ages, backgrounds, abilities, and disability categories when exploring and creating new technological solutions in order to ensure that these new devices are meeting the actual needs of the users to whom they will be targeted.

As smart home technology becomes more widely available, it is important to identify and deal with obstacles that people with disabilities face when it comes to incorporating the new technology into their homes. Money was an issue for many survey participants, as was having enough knowledge to be able to install and use new devices. Also, if the top priority issues of simply being able to access their home easily and safely are taken care of due to the home's design, that would allow them to invest in technological solutions that are more wants than needs.

The literature review showcased the wide variety of assistance in ADLs that are being addressed for several different categories of disabilities. Mobility issues are being addressed by research into robotic assistants, navigation systems for power wheelchairs, and automation through smart outlets and voice assistants. Healthcare assistant devices are starting to allow doctors and therapists to interact remotely with patients as a supplement to in-person visits, leading to an increased level of care for people living independently at home. Monitoring systems for people with cognitive decline or fall concerns allows for more autonomous living and for increased peace of mind for their caregivers. All of these areas of development match up with needs identified through the in-person survey, so those involved in researching new smart home technology are developing devices that will meet real-world needs.

Overall, throughout the survey there was a general consensus that participants were happy to incorporate new technology into their home if it was cost effective, met a need better and easier than the solution they were currently using, and did not cause any significant problems such as a perceived increase in privacy or security breaches. Smart home technology definitely has the ability to increase safety and autonomous living conditions for those living with disabilities; those creating the technology need to partner with the end users of that technology so that the solutions generated meet actual needs in the most effective way possible.

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