"I... caught a person casing my house... and scared him off:" The Use of Security-Focused Smart Home Devices by People with Disabilities

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ABSTRACT

Recent years have seen a proliferation of security-focused smart home devices (SSHDs). SSHDs, such as smart locks and cameras, are designed to accomplish critical tasks, such as protecting one's home and property. However, their use by and for people with disabilities (PwD) has not been broadly investigated. To explore the state of SSHD use by PwD, we collected 114,871 amazon.com reviews for popular SSHDs and created a data set of reviews pertaining to PwD. We performed a broad analysis of the reviews in this data set and found that the presence of SSHDs empowered PwD to secure their domiciles independently. Further, caregivers used SSHDs to monitor PwD, ostensibly for the latter's safety, albeit without explicit consent. Moreover, we also found that SSHDs have several drawbacks that impose various barriers of use on PwD. We analyze the significance of these findings and suggest five future research opportunities for SSHD design.

CCS CONCEPTS

• **Human-centered computing** → **Accessibility technologies**.

KEYWORDS

accessibility, disability, smart home devices, empowerment, home security, surveillance

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1 INTRODUCTION

The last decade has seen a plethora of *smart home devices*[1] become available for use in the home (e.g., smart lights, televisions, thermostats, locks, cameras, etc.). This proliferation of smart home devices has resulted in an increased interest in understanding how people with disabilities use these devices [2, 34, 58, 62, 64, 82]. However, a class of smart home devices whose use by people with disabilities has yet to be explored is **security-focused smart home devices (SSHDs)**. *The term SSHDs designates smart home devices that are designed to protect the user's home and property.* There are many types of SSHDs, including smart locks, smart cameras, smart motion detectors, etc.

In this work, we sought to gain an understanding of how people with disabilities use SSHDs and to what extent the design of SSHDs matches their needs. We thus used a broad definition of disability that included any impairment that affects a person's ability to perform daily tasks (more on this below). Further, we specifically look at the problem using the lens of interdependence [14]. The interdependence framework views the lives of people with disabilities as being highly interdependent with others, such as caregivers, family, support staff, peers, etc. [14]. Therefore when analyzing the experiences of people with disabilities with SSHDs, we not only look at the direct use of SSHDs by people with disabilities but also consider the experiences of others whose lives are interdependent with those with disabilities. For expediency, from here forward we use the term *caregivers* to designate such people.

The goal of this work is to explore three broad questions. (1) In what ways do people with disabilities leverage the design of SSHDs in their lives? (2) In what ways does the design of SSHDs relate to the interdependence between individuals with disabilities and their caregivers? (3) What are the barriers that the design of SSHDs introduces in the lives of people with disabilities? To address these questions, we scraped 114,871 reviews from amazon.com product pages. Out of these, we created a data set of 300 reviews that provided snapshots of the experiences that people with disabilities and their interdependent network have when using SSHDs. Our analysis of this data set found that the presence of SSHDs in the

[1]We define smart home devices as a device with technological features intended to assist with or automate tasks within the home. These devices often provide facilities for smartphone/tablet-app-based control or voice control through voice assistants like Amazon Alexa or Google Assistant.

home empowered people with disabilities to secure their domiciles in ways they could not before. Further, caregivers used SSHDs ostensibly to monitor people with disabilities for the latter's safety. However, this was often done without the knowledge or consent of the person being monitored. Moreover, we also found that SSHDs have several drawbacks that impose various barriers of use on people with disabilities. Based on these findings, we **suggest five areas for further research in order to design SSHDs to better meet the needs of people with disabilities**.

Before we delve into the rest of the paper, we would like to describe some of the benefits of our methodology of using online forum data like amazon.com reviews for our data set. First, there is a considerable body of recent work in the literature that uses such online forum data [41, 48, 50, 53, 88, 99, 101]. The existing literature has shown a number of benefits of using online forum data for examining user experiences. (1) Online data can help gather experiences from a large number of participants asynchronously. This approach can be particularly useful for participants with disabilities for whom synchronous contact may be difficult to orchestrate online in an accessible way [48]. (2) This method also preserves participant safety from the ongoing threat of COVID-19 [48]. (3) Furthermore, online forums can be effective at ethically gathering freely volunteered information on sensitive topics, such as security [88]. (4) Forum data are also produced in a real-world setting outside of the constraints of a formal research study. The use of online forum data has some advantages over researcher-led inquiries (e.g., interviews), as it prevents the researcher from inadvertently influencing participant responses [9].

Online forum data offer and thus allow us to simultaneously study multiple perspectives from people with different types of disabilities. The goal of our broad analysis is not to determine findings that apply universally to all people with disabilities but rather to identify aspects of SSHD use and design that researchers working on SSHD accessibility should consider during the design process. To this end, our findings and discussion sections should be seen as a guide for researchers interested in exploring the next generation of accessible SSHDs. The broad analysis presented in this paper necessarily differs from typical accessibility research that often focuses on people with one or more specific types of impairment. As has been shown in recent work, focusing on a specific disability results in certain communities being underrepresented [71]. Our analysis in this paper thus has the additional advantage of presenting the experience of a variety of people with disabilities who are underrepresented in accessibility research.

Similar to [5], in the rest of the paper we define the term **security** *to mean the protection of one's home and property. Further, we use the related term* **safety** *to mean the protection of an individual from bodily harm.*

2 RELATED WORK

Our work falls at the intersection of smart home devices, people with disabilities, and security/safety. Methodologically speaking, it makes use of online product reviews to understand this nexus of topics. Consequently, we divide the related work section into four broad categories.

2.1 Using online forum data to develop a broad understanding of technology use

The practice of using online forum data, such as product reviews and social media posts, is well established both in usable security research [12, 41, 43, 50, 53, 83, 88, 101] and accessibility research [25, 40, 48, 66, 82, 85, 99]. Additionally, product reviews, which we use for this work, previously have been used to gain insights on the usability and security of smart home devices [43, 82, 83, 88]. Other studies have also used amazon.com reviews as a data source [82, 83, 88], as does this work. Most studies using product reviews to investigate smart home devices have focused on smart voice assistants [43, 82, 83] rather than our focus on SSHDs. One study, [88], used product reviews and forum posts to learn how users of smart home devices experience hacking. However, to the best of our knowledge, no prior work has focused on examining the experiences of people with disabilities with SSHDs.

2.2 Usability of other types of smart home devices by people with disabilities

Prior research has looked at on understanding and improving the usability of *non-security-focused* smart home devices for people with disabilities [2, 21, 30, 34, 56, 58, 63–65, 75, 82]. Work on that topic has focused on creating accessible interfaces to help people with disabilities interact with smart home environments, including through voice interfaces and smart speakers [2, 16, 17, 30, 56, 63, 75, 82], brain-computer interfaces [21, 30], sign language [72], and Morse code [84]. Other work has focused on designing (non-security-focused) smart home devices for use by people with specific impairments (e.g., visual [34, 64, 65, 96] and hearing [16, 17, 58, 72]). Though useful, all of these studies have focused on non-security focused smart home devices and none have studied how people with disabilities use SSHDs specifically.

2.3 Smart-home-based monitoring of people with disabilities

The last decade has seen a considerable number of studies on the design of in-home monitoring systems for people with disabilities. Many of these studies have focused on: the technical design of monitoring systems [6, 7, 32, 36–38, 67, 95]; reviewing available systems for in-home monitoring [46]; and understanding the broader implications of smart home monitoring [35]. Work has also been done on using smart homes to assist with home accessibility and the activities of daily living. The majority of these have focused on technical design work rather than understanding or measuring the usability of such technologies [3, 18, 33, 47, 62]. None of this existing work has tried to understand the role of SSHDs in the in-home monitoring of people with disabilities, as we do in this work.

2.4 Smart home security and safety

In recent years, significant work has focused on digital security and privacy in a smart home environment (i.e., understanding and preventing the exposure of private data through smart home devices) [1, 4, 11, 19, 22–24, 26, 29, 39, 44, 45, 54, 60, 80, 81, 88, 90, 92, 94, 102, 103]. Some of these studies [80, 81] have focused on specific types of SSHDs (e.g., smart cameras) and include some discussion

of usability in addition to the primary focus on digital security and privacy. Additionally, some work has focused on how to better design smart home controls to help maintain users privacy [4, 103]. In addition to security, a few studies have focused on safety within the home [13, 73]. One work [73] addressed how smart home devices facilitated intimate partner violence. Another study [13] explored how family relationships can impact smart-home-device interactions, such as parental concern for their children. However, these prior studies neither focus on SSHDs nor people with disabilities, as we do in the present work.

3 METHODOLOGY

Our aim in this paper was to gain a broad understanding of the use of SSHDs by people with disabilities. To this end, we analyzed reviews posted on amazon.com regarding popular SSHDs. We used Amazon (i.e., amazon.com) reviews specifically for two reasons: (1) Amazon is one of the largest sources of consumer opinions in the world [8] and (2), as discussed in Section 2, Amazon reviews have been used successfully in the past to study security and accessibility aspects of smart home devices [82, 83, 88]. The breadth and detail in these reviews allowed us to develop an understanding of the diversity of experiences that people with disabilities have with SSHDs, which often extend beyond the stated purposes of these devices to enable security (as defined in Section 1).

3.1 Creation of the data set of Amazon reviews

We examined *five categories* of SSHDs for this work: cameras, garage openers, locks, motion detectors, and integrated security systems[2]. For each of the five categories, we conducted Internet searches to find lists of the most popular smart home device manufacturers. We only consulted lists from reputable news or consumer review websites (e.g., PC Magazine [79], Forbes [42], US News [98], and Business Insider [20]), resulting in a list of 72 different device manufacturers, 33 of which had a presence on Amazon. We then searched Amazon to find all SSHDs in each of the five categories (i.e., smart cameras, garage openers, locks, motion detectors, and integrated security systems) sold by these manufacturers. We examined the review sets for each of these SSHDs and removed products with no mention of people with disabilities, resulting in 85 products from the 33 manufacturers, for a total of 114,871 reviews. There were 12 manufacturers of cameras (e.g., Arlo, Yi technology, Wyze, and Blink), nine manufacturers of motion detectors (e.g., Kangaroo Home, Samsung, and Guardline), two manufacturers of integrated security systems (e.g., Ring), five manufacturers of locks (e.g., Schlage, Kwikset, and August Home), and five manufacturers of garage openers (e.g., Chamberlain and Nexx).

To filter out reviews unrelated to disability, we applied a set of keywords that expanded on the original list from [82]. *We used a broad definition of disability that included any impairment that affects a person's ability to perform certain tasks. To this end, we included temporary disabilities, such as rehabilitation from a surgery, health conditions, e.g., cancer, as well as disability due to advanced age.* After using an automated filter to complete an initial pass of the reviews, we randomly selected 50 reviews from each of the five categories. These five sets of 50 reviews each were manually examined for the presence of a narrative about a person or persons with disability, by the first and third authors. Based on this examination, we ended up adjusting the automated filter to include several abbreviations and incorrect spellings to avoid filtering out relevant reviews (e.g., "alz" was added to catch abbreviations and misspellings for Alzheimer's). The final list of our keywords can be found in Table 1. After our filter was adjusted and run again, all of the resulting filtered reviews were examined manually and separately by the first and third authors for relevance. The two authors then discussed and resolved any differences among their findings. The authors also checked for any discernible fake or promotional reviews, although none were found. The filtering process resulted in 300 reviews related to disability. The names of people and places have been removed from the filtered reviews to maintain the privacy and anonymity of the people discussed in the reviews. The reviews are numbered according to category: cameras are C1-C131; garage openers are G1-G10; locks are L1-L39; motion detectors are M1-M39; and integrated security systems are S1-S81.

3.2 Analysis of the data set of Amazon reviews

When conducting research with people with disabilities, it is important to recognize the interdependence framework of disability [14]. That is, people with disabilities typically live a highly interdependent life with others, such as caregivers, family, support staff, peers, etc. Therefore when analyzing the experiences of people with disabilities with SSHDs, it is vital to not only look at the direct use of SSHDs by people with disabilities but also to look at the use of SSHDs by the people around them. In the rest of this paper, we use the broad term caregivers (unless otherwise specified) to mean people who are part of the interdependent support system around individuals with disabilities.

Consequently, our aim in analyzing the reviews was to answer three research questions **RQ1:** In what ways do people with disabilities leverage the design of SSHDs in their lives? **RQ2:** In what ways does the design of SSHDs affect the interdependence between individuals with disabilities and their caregivers? **RQ3:** What are the barriers that the design of SSHDs introduce into the lives of people with disabilities? To this end, the first and the third authors took an iterative approach to their qualitative coding of the reviews in the data set. They performed iterative, open coding of the reviews independently, which were then merged to create a master codebook. After creating the master codebook, these two authors then again coded all of the reviews in the data set using ATLAS.ti [10]. We measured the inter-coder reliability in terms of percentage agreement, which for us was 82.5%[3]. The final codes formed six code groups: *overall opinions*, *how*, *who*, *why*, *safety and security*, and *other experiences*. We provide a full list of codes and code groups in Table 2. The first author then used the codes to develop the initial analytic themes. The second and fifth authors subsequently examined the initial themes, codes, and data set to develop additional analytic themes for the paper.

[2]Integrated security systems are sets of SSHDs, such as alarms, sensors, and cameras, that are sold together and intended to be used for home security monitoring.

[3]Recent work in HCI research has used percentage agreement for inter-coder reliability [27, 28, 31, 70, 77, 78, 105]. The ranges percentage agreement value in these works have ranged from approximately 75% to 95% . The reliability percentage of 82.5% for our study falls within this typical range.

Disability-related keywords used to filter the reviews
AAC, accessibility, accessible, ALS, Alzheimer, Alzheimer's, amnesia, amnestic, amputation, amputee, amyotrophic lateral sclerosis, aphasia, apraxia, arthritis, assistive technology, ataxia, augmentative communication, autism, autistic, blind, blindness, caregiver, cochlear implant, congenital amputation, congenital amputee, deaf, dementia, diabetic retinopathy, disabilities, disability, disabled, Down syndrome, dysarthria, dyslexic, dystonia, epilepsy, essential tremor, fibromyalgia, Friedreich ataxia, Friedreich's ataxia, glaucoma, handicap, handicapped, hard of hearing, hearing aid, hearing device, hearing loss, hemiplegia, hemiplegic, impaired, impairment, impairments, lateral sclerosis, lisp, Lou Gehrig's, macular degeneration, mobility, multiple sclerosis, muscular dystrophy, muscular rheumatism, myopathy, neurological disorder, neurological vision impairment, neuromuscular disorders, nursing home, paralysis, paralyzed, paraplegia, paraplegic, Parkinson, Parkinson's disease, Parkinsonism, quadriplegia, quadriplegic, sclerosis, seizure disorder, short term memory, sigmatism, SMA, speaking disorder, special needs, speech impediment, speech therapy, spinal bifida, spinal cord injury, spinal muscular atrophy, stroke, stutter, TBI, traumatic brain injury, tremor, tremors, vision, walker, wheelchair, bedridden, disease, injuries, injury, limited vision, no vision, non-verbal, nonverbal, poor vision, rehab, rehabilitation, surgeries, surgery, *wheel chair*, *lou gehrig*, *gerig*, *bed ridden*, *alz*

Table 1: Keywords related to disability that were used to filter the reviews. The italicized words were added to catch common misspellings and abbreviations.

Overall opinions: general tone of the review in terms of (dis)satisfaction with the SSHD
Positive, Negative, Neutral
How: how the SSHD was deployed (e.g., locations, times of day, and associated devices)
App, Assisted living facility, Assistive technology, Device, Location, Pet, Remotely, Time, Vehicle
Who: who wrote the review, the type of disability mentioned, any relevant medical concerns mentioned, and the relationship(s) between the reviewer and the individual(s) with a disability
Accident, ADHD, Alzheimer's, Amputee, Arthritis, Aunt, Autism, Bedbound, Blind/visually impaired, Busy lifestyle, Caregiver, Cerebral palsy, Child, Deaf/hard of hearing, Dementia, Disability, Friend, Grandparent, Health problems, Hospice, I, Lives alone, Non-verbal, Older adult, Parent, Parkinson's disease, Patient, Rehabilitation, Short term memory, Sibling, Spouse, Surgery, Tremor, Veteran, Walker, Wheelchair
Why: the reason(s) for purchasing and deploying the SSHD (e.g., intended purpose of the SSHD and any accessibility considerations that may have prompted the acquisition of the SSHD)
Accessibility recommendation, Accessibility/barrier, Feature, Forgetful, Purpose
Safety and Security: safety or security aspects of the SSHD (e.g., alerts, specific crimes the SSHD was intended to prevent, particular features of the SSHD that relate to safety or security, and people who may act as a threat)
Alert, Bad Guys, Crimes, Disoriented, Emergency response, False alarm, Incident, Wander/protect-purpose, Privacy, Safety/security, Safety/security feature, Visitor
Other Experiences: other experiences beyond typical SSHD usage (e.g., feature requests and experiences with customer service)
Customer service, Wish

Table 2: The codes in the final, master codebook grouped by code group

3.3 General impression of the reviews

We first determined the general characteristics of the reviews in our data set. We looked for the following information in each review: the author(s) of the review; which type(s) of disability was mentioned; and the overall impression of the SSHD(s). The characteristics of the review writers are summarized in Table 3. This table includes information on the types of disability mentioned as well as the relationship between the person writing the review and the person with a disability. Roughly one-third of the reviews were written by someone with a disability and the remaining approximately two-thirds by a caregiver of someone with a disability. Note that many of the reviews mention the health/medical condition rather than the impairment caused by the condition (e.g., Parkinson's instead of motor impairment). The disabilities in such cases are, thus, implied. Therefore, for expediency, in this section we treat the health condition and related impairment/disability as interchangeable.

In addition to characteristics of the review writers, we collected information on which disabilities/conditions were discussed in the reviews. We did not attempt to infer any specific disability or health condition if none was stated. These disabilities are listed in Table 4. Some of the most represented groups included people with Alzheimer's or dementia, people who were deaf or hard of hearing, and people with mobility impairments. Notably, some disabilities (e.g., vision impairments, epilepsy) are underrepresented in the reviews. Of course, with any data collection technique it is impossible to get a full representation of the experiences of everyone with disabilities. Nevertheless, the fact that some types of disability are more represented than others is interesting, as it may imply: (1) a difference in SSHD usage, or (2) Amazon not being a preferred review platform for people with certain types of disabilities. We discuss the possible ramifications of the differences in representation further in Section 5.5. *For the rest of this work, all analysis is based on the reviews in our data set, unless otherwise stated.* Further, all quotations from the reviews use the grammar, punctuation, spelling, and capitalization of the original review. We thus do not designate deviations from standard English with the indication *sic*. Edits for brevity and clarity are marked using ellipses or brackets.

3.4 Overall tone of the reviews

About 80% of the reviews in our data set expressed a positive experience with the SSHD. These positive reviews often mentioned particular device features that were valued for helping to keep people with disabilities secure in their homes. For example, one review was emphatic about the importance of a motion detector having a variety of tones at differing volumes to satisfy different user needs:

Review written by someone with a disability		Review written by a caregiver for someone with a disability	
95 reviews		**211 reviews**	
The disability, as described in the review		The reviewer's relationship to the individual with a disability:	
Mobility Impairment	29 reviews	Child	92 reviews
Deaf/Hard of hearing	26 reviews	Parent	49 reviews
Surgery	12 reviews	Spouse	30 reviews
Blind/vision impairment	3 reviews	Grandchild	6 reviews
Amputee	2 reviews	Caregiving professional	4 reviews
Arthritis	2 reviews	Friend	4 reviews
Tremor	2 reviews	Sibling	4 reviews
Memory Disability	1 review	Niece/nephew	3 reviews
Parkinson's	1 review		
Unspecified disability/health condition	17 reviews	Unspecified relationship	20 reviews

Table 3: Characteristics of the review authors represented in our data set. These numbers add up to greater than 300, as some reviewers have disabilities and are also writing about one or more other people with disabilities

Number of reviews that mention a certain disability or condition							
Alzheimer's disease/dementia	65	Parkinson's disease	8	Amputation	3	Cerebral palsy	1
Deafness/hearing impairment	43	Arthritis	7	Confinement to bed	3	Learning disability	1
Mobility impairment	43	Blindness/vision impairment	5	Epilepsy	3	Quadriplegia	1
Autism	23	Memory impairment	5	Tremors	2	Tourette's Syndrome	1
Surgery	16	Hospice care	4	ADHD	1		
Unspecified disability/health condition				76			

Table 4: The disabilities or health conditions mentioned in the reviews. The number of reviews adds up to greater than 300 for two reasons: (1) some reviews mention multiple people with a disability and (2) some individuals in the reviews have multiple stated disabilities.

"Great! product!... I am a bit hard of hearing, If you can't find an alarm tone that would wake Lazarus in the 32 tones you are missing something. There are many gentle soothing tones and an annoying rendition of Jingle Bells that I intend to launch as the Holiday Season approaches to drive away guests. (Really it is quite amusingly Jolly. HRUuuuumph)" (M32). Additionally, reviewers who left positive reviews commented that the SSHDs provided peace of mind to both people with disabilities and their caregivers, due to the security these devices provide: *"Saved me from intruders. I am wheelchair bound and gives me great comfort and security when a stranger comes to the door." (S79).*

In contrast, the negative and neutral reviews often mentioned technical or accessibility issues with the device: *"The monitoring plan is very affordable. Easy to use and install but... I am visually impaired and the phone app is clunky and difficult to navigate when using voiceover and gestures." (S47).* The negative reviews often reported that the SSHD was unreliable or did not work at all. Negative reviews concerning technical failures often expressed exasperation: *"I should just stamp sucker on my head. I keep falling for these gimmick products. I have a 86 yr. old mother with full blown dementia and needs to be monitored quite a bit... I've had it a week and it won't connect to the sync module now... I'm sure that if I reboot the sync module it will work again but that should not have to be. What if I was just 15 miles away, how would I reboot the system.... IT IS NOT RELIABLE!!!!" (C55).*

4 STUDY FINDINGS

In our analysis of our reviews, we found three core themes that relate to our three core questions: (1) In what ways do people with disabilities leverage SSHDs in their lives? (2) In what ways does the design of SSHDs relate to the interdependence between individuals with disabilities and their caregivers? (3) What are the barriers that the design of SSHDs introduce in the lives of people with disabilities? We discuss our findings for each of these themes in detail. Table 5 summarizes our findings. Additionally, in order to provide background context for each of our core findings, we provide a quantitative analysis of the reviews for each of our core findings. The quantitative information we provide includes both the disability or health condition as well as the relationship between the author of the review and the individual with a disability. The conditions/disabilities and relationships are outlined in a separate table for each of our findings: 6, 7, and 8.

4.1 Study findings 1: People with disabilities leveraged SSHDs to better control their home security and automate non-security tasks

For this study, we began by trying to understand in what ways people with disabilities leverage SSHDs in their lives. Table 6 shows the disability of the person using the SSHD as well as their relationship to the author of the review. Interestingly, reviews related to using SSHDs to increase security or accessibility were primarily written by people with disabilities themselves rather than by caregivers. This authorship by people with disabilities helps to contextualize our discussion of how SSHDs often contribute to the agency of people with disabilities.

We found three main themes regard to the ways in which people with disabilities leverage SSHDs, which we describe next.

Study findings 1: People with disabilities leveraged SSHDs to better control their home security and automate non-security tasks
People with disabilities used SSHDs to make the process of securing their home more accessible *"Its the first time I can lock the door without help when leaving since my accident."* (L18).
People with disabilities expressed that they experienced greater agency in securing their homes using SSHDs *"I am a recent amputee and knowing whether or not I need to rush to the front door to sign for something is so powerful. Thank you Ring for giving me back some control over my life!"* (S4).
People with disabilities and their caregivers repurposed SSHDs to simplify non-security-related tasks in their homes *"We actually bought [a motion detector] to let us know when the mail comes."* (M27).
Study findings 2: Caregivers used SSHDs to monitor people with disabilities and their environment, often without explicit consent
Caregivers both with and without a disability use SSHDs to monitor others with disabilities *"My husband has Alzheimer's and my son set [a camera] up in the bedroom and another that covers dining room kitchen so now I can see what he is doing and if he needs anything without having to get up. Saves me a lot of steps as I have hip back problems."* (C15).
Caregivers of people with disabilities used SSHDs to help catch direct support personnel acting in an abusive manner *"Within 48 hours I caught one of the subcontracted employees stealing money out of my mom's purse!!!"* (C96).
Caregivers relied on SSHDs to both proactively protect people with disabilities from harm *"What i like about this lock is the ability to know when the door is open and for how long the door is open. this is good due to my father in law who has dementia and some times tries to to slip out unnoticed."* (L16)
Caregivers often used SSHD-based safety monitoring without explicit consent of the people being monitored *"Mum has no idea the system is there..."* (C20).
Study findings 3: People with disabilities faced barriers during the entire life cycle of SSHDs
People with disabilities faced cost and installation barriers with respect to SSHDs *"Worked great until trial cloud time period was up.... For the price cloud services should be free. I am handicapped and live on fixed income don't need another expense."* (S29).
People with disabilities struggled with some of the hardware-related choices made in the design of SSHDs *"The only thing I wish was better, is the volume on the [base station]. I suffer from hearing loss, and it is hard for me to hear what it is saying."* (S44).
People with disabilities found the apps accompanying SSHDs difficult to use *"Their iOS app needs a lot of accessibility work, as it is currently not fully usable by those who rely on VoiceOver (Apple's screen reader for the visually impaired)."* (C1).
People with disabilities misunderstood the capabilities of SSHDs *"The only thing I worry about is the auto-unlock with Bluetooth proximity. Others have pointed out that this is a security concern since it will unlock your door as you approach it from the inside to see if the person who rang the bell is a mass murderer."* (L20).
People with disabilities and caregivers often struggled with the support provided for SSHDs *"Customer Service wasn't helpful VIA email, they really wanted to talk on the phone which isn't the best way for the hearing impaired to communicate (me)."* (C86).

Table 5: Summary table of our three main study findings. An example quotation is included for each section. Each quotation was chosen because it is representative of the core themes present in the section from which it was taken. The quotations are sometimes truncated for clarity.

Number of reviews about increasing home security and accessibility using SSHDs			**70**
Disability of person benefiting from the SSHD			
Mobility impairment	23	Parkinson's disease	3
Alzheimer's/dementia	10	Amputation	2
Deafness/hearing impairment	7	Memory impairment	2
Arthritis	6	Tremors	2
Surgery	4	Cerebral Palsy	1
Unspecified disability/health condition	11		
The reviewer's relationship to the individual with a disability			
Self	34	Friend	2
Child	17	Sibling	2
Spouse	11	Parent	1
Unspecified relationship	4		

Table 6: The condition/disability and the relationship between the reviewer and the individual with a disability for reviews related to SSHD use for home security and accessibility. Sometimes there are multiple people with disabilities mentioned in the review or someone has multiple disabilities. Therefore, the number of particular conditions/disabilities and relationships adds up to more than the total number of reviews about increasing home security and accessibility using SSHDs.

4.1.1 People with disabilities used SSHDs to make the process of securing their home more accessible. Our analysis of the reviews showed that, for a variety of disabilities, such as upper extremity impairments[4], locking and unlocking doors using physical keys can been difficult because it requires robust motor control to do so: *"... [my mother-in-law's] arthritis is so bad she cannot turn a key." (L3).* Similarly, people who use mobility assistive technologies (AT), such as walkers or wheelchairs, also face barriers in terms of reaching to open, close, lock, or unlock doors: *"I use a walker and a wheelchair. It can be cumbersome manipulating a key, especially while holding a bag or box." (L25).*

People with these kinds of disability-related needs thus leveraged SSHDs (e.g., locks and garage door openers) to make the process of locking and unlocking their homes more accessible: *"Bought as a gift for Mom and they are so much better than turning a knob when she has rheumatoid arthritis (she can press down with an elbow) and she no longer has to dig a key out of her purse." (L5).* People with disabilities used the SSHD to avoid having to use inaccessible buttons or keys to open and close doors: *"I am handicapped and in a wheel chair and my ramp is in my garage. I use this to open the garage from in the house or out in the driveway as the button to open in the house is too high and the opener in the car uses batteries that die quickly. Now I use my phone which is always charged and is always on my side." (G4).* Moreover, the use of SSHDs allowed people with disabilities to lock and unlock their homes without relying on assistance from another person: *"Perfect for someone with a disability or has trouble with keys. Its the first time I can lock the door without help when leaving since my accident." (L18).*

In addition to making using and (un)locking doors easier, reviewers with memory impairments leveraged SSHDs' alerts to help them track whether doors were locked or not. For instance, one review detailed how, in the past, not remembering to close the garage door had resulted in the reviewer experiencing property loss. However, the new garage opener now provided a reminder alert to close the door, resulting in increased security and peace of mind for the reviewer: *"It's great for folks with short term memory like me. With a busy life style and old age, I tend to leave my garage door opened overnight unintentionally. Of course the garage got raided and I lost a few precious items.... With Nexx Garage, this is the perfect solution for our piece of mind. It alerts us when the garage is open and remind us every 15 minutes if its still opened." (G6).*

4.1.2 People with disabilities expressed that they experienced greater agency in securing their homes using SSHDs. Overall, the deployment and use of SSHDs helped people with disabilities feel that they had more agency and control in securing their homes. This was something that they had not felt when using more traditional means of securing their homes. For instance, people with disabilities used SSHDs (e.g., cameras) to alert them when someone approached the door to their home. This ability to monitor people outside their home made people with disabilities feel more in control of securing their domicile: *"I am a recent amputee and knowing whether or not I need to rush to the front door to sign for something is so powerful. Thank you Ring for giving me back some control over my life! Plus, my husband can see who is at the door when he is at work. That takes a lot of fear away!" (S4).* Similarly, many SSHDs were used to inform their users about people outside their homes even when they are out. This was seen as another crucial way in which SSHDs enabled people with disabilities to feel in control of their homes at all times: *"It's also nice when you are not home and the doorbell announces that someone is at the door. You can possibly avoid having a package stolen by speaking to the visitor." (S67).*

Additionally, some SSHDs have an intercom feature that allowed users with disabilities to interact with outsiders from across their home, which is another way in which people with disabilities felt safer and more in control of their home security using SSHDs: *"I have health issues that limit my mobility.... With the video feature I can see who it is and decide if I want to try and get to the door to answer, or send the person on their way. The intercom feature allows me to discuss whether their issue is important, or not...and gives me the peace of mind knowing I won't have to kill a salesman... for making me get up and go to the door in pain for something stupid." (S64).*

As a direct consequence of SSHDs' ability to bring a sense to control to home security for people with disabilities, they felt a great sense of personal safety: *"I am in the back of the house alone several times a week. My mobility is not good in the best of times, and I think what if an intruder came in and I did not hear them. I feel safer with these cameras." (C89).* This sense of safety was particularly useful when the homes of people with disabilities were not designed for easily seeing who is outside: *"Perfect for this 60 year old, handicapped, live alone female veteran...me. I have no peep hole, no windows near my door to look out from and getting to the door quickly can really be a chore. A friend recommended it to me for my safety and security...which I now have." (S31).*

Interestingly, not only did people with disabilities feel more in control of their home security using SSHDs, there were also a few instances when individuals with disabilities were able to their SSHDs to actually mitigate threats to their homes. For example, a review written by an individual with hearing impairment stated that they were able to use visual notifications on the SSHD app to protect themselves against a potential intruder: *"The very first night after installing my ring I woke up at 2:00 AM and noticed I had motion detection on my front porch. I didn't hear the audible alert because I am hearing impaired. This guy had been out there for 2 hours. Called the Sheriffs Dept and they arrested him and took him to jail." (S53).* Similarly, another person with a disability used the intercom feature of their SSHD to proactively deter a potential thief by to project their presence and scaring them off: *"I even already caught a person casing my house. Sneaking around peeking through windows and scared him off by using the Rings speaker to ask him what he was doing. He ran off and hasn't returned." (S25).*

4.1.3 People with disabilities and their caregivers repurposed SSHDs to simplify non-security-related tasks in their homes. People with disabilities often have limited physical and/or mental energy [74]. It is therefore often necessary for them to conserve this energy wherever possible in order to carry out routine tasks. The reviews included some creative ways in which people with disabilities repurposed SSHDs to simplify executing routine tasks in light of the impact of their disability on their energy levels. For example, a reviewer with motor impairments used their SSHD to help reduce

[4]An upper extremity impairment reduces the range of motion, strength, endurance, speed, and/or accuracy associated with movement in the shoulders, upper arms, forearms, hands, and/or fingers.

physical exertion by minimizing the number of trips to the mailbox: *"We actually bought [a motion detector] to let us know when the mail comes. I'm handicapped and now I don't have to go out numerous times to check to see if the mail has come." (M27).* In another review a caregiver used SSHDs to help a person with dementia find misplaced items: *"I use it to watch my mom who has Alzheimers...We have found many things that she lost because of Blink [a camera]." (C6).* Similarly in another case a caregiver leveraged the intercom feature of camera SSHD to be able to talk to a person with a disability who, because of their dementia, could not use a telephone anymore: *"My dad with dementia cannot operate the phone, so it is great that I can talk to him via the camera if needed." (C61).* Additionally, many SSHDs were bundled with Amazon Echo and Alexa voice user interfaces. This allowed people with disabilities to use their SSHDs to complete physical tasks with their voice instead: *"Because these make lights hands-free, they're perfect for elderly that need their hands for walker stability. They also love being able to use their voices to turn on\off their lights at night." (S15).*

4.2 Study findings 2: Caregivers used SSHDs to monitor people with disabilities and their environment, often without explicit consent

Next, we wanted to understand in what ways does the design of SSHDs affect the interdependence among people with disabilities and their caregivers. We found that SSHDs were primarily used by caregivers to monitor people with disabilities. This was done ostensibly to keep people with disabilities safe but often did not involve gathering appropriate informed consent. Table 7 shows the condition/disability of the person being monitored and their relationship to the author of the review for the reviews about caregiver monitoring. No reviews about monitoring were written by people with disabilities: this raises potential issues about the low degree of agency people with disabilities have when it comes to their own monitoring. We discuss these implications in more detail in Section 5.3.

Overall four themes emerged in regard to interdependence among people with disabilities and their caregivers, which we describe below.

4.2.1 Caregivers with and without a disability use SSHDs to monitor others with disabilities. In the reviews we found that caregivers often used SSHDs to remotely keep an eye on someone with a disability. Most of these reviews mentioned monitoring someone with a disability to ensure their safety: *"My mom is handicapped and lives alone. I set one [camera] in a common area near her living room so I can check in on her and know when shes up and about. She feels safe that I can see her and I love being able to live feed if I have any concerns about her." (C75).* Several reviews mentioned caregivers using the communication feature of SSHDs to reach out to help people with disabilities: *"I can see if Mum seems puzzled, lost, or confused, so I'm able to call her immediately to bringing Mum back to calm stability." (C20).* Similarly, caregivers used SSHDs to ensure a person with disabilities followed their prescribed routine: *"Purchased [a camera] to watch my wife exercise due to my cancer and her Parkinson's. Exercise is very important for persons with Parkinson's." (C102).* Several caregivers had disabilities themselves. For example, one review describes how a person with mobility impairments who uses a camera to ensure the safety of their spouse with Alzheimer's: *"My husband has Alzheimer's and my son set [a camera] up in the bedroom and another that covers dining room kitchen so now I can see what he is doing and if he needs anything without having to get up. Saves me a lot of steps as I have hip back problems." (C15).*

4.2.2 Caregivers of people with disabilities use SSHDs to help catch direct support personnel acting in an abusive manner. There are approximately 4.5 million people working as direct support personnel (DSP) in the US alone for adults and children with disabilities [76]. DSPs are individuals who are contracted to work closely with people with disabilities and help them live their lives and to enjoy the same benefits as people without disabilities [76]. Unfortunately, this close relationship can sometimes leave people with disabilities susceptible to abuse by DSPs [55]. While many SSHDs are designed for monitoring threats from outsiders, people with disabilities and their caregivers often deploy SSHDs differently and use them to monitor insider threats, such as from abusive DSPs: *"I originally got this for me to keep an eye on my elderly mom.... When we moved her to an assisted living facility, the camera went with her. Within 48 hours I caught one of the subcontracted employees stealing money out of my mom's purse!!! She even had the nerve to comeback in and see if she could unplug the camera. With the protection plan, the video was saved so she was arrested." (C96).* Several reviews mentioned reviewers using evidence, collected by SSHDs, of DSPs committing abusive acts: *"It actually helped me prove one of the [DSPs] was not doing her job and after I showed the video to the agency, they fired her and credited me with the night she was there to help." (C22).*

Even when caregivers did not suspect that any abuse was occurring, they used discreetly placed SSHDs to help reassure themselves that their family members with disabilities were safe: *"Mom's in assisted living with dementia. She was making weird claims that we were writing off as disease related. Consequently, I wanted the system to be as invisible as possible... Turns out this little system allowed me to document activity and make sense of Mom's assertions (thankfully no theft or abuse) and ease everyone's minds." (C70).* The reviews also mentioned that caregivers felt that the presence of cameras could proactively prevent abuse when the DSPs know that they were being monitored: *"We are using this [camera] to watch my mom who is in a nursing home.... The facility placed a sign on her door that states this room is being monitored by surveillance camera, which we feel lets everyone know that we expect the highest standards possible in her care. This makes the staff aware, as well as mom. Her room is private, thus we have had no issues; however if she shared a room the other occupant would have to sign a waiver, so keep that in mind." (C95).*

4.2.3 Caregivers relied on SSHDs to proactively protect people with disabilities from harm. People with disabilities often have safety concerns associated with their disability or hazards caused by lack of accessibility in their environment. As a result, they sometimes want or need assistance in order to maintain safety. Caregivers used SSHDs to proactively monitor the environment to avoid potentially dangerous situations and sources of harm: *"What i like about this lock is the ability to know when the door is open and for how long the door is open. this is good due to my father in law who has dementia and some times tries to to slip out unnoticed." (L16).* Similarly, when

Number of reviews about caregiver monitoring			**139**
Disability of person being monitored			
Alzheimer's disease/dementia	59	Memory impairment	2
Autism	17	ADHD	1
Mobility impairment	6	Cerebral Palsy	1
Deafness/hearing impairment	4	Hospice care	1
Parkinson's disease	4	Learning disability	1
Confinement to bed	3	Surgery	1
Epilepsy	3	Tourette's Syndrome	1
Unspecified disability/health condition		40	
The reviewer's relationship to the person being monitored			
Child	72	Caregiving professional	3
Parent	36	Grandchild	3
Spouse	15	Sibling	3
Unspecified relationship		7	

Table 7: The condition/disability of the individual being monitored and their relationship to the author of the review for the reviews related to caregiver monitoring. There are no reviews where the person with the disability writes about their own monitoring by a caregiver. Sometimes the person being monitored has multiple disabilities. Therefore, the number of disabilities adds up to more than the total number of reviews about caregiver monitoring.

caregivers could not be present in person, many used the intercom feature present on some SSHDs to talk to a person to discourage them from getting into dangerous situations: *"I can even speak to her through the camera. This is a life-saver if I have to run errands while she is awake. The audio is actually very high quality, so when I speak into my phone she actually thinks I am there in the house. That makes it easy to call her downstairs away from the front door." (C25).* Some reviews also mentioned that caregivers used SSHDs to control physical access to specific parts of the home for the family member with a disability, usually autism. Many of these reviews did not give a reason for controlling such physical access. An example of one that did provide a reason mentioned keeping the person with a disability out of a room because they often engaged in messy activities there: *"We use this to secure our kitchen so that our autistic son cannot make frightful messes and waste food in his Aurtistic pursuits.... Except for our daughter showing our little aurtist the combination once which necessitated a code change, it has worked without any problems." (L10).*

4.2.4 Caregivers often used SSHD-based safety monitoring without explicit consent of the people being monitored. Caregivers were able to use SSHDs to avoid constant, in-person supervision of people with disabilities: *"I can even speak to her through the camera. This is a life-saver if I have to run errands while she is awake. The audio is actually very high quality, so when I speak into my phone she actually thinks I am there in the house. That makes it easy to call her downstairs away from the front door." (C25).* Often such use of SSHD-based surveillance was accomplished without the person with a disability being made aware of the monitoring. For example, one review reported that their mother with dementia was not aware of the presence of the camera monitoring her *"I can see if Mum seems puzzled, lost, or confused, so I'm able to call her immediately to bringing Mum back to calm stability. Mum has no idea the system is there, but my sister and I are so grateful for your product!!" (C20).* Such surreptitious monitoring sometimes extended beyond just the person with disability to include other people employed in the home (e.g., DSPs) as well: *"The [camera] motor isn't loud, but if you're trying to be sneaky about watching someone in your home, like a maid or visiting nurse, they're probably going to hear the camera move." (C1).*

In some cases, caregivers stated that they felt their monitoring via SSHDs increased the independence of the person with a disability while maintaining their privacy. However, the reviews actually focused on how the SSHD-based monitoring ensured the caregiver's peace of mind: *"I purchased this item to ease my mind after my child was diagnosed with epilepsy! The app alerts to any sound or motion. I no longer feel the the need to jump up every 3 minutes just to ensure the safety of my child. I can easily check his safety upon receiving an alert [and] still maintain his privacy, otherwise." (C72).* Many reviews mentioned a certain kind of scope creep in terms of who was doing the monitoring. Caregivers were not careful about sharing the ability to monitor with others without informing the person being monitored: *"I put the app on everyones cell phone and we all like watching her while shes alone in her room."(C119).* As the quotation shows, this problem of allowing more and more people to participate in the monitoring of another is exacerbated by the ease of deploying the monitoring app on modern smartphones.

Interestingly, some reviewers did show concern for the privacy and agency of their loved ones and deliberately found a way to deploy their SSHD in a manner that least impacted their privacy. Often their solution involved monitoring things (e.g., windows, entrance ways, door thresholds) instead of monitoring the person: *"I have an autistic sonnon-verbal who tends to elope. So Ive struggled in the past to allow him his privacy (hes 13) while being sure of his safety. Now I can easily know if hes opening a window and intervene. " (S10).* Solutions like these could potentially be leveraged to determine best practices in terms of monitoring people with disabilities, their surroundings, and their aides, using SSHDs.

4.3 Study findings 3: People with disabilities faced barriers during the entire life cycle of SSHDs

Finally, we wanted to understand the barriers that the design of SSHDs introduce for people with disabilities. Table 8 shows the condition/disability of the person experiencing accessibility barriers

Number of reviews about accessibility barriers during SSHD use			**29**
Disability of person experiencing accessibility barriers			
Deafness/hard of hearing	17	Mobility impairment	1
Blindness/vision impairment	4	Parkinson's disease	1
Autism	1	Surgery	1
Cerebral Palsy	1		
Unspecified disability/health condition	3		
The reviewer's relationship to the individual with a disability			
Self	18	Parent	1
Child	4	Sibling	1
Spouse	4		
Unspecified relationship	1		

Table 8: Condition/disability of the person experiencing accessibility barriers and their relationship to the author of the review.

with SSHDs and their relationship to the author of the review for the reviews discussing accessibility barriers. Most of the reviews on accessibility barriers were written by people who are deaf or hard of hearing. There were more reviews written by or about people who are deaf or hard of hearing about accessibility barriers than there are about security and accessibility uses for SSHDs or caregiver monitoring using SSHDs. Additionally, the majority of reviews written by or about people with vision impairments were written about accessibility barriers. The high proportion of reviews about accessibility barriers for these communities contrasts with the low proportion of reviews about accessibility barriers written by or about people with other disabilities. For example, only one review about accessibility barriers was about a person with a mobility impairment. In contrast, the majority of reviews about people with mobility impairments were written about using SSHDs to increase security and accessibility in the home. The tendency for certain communities to be primarily represented in reviews about accessibility barriers further emphasizes the need to fix these barriers, as certain communities of people with disabilities are not able to fully benefit from SSHD use. Further research is needed to better determine the specific needs of each community of people with disabilities, especially the needs that people underrepresented in our data set have with SSHDs (e.g., people with vision impairments). We discuss exploring SSHD use by people with disabilities who are underrepresented in the online reviews further in Section 5.5.

Below we discuss five themes that emerged in regard to barriers in SSHD design.

4.3.1 People with disabilities faced cost and installation barriers with respect to SSHDs. Many reviews mentioned that the price of individual SSHDs and any additional subscription fees were too high. Even when the purchase price was affordable, many people could not afford its subscription-based features: *"Worked great until trial cloud time period was up.... For the price cloud services should be free. I am handicapped and live on fixed income don't need another expense. Will be looking for a different type." (S29).* In some reviews, the installation was a significant enough barrier that the reviewer wanted to return the SSHD. However, processing the return also turned out to be a barrier to certain people with disabilities, which prevented the successful return of the SSHD: *"I wanted to return because I didnt realize I had to run wires. The thing is I had surgery and couldnt get to a postal shop." (G7).*

4.3.2 People with disabilities struggled with some of the hardware-related choices made in the design of SSHDs. People with a variety of disabilities often stated that the hardware components of SSHDs were not designed to be accessible. An aspect of SSHDs that was responsible for many accessibility complaints was the lack of loud notification sounds available within SSHDs: *"The only thing I wish was better, is the volume on the [base station]. I suffer from hearing loss, and it is hard for me to hear what it is saying." (S44).* However, it is not sufficient to just create louder sounds. Sometimes the frequency and timber of the sound used also made it difficult for people with disabilities to hear: *"It would be nice if the chime could be changed. There's a volume control, but no ability to change the sound. My husband is partially deaf and he doesn't always hear the chimes particular tone." (S17).* Other reviews included requests for additional accessories to address accessibility needs, such as external speakers, dome sirens, and even strobe lights: *"I was led to believe a strobe was likely in near future! System is installed with my wife's safety being the primary reason as she is deaf, the system in it's current form is useless!" (S19).* Another review commented that the keypad for the security system was not accessible: *"The keypad buttons are small and there is no backlight.... I live with a vision impaired person who won't be able to use it. I put Velcro on the keychain button to identify the off button, because those buttons are very small too." (S56).*

4.3.3 People with disabilities found the apps accompanying SSHDs difficult to use. Most SSHDs are accompanied by an app to control them. People with disabilities often found these apps to be not accessible. For instance, screen readers did not work effectively with the SSHD app: *"Their iOS app needs a lot of accessibility work, as it is currently not fully usable by those who rely on VoiceOver (Apple's screen reader for the visually impaired)." (C1).* Another review noted how the lack of a PC application prevented their brother with cerebral palsy from being able to use the camera (because they could not use the touchscreen on mobile devices). This was compounded by the fact that the SSHD's Alexa-based voice assistant could not understand the brother's speech, making it impossible for him to use voice commands as a workaround for not being able to use a touchscreen: *"There really needs to be an app for PC use. [My brother] is in a wheelchair. HE HAS CEREBRAL PALSY and as such has great difficulty using touch screens and so on. BUT, he NEEDS to know who is at the front door and we have set one of the cameras for him. NO*

ALEXA DEVICE... WILL UNDERSTAND THE DISABLED GRAVEL VOICE OF SOMEONE WITH CEREBRAL PALSY" (C71).

4.3.4 People with disabilities misunderstood the capabilities of SSHDs. Reviewers often lacked an understanding of how SSHDs function and possessed several misperceptions about them. For example, in a review written by someone with a physical disability, they mentioned that a smart lock would automatically open from inside the home when one approached the door: *"The only thing I worry about is the auto-unlock with Bluetooth proximity. Others have pointed out that this is a security concern since it will unlock your door as you approach it from the inside to see if the person who rang the bell is a mass murderer." (L20).* However, this is a misconception. Some smart locks do unlock when the user is close to them. However, the unlocking only occurs when the user approaches the door from outside the home (usually via a smartphone app) [87]. Identifying such misperceptions is important, as features like automatic door (un)locking were important to help people with disabilities have agency over their home security, as discussed in Section 4.1.1.

Similarly, another reviewer warned others that SSHDs generally save private user data at specific remote locations and named privacy implications they thought this would entail: *"I have tried other cameras, but they all seem to make you store your videos on a remote server (usually in China) and then they start making you pay for storage." (C61).* However, it is highly unlikely that video data from all SSHDs would be co-located in a single location. In fact, some SSHDs use their own servers to store the data and others use a cloud service provider to store the data. Usually, cloud service providers have their servers distributed around the world to reduce the latency [91]. Misconceptions like these could cause people with disabilities and caregivers to avoid using SSHDs despite the many benefits.

4.3.5 People with disabilities and caregivers often struggled with the support provided for SSHDs. About a sixth of the reviews included incidents where people with disabilities faced an issue with the SSHD and had to look for help. A review mentioned that the images in the help pages of an SSHD app were rendered too small to be readable: *"There is a help section that seems to be drawing from the online forum, but it doesn't seem to be optimized for mobile – there are illustrations to go with the text, but I can't see them." (C2).* Another review commented on the lack of accessible contact methods for customer support: *"Customer Service wasn't helpful VIA email, they really wanted to talk on the phone which isn't the best way for the hearing impaired to communicate (me)." (C86).* Even when people with disabilities or their caregivers were able to contact customer support, they were instructed to do things that would have been detrimental: *"The support person was telling me to wipe out things on my phone, pretty much disable the security on my modem (which is crazy!) All of this while dealing with a husband with Alzheimers. Way.Too.Much.Trouble!" (C14).* Finally, a lot of the SSHDs, especially those used for care monitoring, are deployed for remote observation. In the reviews we found that for such cases if the SSHD stops working, the person monitoring (i.e., the caregiver) can experience a considerable struggle in getting the support they need to get the SSHD operational again: *"FRUSTRATING! I set up one device in my mother's memory care facility in OK [Oklahoma state] the day before we left to go back to WA [Washington state]. At first it was great! I could talk to her and her caregivers live and monitor that she was given care at scheduled times, night or day. Today, Live feed stopped and I cannot determine the cause. Worse, no way to receive live help, even after purchasing a 99 year's membership. So now I have 2 devices, a 99 membership, plus a 3 year protection plan, and it isn't working." (C39).*

5 DESIGNING SSHDs TO MEET THE NEEDS OF PEOPLE WITH DISABILITIES IS A NASCENT RESEARCH AREA THAT MERITS FURTHER EXPLORATION

In this paper, we focused on developing a broad understanding of the use of SSHDs by various communities of people with disabilities. To wit, we analyzed Amazon reviews written about the experiences of people with disabilities and their caregivers with SSHDs. We found that SSHDs: (1) provided novel ways for people with disabilities to keep their homes secure; (2) enabled caregivers to remotely monitor people with disabilities and their surroundings, albeit often unethically; and (3) presented several barriers of use for people with disabilities. In this section, we describe the implications of our findings by discussing five areas for future research opportunities for the HCI and accessibility communities. For each opportunity, we list a few specific research questions that we believe need to be tackled.

5.1 Opportunity 1: Exploring the unintended consequences of controlling physical access

In our findings, we saw that SSHDs were used to control physical access to part of the home for people with disabilities. *Such control of physical access can often create or exacerbate hierarchies within the home where people with disabilities are often subject to more control than non-disabled members of the household.* For example, one review in Section 4.2.3 mentioned that the SSHD code to unlock the kitchen was shared with their neurotypical daughter but not with their autistic son. Of the several reviews that mentioned restricting access to parts of the home for the individual with a disability (usually autism in these cases), most wrote unproblematically about controlling access without including any reason for doing so. This particular review writer states that their reason for controlling access was due to the autistic child creating a mess when left unattended in the kitchen. However, even with a good reason, the differing levels of access establishes a hierarchy in which neurotypical people rank above people with disabilities. The use of SSHDs makes creating and maintaining such hierarchies within the home very easy. Furthermore, other forms of smart home devices (e.g. smart speakers) have already been shown to affect family dynamics within the home [13]. Consequently, it is critical that future research examine the unintended consequences of SSHD-mediated control of physical access, especially when this control is used to limit people with disabilities more so than others, so that families and caregivers can make informed decisions about using SSHDs. Some research questions in this area include:

- What are the long-term impacts of SSHD-mediated control of physical access that restricts people with disabilities more than others in a home on people with disabilities?

- What steps can be taken when using SSHD-mediated control of physical access to avoid creating hierarchies within the home between people with disabilities and others?
- How can SSHD designers inform users of the potential impacts of the control of physical access on people with disabilities so that users can make informed decisions?

5.2 Opportunity 2: Improving the projection of presence using SSHDs

In our findings we noted that SSHDs were often used for the remote projection of presence. By projection of presence, we mean the ability of an SSHD user to convey to someone that they are present in a location where they are not physically located. We found two main situations in which an SSHD user projected their presence to others (a recipient) using *auditory* means. These include: (1) using the SSHD loudspeaker to speak with the individual with a disability to help them mitigate situations related to their disability (e.g., a flareup of their symptoms, an increase in confusion) and (2) using the SSHD loudspeaker to speak to strangers outside their home in order to scare them away, thus mitigating potential threats. *Projection of presence using SSHDs is interesting, as the SSHD is not merely used to chat with others but to rather to make the recipient feel that the user of the SSHD is with/near them.* The HCI literature has started exploring ideas similar to projection of presence in recent years with several studies on being virtually present. These have included work that focuses on improving remote presence through biosignals [68] and haptic feedback [104] and designing remote presence for funerals [97]. Ideas from these studies could be used to help improve the ability of SSHD users to better project their presence beyond just using the auditory means, to include embodied cues. Some of the broad research questions in this area include:

- What are the various ways in which the projection of presence is used by/for people with disabilities using SSHDs?
- What are some of the barriers that people with disabilities and their caregivers encounter while projecting their presence using SSHDs?
- How can SSHDs be designed to improve the projection of presence beyond the current auditory means?

5.3 Opportunity 3: Empowering people with disabilities to have agency over their own monitoring

One of the most prominent uses of SSHDs that we observed from the reviews was that caregivers used them to monitor people with disabilities, ostensibly to help ensure the latter's safety. Such reviews were invariably written by the people who performed the monitoring. Therefore, it is not clear from the reviews how people with disabilities feel about being monitored or if they are aware of all of the implications of being monitored via SSHDs. We also noticed that such monitoring was often done in a way where the consent of the person being monitored (which included not only people with disabilities but also anyone who enters the home to perform work) was not sought. In fact, the individuals with disabilities were often not given any agency over their own monitoring and were not even always made aware that they were being monitored. Prior work has shown that when people with disabilities are given agency they do, in some cases, choose to share privacy-sensitive information with people close to them [51]. However, even when a person with disabilities is potentially open to sharing their privacy-sensitive information with others, it is essential that the person with disabilities is given the opportunity to decide: (1) with whom they share their private information, (2) what private information they share, and (3) specify specific limitations on the sharing (e.g., revocability). Our results demonstrate that, in the context of SSHD-based monitoring, people with disabilities are not being given a say on who has access to their privacy-sensitive information or to what extent. Additionally, the reviews about monitoring disproportionately focused on people with dementia. This trend raises additional research questions on how people with dementia and their caregivers can work together to maintain ongoing knowledge of and consent to monitoring. Consequently, more research is required to determine how best to ensure that any monitoring of adults via SSHDs is informed and with permission. Some research questions in this regard are:

- What do people with disabilities think about being monitored via SSHDs?
- What are the best practices for informing people who are to be monitored via SSHDs?
- How should these practices be adapted when dealing with people with a cognitive disability (e.g., dementia) that may affect their ability to realize or remember that they are being monitored?
- How can SSHDs be made customizable so that people with disabilities can design their own privacy controls to meet their specific needs?

5.4 Opportunity 4: Designing SSHDs to monitor potential abuse by direct support personnel

As we saw in the reviews, SSHDs were often used to monitor for or to deter abuse by direct support personnel (DSP). Such monitoring may help to ensure the safety of people with disabilities; however, it also raises privacy concerns both for the DSP as well as for anyone else who may live in or be present in the SSHD's field of view[5]. Some work has been done to better understand how workers in a home (e.g., childcare workers) feel about being monitored [15]. However, the literature in this area is particularly lacking and further research is necessary to understand the effects of SSHD-based monitoring for a broader category of aides, including those who help people with disabilities. Further, the presence of SSHDs may incentivize certain DSPs to tamper with or disable the SSHD, which they can do both for privacy as well as nefarious reasons, such as to perpetrate abuse or theft. Prior research on the security of SSHDs has focused on digital security rather than on direct tampering by malicious actors within the home [80, 81]. Such tampering can impede the detection of potential abuse and/or other kinds of protection of the individual with a disability. It also can be costly for the owner of the SSHD, who may have to replace or repair the SSHD. Some research questions in this area include:

[5]Since we already mentioned the need for consent from the person with a disability, we do not mention it again here

- How can SSHDs be used to monitor for abuse while still respecting the privacy of DSPs and third parties in the vicinity?
- How can SSHDs be designed to effectively protect against their tampering, such as by DSPs or other aides?

5.5 Opportunity 5: Exploring SSHD use by people with disabilities who are underrepresented in online reviews

There are multiple communities of people with disabilities who are not well represented in our data set. There are many potential reasons that could result in a lack of reviews from certain communities, including: a lack of interest in SSHDs; inaccessibility of SSHDs that results in people from certain disability communities to not even attempt their use; and inaccessibility challenges in entering the reviews on Amazon. In fact, e-commerce websites present known accessibility barriers for people with vision impairments [69, 89, 100]. Furthermore, the resulting lack of representation has a potential effect on the future designs of SSHDs, especially when there are competing design requirements. For example, as mentioned in Section 4.2, camera features like viewing who is at the door can have great security benefits to people with motor impairments. However, these SSHDs also could cause accessibility issues for people with vision impairments. Existing studies on smart-home-device use by people with particular types of impairments have focused on non-security-related devices rather than SSHDs [16, 17, 34, 58, 64, 65, 72, 96]. Future research could more deeply explore the desires of particular communities of people with disabilities with respect to SSHDs specifically. Prominent research questions in this area include:

- What experiences do specific communities of people with disabilities (e.g., people with vision impairments, hearing impairments, etc.) have with SSHDs and why?
- What accessibility challenges do specific product review platforms (e.g., Amazon) pose for different disability communities?
- How can product review platforms be made more accessible to allow more disability communities to accessibly provide reviews in the future?

6 LIMITATIONS

Our study has a few limitations. Many of our reviews were written by caregivers of people with disabilities, with some communities (e.g., those with cognitive disabilities) being only represented in reviews written about them. While these reviews provided valuable information about the use of SSHDs by people with disabilities (and their caregivers), they did not directly present the point of view of the people with disabilities. This highlights the need for follow-up work to gain a more detailed understanding of the experiences of specific communities of people with disabilities when using SSHDs, to build upon the broad overview that we provided in this work. Moreover, some communities with disabilities are better represented in certain interactions with SSHDs. For instance, people with motor impairments are more represented in reviews about use of SSHDs to increase their agency over security, whereas people with Alzheimer's/dementia are more represented in reviews about care monitoring. More research is needed to explore the specific uses and needs of the communities represented in our reviews. Additionally, the reviews predominantly contained strongly positive or negative experiences, which is probably because people who have stronger feelings about a product are more likely to leave a review [49]. Furthermore, when looking at SSHDs, we only considered top products with a large number of reviews to allow us to analyze some of the most commonly used devices. However, since these devices were popular, this strategy may have resulted in reviews that were more skewed toward being positive. Our reviews were also all taken from amazon.com. It is therefore likely that a majority of the reviews were written by people living in the US. Future work should examine SSHD use by people with disabilities in different countries and across various cultures and subcultures. Finally, while online reviews have been examined in prior studies [43, 61, 82, 83, 86, 88, 93], there is still the potential for false or misleading reviews [52, 57, 59]. We mitigated this risk by only choosing reviews that explicitly discussed the lives and experiences of people with disabilities. However, it is still possible that our reviews may be vulnerable to some forms of review dishonesty that we were not able to catch through manual examination of our reviews.

7 CONCLUSION

In this paper, we sought to understand how security smart home devices (SSHDs) impact the lives of people with disabilities. Consequently we collected 114,871 Amazon reviews across five broad categories of SSHDs. We used these reviews to create a data set of relevant reviews written about or involving people with disabilities. We then broadly analyzed this data set and found that people with disabilities used SSHDs in their home to independently secure their domicile. SSHDs also were used by caregivers to monitor people with disabilities, ostensibly for the safety of the latter and without explicit consent. Moreover, we also found that SSHDs have multiple drawbacks that impose different barriers of use on people with disabilities. Based on these results, we suggested five areas of future research in SSHD design.

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