“Accessibility Came by Accident”: Use of Voice-Controlled Intelligent Personal Assistants by People with Disabilities

Alisha Pradhan[1], Kanika Mehta[1], Leah Findlater[2]

[1]College of Information Studies
University of Maryland, College Park
alisha93@terpmail.umd.edu, mkanika@umd.edu

[2]Human Centered Design and Engineering
University of Washington
leahkf@uw.edu

ABSTRACT

From an accessibility perspective, voice-controlled, home-based intelligent personal assistants (IPAs) have the potential to greatly expand speech interaction beyond dictation and screen reader output. To examine the accessibility of off-the-shelf IPAs (*e.g.*, Amazon Echo) and to understand how users with disabilities are making use of these devices, we conducted two exploratory studies. The first, broader study is a content analysis of 346 Amazon Echo reviews that include users with disabilities, while the second study more specifically focuses on users with visual impairments, through interviews with 16 current users of home-based IPAs. Findings show that, although some accessibility challenges exist, users with a range of disabilities are using the Amazon Echo, including for unexpected cases such as speech therapy and support for caregivers. Richer voice-based applications and solutions to support discoverability would be particularly useful to users with visual impairments. These findings should inform future work on accessible voice-based IPAs.

Author Keywords

Intelligent personal assistants; conversational interfaces; speech; accessibility; disability.

ACM Classification Keywords

H.5.m. Information interfaces and presentation (e.g., HCI).

INTRODUCTION

Voice-controlled intelligent personal assistants (IPAs), such as Amazon Echo and Google Home, have introduced a new interaction paradigm into the mainstream. These devices provide a conversational interface in the home to allow users to ask for and save information (*e.g.*, check weather, add to a shopping list), control smart home appliances, and perform a range of online actions (*e.g.*, shopping, banking).

From an accessible technology perspective, voice-controlled IPAs offer the potential to apply speech input and output beyond the traditional confines of text dictation and screen reader software. A person with limited mobility, for example, can control their home’s lighting or door locks by voice, while a blind user can ask for the time or weather. Due to their relatively recent introduction, however, researchers have only begun to understand how these devices are being used by the general population (*e.g.*, [16,32]), much less by users with disabilities. As such, our focus is to address exploratory questions such as: To what extent are off-the-shelf IPAs, which were not necessarily designed with accessibility in mind, accessible? How are people with disabilities making use of them? What design opportunities do these devices offer to further support everyday activities for users with disabilities?

To answer these questions, we conducted two studies. The first study broadly examined use of IPAs by people with disabilities, by collecting and analyzing online customer reviews of the Amazon Echo, a popular IPA, and its offshoots, the Echo Dot and Tap. We identified 346 reviews that described use of the device by a person with a cognitive, sensory, or physical disability, written either from a first- or third-person perspective. We conducted a content analysis of the reviews, qualitatively coding them along dimensions such as overall tone (positive/negative), uses of the device, and accessibility challenges. To complement these findings, we then conducted a second study to offer a more in-depth understanding of one specific subset of users: those with visual impairments. Here, we interviewed 16 participants with visual impairments who owned an Amazon Echo or Google Home device. The interview covered similar themes to the analysis of reviews.

Findings from both studies show that the new paradigm offered by voice-controlled IPAs offers tremendous potential for inclusive, accessible interaction. Although some accessibility challenges arose, Study 1 shows that users with a broad range of disabilities, even some with hearing loss and speech impairments, are making use of IPAs. Reviews were overwhelmingly positive, mentioning impacts such as ease of use compared to existing technology and the ability to more independently complete everyday tasks. At the same time, the currently limited functionality of the device and unexpected use cases of speech therapy, learning support, and memory support point to potentially fruitful avenues of future work. Study 2 findings confirm many of the conclusions from Study 1, albeit specifically with blind and visually impaired users.

CHI 2018, April 21–26, 2018, Montreal, QC, Canada

ACM ISBN 978-1-4503-5620-6/18/04…$15.00
https://doi.org/10.1145/3173574.3174033

As well, while smart home appliance adoption was relatively low at the time of study, participants viewed smart home technologies favorably due to the potential to address accessibility issues in the physical world.

The primary contributions of this paper are: (1) a characterization of how voice-based intelligent personal assistants are being used by people with disabilities; (2) identification of accessibility benefits and barriers; (3) and recommendations for design as well as future work on conversational voice interfaces for users with disabilities.

RELATED WORK

We cover work on voice-based accessible technologies and, because a key marketing component of IPAs is smart home control, smart home environments for independent living.

Speech Interaction as an Accessible Technology

Speech input and output is commonly used to support accessibility. Traditionally, the two most widely adopted forms of accessible speech interaction have been screen readers, which provide audio output for users with visual impairments (*e.g.*, Apple's Voiceover [44] or JAWS [45]), and speech dictation software, which provides a text entry alternative to the keyboard (*e.g.*, Dragon [46]). Speech input has been helpful for a range of applications for users with motor impairments, including text input on desktops [26,38] and smartphones [28], controlling wheelchairs [29,34], and "free-hand" drawing [20]. For users with visual impairments, speech input on mobile devices is more common than it is for sighted users [4,42], due to efficiency for text entry [4] and browsing [3].

Speech interaction has also been studied for users with other types of disabilities. For example, computerized speech interaction can be useful for speech practice [18] and therapy [30] for people with speech impairments. Derboven *et al*. [14] conducted an exploratory study on how people with speech and physical impairments form commands for a speech interface, finding that commands were short, directive statements and were often ambiguous. Speech interaction has also been explored for people with cognitive impairments, for example, to derive design guidelines for spoken dialogue assistants for users with dementia [40], and to provide audio prompts that support routine daily living tasks [11]. In contrast to the above work, our focus is on voice-only conversational interaction with an off-the-shelf, general purpose IPA.

Voice-based Intelligent Personal Assistants

Challenges with smartphone-based conversational assistants (*e.g.*, Siri, Google Now) may also apply to home-based IPAs such as Amazon Echo and Google Home. User expectations for smartphone-based assistants tend to exceed the agents' abilities, with actual use being for simple tasks such as checking the weather or setting reminders [24]; privacy is also a concern [17]. At the same time, home-based assistants such as Amazon Echo and Google Home offer different affordances and accessibility opportunities. Interaction is remote (*e.g.*, across the room), which lowers the barrier to use in comparison to having to hold/use a device, and home-based assistants can connect to smart home appliances, becoming integrated into the home environment. Home-based assistants are relatively new, and the research literature on their use is accordingly sparse. Purington *et al.* [32] studied device personification in Amazon Echo reviews, concluding that users who personified the device were more likely to be satisfied with it. Druga *et al.* [16] studied how children perceive intelligent personal assistants (*e.g.*, trust, intelligence level), including Amazon Echo and Google Home, although the focus was not on the children's actual or desired use of the devices. Finally, researchers have begun examining issues of privacy and security with always-on smart home devices, such as concerns arising in multi-user homes [43]. This body of research is in the early stages and, to our knowledge, no one has examined use of home-based IPAs by users with disabilities—our focus.

Smart Home Technology and Users with Disabilities

Smart home technologies have long been touted as useful for users with disabilities (*e.g.*, [15]), although until recently many solutions have remained as research prototypes or have been too costly for mainstream adoption. More smart home studies have focused on older adults than users with disabilities, showing, for example, that the most desired features are emergency help, health monitoring, and environmental control (*e.g.*, lights, temperature) [13,27]. Smart home technologies also introduce challenges such as privacy and security [43], cost [8,13], and a worry about becoming dependent on the technology [31]. To do with privacy, specifically, people with disabilities may be more accepting of sharing and recording smart home information than people without disabilities [6]. Moreover, work with older adults has shown that the location in which the smart home sensors are placed may mitigate this concern [27].

Most relevant to our studies is work on voice-based control of smart homes. Vacher *et al.* [37] found that older adults and people with visual impairments were both positive about controlling a smart home using voice. Other studies have shown that users with multiple sclerosis [35] and older adults [10], many of whom had motor impairments, desired voice-based control over the home (*e.g.*, doors, windows), while the latter group also strongly desired communication via phone. Despite these positives, there may be downsides of smart home voice control, such as accessibility issues around speech input (*e.g.*, adults with non-continuous speech due to Alzheimer's disease) [33], and a reduction in perceived control compared to manual input [25]. Compared to this past work our study is timely: because smart home technology has entered the mainstream, we can analyze real-world impacts with a broad range of users.

STUDY 1: ANALYZING AMAZON REVIEWS

To understand the experience of users with disabilities in using voice-controlled intelligent personal assistants, we

Disability-Related Search Terms Specified in Advance
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.
Emergent Keywords
Bedridden, disease, injuries, injury, limited vision, no vision, non-verbal, nonverbal, poor vision, rehab, rehabilitation, surgeries, surgery.

Table 1. Disability-related search terms used for extracting reviews, including terms defined *a priori* and emergent keywords identified through reading a subset of reviews.

conducted an exploratory study of online customer reviews of Amazon Echo, Echo Dot, and Tap that mention use by an individual with a disability. Our coding scheme focused on overall experience with the devices, accessibility issues encountered, and suggested improvements. For this first study, we defined disability broadly, including motor, sensory, and cognitive impairments, while in the interview study described later, we focused on the largest user group from the reviews—users with visual impairments.

Method

Our approach is inspired by analyses of online content to derive implications for accessible design [2,9], and a study on personification in Amazon Echo reviews [32].

Dataset

We first collected 28,921 Amazon Echo, 27,286 Echo Dot, and 5,370 Tap reviews in June, 2017 from Amazon.com. All reviews were *verified* reviews, meaning that Amazon confirmed that the customer had purchased the device before reviewing. To identify reviews related to disability, we created a list of keywords related to cognitive, sensory, or physical abilities (following [2,9]). As shown in Table 1, the list included 95 keywords identified *a priori* and 13 emergent keywords identified by reading ~500 reviews.

Of the full review set, 792 included at least one keyword, but not always in the context of disability. We thus defined a *relevant* review as one that contained a first- or third-person mention of a user with a disability. Two research team members independently evaluated the relevancy of 50 randomly selected reviews, agreeing in 49/50 cases (Cohen's kappa = 0.96). One team member then assessed all remaining reviews. The final dataset included 478 relevant reviews, although as mentioned below, we further eliminated reviews that only *hypothetically* mentioned a user with a disability, leaving 346 reviews in total.

1. Perspective: first person, third person, third person (hypothetical)
User details 2. Disability: motor, vision, speech, cognitive, hearing, other, unspecified 3. Length of disability: short-term, long-term, unspecified. 4. Age: older adult, child, younger adult or unspecified 5. Household size: lives alone, other in house, unknown 6. Use in nursing home/rehab center/hospital: yes, no/unknown 7. Obtaining the device: was given it, bought it or unknown
Overall opinion 8. Overall tone of the review: positive, negative or neutral
Social aspects 9. Device as companion 10. Independence 11. Indispensable 12. Helpful for caregiver/family member to support caregiving 13. Enables digital tech access 14. Safety 15. Awkwardness or discomfort with device interaction 16. Privacy 17. Security 18. Other
19. Limitation (Functional Limitation, Criticism, or Suggestion)
User interface / interaction 20. User interface positives 21. User interface negatives
Speech recognition 22. Speech recognition positives 23. Speech recognition negatives
24. Device setup
Device usage 25. Specific activities performed 26. Home automation: yes, no

Table 2. Primary codes used for the reviews in Study 1.

Review Analysis

The reviews were coded along the 26 dimensions shown in Table 2, which include both inductive and deductive codes. Deductive codes were informed by related work (*e.g.*, on smart homes, privacy) and our own experience with IPAs, while inductive codes were added upon reviewing the data. Two research team members built an initial codebook, with one person reading approximately one-third of the reviews in depth, and the second person participating in discussions, reading a smaller subset of the reviews, and helping to add, merge, and delete codes.

To ensure coding reliability, we used a multi-phase process [21]. First, one researcher involved in the initial codebook creation and one new team member independently coded 20 randomly selected reviews, discussed disagreements, and refined problematic codes. Second, the same two researchers independently coded 40 new randomly selected reviews. Cohen's kappa calculated on the primary codes (all numbered codes in Table 2) after this second round was on average 0.96 (*SD*=0.07, *Range*=0.79-1.00). Four codes that had been present in the first round were by chance not applicable in the second round, and were excluded from these calculations (*Indispensable, Privacy, Home automation,* and *Awkwardness/discomfort with device interaction*). We also removed one primary code (*Technology comfort*) due to sparsity, and added *Use in nursing home/rehab center/hospital*. Finally, one researcher coded all reviews using the refined codebook. The excerpts marked with each code were then qualitatively analyzed to obtain richer descriptions to complement the coded data. We also computed basic statistics on review length, rating (on a 5-point scale), and age (based on date of posting).

Findings

We report on review and user characteristics, overall experience, device usage, accessibility issues, and emergent themes such as independence and safety. To focus on reviews based on *experience* with the device, we exclude from this analysis 132 reviews that only mentioned disability or accessibility in a hypothetical sense (under the coding dimension *Perspective*); for example, from R14: *"Alexa could be immensely valuable in helping a person with limited mobility and/or physical disability."* Our analysis thus includes 346 of the 478 reviews. We refer throughout to reviews by ID numbers R1-R478.

Review Characteristics

The reviews were on average 775 characters long (*SD*=810) and had a rating of 4.5 out of 5 (*SD*=1.0). As of June 15, 2017, the reviews were 312.2 days old (*SD*=205.7, *Range*=0-727). About a third (*N*=114; 32.9%) were written from the first-person perspective of someone with a disability, whereas 232 (67.1%) were written from a third-person perspective. These latter reviews were mainly written by people who had close ties with the user with a disability, such as a son or daughter (in-law) (36.6% of the 232 third-person reviews), spouse (26.7%), parent (16.8%), other family member (11.6%), or friend (4.3%); the remaining 4.3% of reviews did not mention what relationship the author had to the user. One review included purchases for two separate users with disabilities, so percentages sum more than 100%. Ratings from both first-person and third-person reviews were positive on average, at 4.6 (*SD*=0.9) and 4.3 (*SD*=1.2), respectively.

User Characteristics

Our dataset included users with a diverse set of disabilities: visual impairment (37.9% of reviews), motor or mobility impairment (30.6%), speech impairment (13.6%), cognitive impairment (11.8%), and hearing loss (4.6%). An additional 18.2% only mentioned disability in general. Some reviews mentioned more than one specific type of disability, so percentages sum to more than 100%. Nineteen (5.5%) of the reviews mentioned that the disability was only short-term, such as a user recovering from an injury or surgery.

In terms of age, we looked for mentions of older adults or children, and found that 46 reviews (13.3%) mentioned a user who was 60+ years old or used age-specific keywords (*e.g.*, elderly, old, older), while 16 reviews mentioned that the user was a child (4.6%). While only 145 reviews explicitly mentioned whether the user with a disability lived alone or with others, the vast majority of these mentions were of households with multiple members (138 reviews; 95.2%); the remaining seven mentioned living alone. A small number of reviews (4.0%) mentioned use in a nursing home, rehab center, hospital, or assisted living center.

Users tended to receive the device as a gift rather than buying it themselves. Of the 202 reviews that mentioned how the device was obtained, 79.2% involved a gift (*N*=160). Examining this data by user age revealed that older adults were disproportionately represented: 22.5% of gift recipients were older adults, although older adult users were only mentioned in 13.3% of all reviews.

User Interface and Interaction

In terms of overall tone, most reviews were positive (85.6%). Some reviews (*N*=23; 6.7%) referred to the device as a companion, using terms such as *"new best friend"*, *"bff"*, and *"someone to talk to"*. Eight reviews even mentioned that the device had become an integral part of the user's life. For example, R94 stated: *"This has to be the best gift I have gotten in years. I'm so used to it being here that I would be lost without it."* In contrast, only 11.9% of the reviews were negative, while 2.6% were coded as neutral. Here, we discuss more specific positive and negative comments about the user interface and interaction.

Ease of use was commonly brought up as a positive, arising in 23.4% of reviews. The voice-based interaction, which allowed for control from a distance and without the need for visual output was valued. For example:

> *"I can't begin to tell you what a difference the echo has made to my disabled veteran husband. After his stroke, his mobility and speech were effected. Giving him a whisper of a voice. He can now ask Alexa to play any song of his choosing without having to getup." (R21)*

Many reviews (*N*=46; 13.3%) also positively compared the IPA to a smartphone, computer, or other device. People with visual impairments (29 of 46 reviews), in particular, described how the IPA allowed them to perform a variety of tasks that had previously required multiple technologies (*e.g.*, computers, radios, audio book readers). For example:

> *"Audible books, alarms, conversions, calculator functions- It does a lot of things that I would have previously had to get other specialized products to achieve." (R281)*

Several reviews (9.2%) mentioned that the device provides easy access to digital technology as compared to other computing devices. Most of these reviews included users with visual impairments (21 of 32) and/or older adults (14 of 32). For example, from R470:

> *"I've purchased him [elderly father with poor vision] a computer and tablet in the past and the steps to use it were too difficult for him to remember. However, he has no problem using Echo because Amazon has made it easy and more natural to interact with." (R470)*

However, 19.1% of reviews mentioned limitations, criticisms, or suggestions. Nineteen reviews (5.5%) mentioned that a desired feature was missing, such as voice calls and messaging, emergency calls, alternative input via a remote, or braille to make the case more accessible. (Note that subsequent releases of the devices have addressed some of these concerns.) Another criticism was that the device

Activities performed	(%)	Activities performed	(%)
Listening to music	34.7	Listening to jokes	7.5
Looking up information	18.5	Setting a timer	6.7
Checking the weather	17.5	Managing a shopping list	6.1
Playing audio books	15.6	Managing a calendar	5.2
Home automation	15.0	Playing games	5.2
Listening to news	10.1	Third-party skills (*e.g.*, Uber)	4.1
Asking time or date	9.5	Managing a to-do list	3.8
Playing the radio	8.4	Online shopping	3.5
Setting an alarm	7.5	Other (*e.g.*, calls, spelling)	13.7

Table 3. Percent of the 346 reviews in Study 1 that mentioned a specific task.

offered limited use, which was mentioned in 4.0% of reviews and is a criticism that has been aimed at smartphone-based IPAs as well [24]. For example, R405 said, *"...echo still is not very smart. About 80% of my questions i ask it did not know."* Other less common criticisms mentioned in at least five reviews included having to pair the device with a phone, need for wifi, lack of portability, issues with the audio sensing, and issues with specific apps. Finally, a few reviews (2.9%) mentioned that cost was a challenge. Even when the base cost of the device is relatively cheap, additional skills or subscriptions (*e.g.*, Amazon Prime, Audible) are often needed.

Specific Uses of IPAs

Over half of the reviews (66.2%) mentioned specific tasks for which the device was used. The most common tasks demonstrated a mix of entertainment and utility—listening to music, looking up information, checking the weather, playing audio books, and home automation. See Table 3.

Because control over home automation is a primary marketing component of IPAs, we further examined these mentions. Table 4 shows that most of the 52 reviews mentioning home automation included a reference to lights, and other smart home devices were much less common (Table 4). The majority of reviews with home automation included users with motor impairments (71.2%; 37 of the 52 reviews). Approximately a third (28.8%; 15 of 52) mentioned an improvement in independence and just over half (53.8%; 28 of 52%) mentioned ease of using the voice for control. For example, R213 discussed how home automation saved effort and could be used to communicate with others in the home:

> *"If I want to turn lights on or off after I go to bed, I just tell the Dot to do that. More complex instructions can be routed through the Alexa Channel on IFTTT, including flashing lights to signal my son to go to bed or turning off all of the lights that were accidentally left on. I can turn off my air conditioner in my bedroom in the middle of the night with the lights out by saying, "Alexa, turn off bedroom air." The not having to get up after I've gone to bed thing makes a difference in my exhaustion level.*

Independence

Increased independence emerged as a theme, mentioned in 14.2% of reviews (*N*=49), all but five of which included users with visual and/or motor impairments. For example, R8, who is quadriplegic, mentioned:

> *"It allows me to help my husband just a little bit, not something that I have been able to do for a while. It gives you just a little bit of independence, and that is huge for folks who don't have any." (R8)*

Home automation	(%)	Home automation	(%)
Lights	82.7	Television	7.7
Smart outlets	21.2	Security system	5.8
Thermostats	19.2	Door locks	5.8
Switches	7.7	Other (*e.g.*, fan, sprinkler)	15.4

Table 4. Specific types of home automation mentioned, as a percent of the 52 reviews containing home automation.

An important source of independence was the ability to control smart home appliances such as lights or thermostats, especially for users with mobility impairments. For example, R345, who has ALS, stated:

> *"I am so thrilled with my new Amazon Echo (aka Alexa) and the freedom it has given me. I use the word freedom over independence because a person does feel somewhat caged when you have an active mind in an inactive body. You also feel guilt from fear of over burdening your caregivers. Alexa has alleviated much of this problem for me...." (R345)*

For people with visual impairments, a common theme was the ability to use the device for a range of small tasks without having to depend on someone else for help (48.9% of the 49 reviews), such as listening to music, checking the weather, asking for the time or date, reading books, or listening to the news. For example, R472 said:

> *"My wife who is legally blind and has disabilities due to a stroke [...] used to have to depend upon others to assist her with time, weather, making lists, taking care of her calendar, and many other daily chores. Thanks to Alexa she is in control of all of these as well as enjoying music again." (R472)*

Finally, the impacts of independence extended to alleviating the burden on caregivers, reflecting past work on the utility of some new technologies for caregivers (*e.g.,* [23,36]). A few reviews (3.2%) mentioned that the device had reduced some caregiver demands, such as reading books, playing music, controlling the home environment, or answering simple questions. For example, R350 said that instead of frequently having to repeat the time, daily agenda, and so on: *"Alexa has been phenomanal with taking some of the pressure off of me. She can answer the time ALL DAY LONG, and never get annoyed, lol."*

Safety

Sixteen reviews (4.6%) mentioned that the device had improved safety, 12 of which included people with motor impairments. Several of these reviews (*N*=7) commented on an app that sends an emergency alert to a contact. R289 also described using home automation to send messages:

> *"This was a gift for our son who has ALS. It has been very helpful to him in turning lights on and off where he can't access them and has even brought needed assistance by blinking lights in another room to get someone's attention when help was needed." (R289)*

Accessibility Challenges

Accessibility challenges arose, primarily related to speech interaction, the device ecosystem, and memory demands. Sixty-four reviews mentioned speech recognition accuracy, most of which (59.4%) were positive mentions. However, speech input can be particularly problematic for people with speech impairments. There were 31 reviews that included a user with a speech impairment and comments about speech recognition. Perhaps surprisingly, many of these comments were positive (23/31; 74.2%). For example, R144 stated, *"Most humans can not understand me, but Alexia can*," while R318 wrote, *"Ordinarily voice programs can't understand what I am saying due to my speech impairment, but Alexa responds to my commands without fail."* Another review (R126) mentioned using their AAC device to give commands to Amazon Echo, a behavior identified in [22].

Still, 10 users with speech impairments also or solely mentioned difficulties with speech recognition, such as the need to enunciate clearly and speak loudly. Another issue that arose for users more broadly, beyond those with speech impairments, was the device timing out before the speaker could complete their command (an issue noted for users with Alzheimer's disease [33]). Speech output challenges also arose in a few reviews. Three users with hearing loss experienced difficulty in understanding the output and could benefit by additional speech settings and paired earphones. R154 said, for example: *"...just a bit too much bass for speech (I'm a hard of hearing with typical treble roll-off)... wish there was a music & speech tone setting."*

A second accessibility challenge arose from the paired smartphone app, which is required for device setup, troubleshooting, and detailed help. Six users with visual impairments mentioned accessibility issues with the app, which highlights the need to ensure that the entire device ecosystem—not just the voice interaction—is accessible.

Memory demands of the voice-based interaction were also an issue. Some reviews (4.9%) mentioned difficulties in remembering voice commands, which could be particularly problematic for older adults or users with cognitive impairments. For example, R81 mentioned that an older user who had difficulty remembering how to wake the device (with the word "Alexa"), while R200 said of his 86-year-old father with limited vision: *"Unfortunately, he's not making full use of it's potential because he can't quite remember exactly the words needed to [use] some of the skills that are available."* At the same time, the ease of the conversational interface offered benefits for some users with memory issues. R91, for example, mentioned a user with dementia who sometimes forgets how to dial a phone, but can use a voice command to call his partner with Alexa.

Unexpected Uses

Along with the conventional uses of the device in Table 3, some unexpected use cases arose, including for speech therapy, learning support, and as a memory aid. These use cases offer insight into potentially rich avenues of research.

In terms of speech therapy, seven reviews (2.0%) described how the device had helped users with speech impairments to talk slowly, clearly, and loudly. The conversational nature of the device was also seen as helpful. For example:

> *"Our oldest daughter has a pretty challenging speech impediment and using Alexa has forced her to slow down and enunciate clearly. Not only is Alexa learning how to understand my daughter, my daughter is also slowing down and learning to communicate with Alexa. The huge benefit is she is now slowing down to communicate more clearly with us. This is something her speech therapists have been working on with her for years. Alexa has gotten these results from her in a few months." (R185)*

R329 described how the device was used to measure speech improvement for the reviewer's brother with autism: *"He'll speak to Alexa, ask her questions about the weather, and if Alexa responds, my parents know his speech is improving."*

Use of the device to support learning also arose. The voice-based, conversational interaction allowed some users with print disabilities to access information. Specifically, of the five reviews (1.4%) that mentioned a user with dyslexia, four reported that the device was useful for reading audio books or asking questions. For example, R68 said:

> *"My daughter is dyslexic and struggles with reading, but we load audio books on to our Amazon music account and Alexa plays the books while she is playing, resting, falling asleep. She asks her questions about everything under the sun, and Alexa never tires of answering them." (R68)*

A third unexpected use case was as a memory aid for users who had memory difficulties (mentioned as an issue for 19 of the 41 users with a cognitive impairment). Features like setting reminders, timers, managing a calendar, to-do lists, and shopping lists, and asking for the time, date and weather were seen as most helpful. For example, R190 said:

> *"I live alone, and was recently diagnosed with a disease that leaves me confused on details and the passage of time. It has been a godsend to be able to ask Alexa the day, date, time, or weather, set wake-up alarms or reminder alarms (for example, turn off the oven in an hour, or take my medicine), add to my to-do list or shopping list, etc."*

Finally, the applicability of the device to a medical setting and for short-term disabilities such as injury or recovery after surgery arose (5.5% of reviews). In some cases, the device was seen as useful for maintaining medication timing (N=5). Nineteen reviews mentioned short-term disabilities and reported benefits similar to those expressed by users with long-term disabilities, such as being able to listen to music or jokes, or query information by voice. For example, R422, who was recovering at home from surgery, said the device, *"Takes away my anxiety of being alone while my husband is at work."*

Summary

Users with a broad range of disabilities are making use of voice-based intelligent personal assistants in the home. Reviews were overwhelmingly positive, mentioning

ID	Age	Gender	House-hold Size	Self-reported Vision Level and Mobility Aid If Applicable	Devices Owned (Count)	Device Location	First Acquired?	Home Automation
1	42	M	4	Blind (some usable vision)	Echo (4), Home (1)	Living room, bedroom, office	2.5 years	None
2	35	F	1	Blind one eye, “little” vision in other	Echo (2), Dot (1)	Living room, bedroom	2 years	None
3	54	F	3	Blind (total blindness), uses wheelchair	Dot (2)	Living room, bedroom	9 months	None
4	44	M	3	Blind (total blindness)	Dot (2)	Living room, bedroom	9 months	None
5	62	F	1	Blind (total blindness)	Echo (1), Dot (1)	Living room, bedroom	1 year	None
6	48	M	1	Blind (total blindness)	Dot (2)	Living room, bedroom	10 months	None
7	34	F	4	Blind	Echo (2)	Living room / kitchen, family room,	2 years	TV
8	61	F	1	Blind (total blindness)	Echo (1), Dot (1)	Living room, bedroom	1.5 years	Lights, stereo
9	49	M	1	Blind (total blindness)	Echo (1), Dot (1)	Living room, bedroom	2 years	None
10	57	F	3	Low vision, no peripheral vision, uses walker, cane or wheelchair	Echo (4), Home (1)	Bedrooms, kitchen, office	7 months	Lights, thermostat, switches
11	65	F	1	Blind (no useful vision)	Echo (2)	Living room, bedroom	1 month	None
12	57	F	1	Blind (some vision)	Dot (1)	Dining room	7 months	None
13	54	F	3	Blind (some vision)	Echo (2), Dot (1), Home (1)	Living room, bedroom, office, basement	2.5 years	Lights
14	62	F	1	Blind (some vision)	Echo (1)	Living room	7 months	None
15	62	F	2	Blind (light perception)	Echo (1), Dot (2)	Living room, bedroom, kitchen	2 years	None
16	42	M	1	Blind (total blindness)	Echo (1)	Living room	1 year	None

Table 5. Demographic and device details of the 16 participants in Study 2. (Note: P3 and P4 were husband and wife.)

impacts such as ease of use compared to existing devices and the ability to more independently complete everyday tasks—due both to internet-connected apps as well as smart home appliances. Despite being highly accessible, challenges still arose, particularly for people with speech impairments and for users with hearing loss. Accessibility of the larger device ecosystem (*e.g.*, physical device design, smartphone app, smart home appliances) needs to also be considered. Unexpected use cases of speech therapy, learning support, and memory support point to potentially fruitful avenues of future work. A limitation of this study, however, is that, while the online reviews provided a large sample size, the data itself is sparse and does not allow for an in-depth understanding of individual users’ experiences. As such, we turn to an interview method in Study 2.

STUDY 2: INTERVIEW STUDY

To complement the breadth offered by Study 1, we conducted a second, in-depth study to examine use by one specific subset of users: 16 blind and visually impaired users Amazon Echo or Google home users.

Method

Participants

We recruited 16 participants (11 female, 5 male) with visual impairments who owned an Amazon Echo, Echo Dot, Amazon Tap, or Google Home device; three participants also reported having a mobility impairment. Details are shown in Table 5. Fifteen participants owned a smartphone. Participants were recruited from across the United States through Facebook groups specific to Amazon Echo, Echo Dot and Google Home, participant lists maintained by our research team, and snowball sampling. Participants were each compensated with a $15 Amazon gift card.

Procedure

We conducted semi-structured interviews over Skype or Google Hangout, or via a regular phone call. Conducting remote interviews provided us the flexibility of reaching a larger number of participants than would have been possible locally. Interviews were designed to last one hour, but ranged from 33–85 minutes long. Interview questions covered the following categories: background and demographics, number of devices owned, when/how device was acquired, device usage (frequency, activities), motivation for buying the device, comparison of expectations beforehand to actual experience, benefits and concerns/challenges/limitations of using the device, speech recognition experience, current use of and desire for home automation, user interface preferences, and suggestions for improvement. All interviews were audio recorded.

Analysis

Interviews were transcribed and qualitatively coded using a thematic coding approach that included both inductive and deductive codes [7]. Two researchers worked together to prepare an initial codebook, with one member reading all transcripts and discussing with a second team member to add, merge and delete codes. The first researcher applied this initial codebook to two randomly selected interview transcripts, which were reviewed by the second researcher. The two researchers refined the codebook, and in doing so added one new code (*Device Setup*). For validation of the refined codebook, we then followed a peer debriefing method [5]. Here, the first researcher and a third researcher independently coded one interview transcript and discussed disagreements. There were 15 disagreements out of 186 codes applied, which were resolved through consensus; one code definition (*General positive*) was refined and one sub-code removed. The final codebook, which the first researcher then used on all transcripts, contained 20 primary codes, 13 of which had sub-codes.

Findings

As shown in Table 5, most participants (13/16) owned multiple Amazon Echo and/or Google Home devices, placing them most often in a living room or bedroom.

Overall Usage Patterns and Perceived Utility

All participants found the device to be useful, with five participants mentioning that it had become an integral part of their lives—reflecting some of the reviews in Study 1. For example, P10 said, *"I cannot imagine life without them [Amazon Echo and Google Home],"* while P13 said, "*Initially, I heard about it and I thought, 'Who'd ever buy that?' Honestly, I thought, 'Oh, what a waste of money.' And then now it's just become such an integral part of our lives.*" Most participants (*N*=14) used the device multiple times a day, while two used it once every few days.

Participants made use of and valued a range of features. The most commonly reported uses were playing music (*N*=15) and checking the weather (*N*=14). Less frequent but still popular tasks included setting timers (*N*=12), listening to news (*N*=12), playing games (*N*=9), online shopping (*N*=9), looking up information (*N*=9), checking the time or date (*N*=8), reading books (*N*=7), setting an alarm (*N*=7), playing the radio (*N*=6), and calling people (*N*=5).

Initial Purchase and Change in Use Over Time

Most participants (*N*=13) had purchased the device themselves, while the others had been given it as a gift. The most common reasons for acquiring the device were expected ease of use of the voice interaction (*N*=8) and expected utility (*N*=6). For example, P1 touched on themes of utility and independence:

> *"It was the fact that I could do things that sighted people can do, you know, people with vision. It allowed me to do things very easily and not have to use a separate app for each thing I want to do." (P1)*

Uniquely, P12, who had low vision and primarily interacted visually with computers, reported buying the Echo Dot as a more attractive entry into voice and audio-based interaction than she had experienced with screen readers:

> *"I do have JAWS and things like that, the screen reader, but for right now it's not pleasing to my ear to be hearing that. […] But I do wanna take control of this [vision loss], so I'm hoping that starting out with Amazon Dot will motivate me to get this other audio help in my life." (P12)*

All but three participants reported being familiar with at least the device's basic capabilities before acquiring it. When asked about their initial use and whether use had changed over time, only two participants reported that their use had dropped off with time, due to frustration with the smartphone app or novelty wearing off. Overall, though, these trends demonstrate persistent utility for most people.

Strengths and Benefits

Three main benefits that arose were efficiency, impacts on independence, and an ability to replace a range of other technologies. Toward the theme of efficiency, seven participants mentioned that the device had enabled them to perform tasks faster than before, such as online shopping, checking the weather, listening to news, playing music, and setting timers. For example, P11 said that compared to using a traditional browser, Alexa is *"able to accomplish [making a purchase] in seconds versus a few minutes."* Four participants also referred to the IPAs as enabling them to multitask in new ways. P15, for example, felt that the voice interface was easier than using a smartphone to set a timer while cooking because it was hands-free: *"I think as a blind person, you tend to get your hands messier than perhaps some sighted people do."*

Another main benefit was to improve on a disparate set of existing technologies (mentioned by *N*=10 participants). Positive comparisons were made against smartphones, computers, tablets, talking clocks, talking calculators, braille timers, and e-book readers. P13 said,

> *"I mean you have to buy adaptive games and they're so prohibitively expensive. And the books... Right now, we don't have to buy machines, for the most part, that are separate. […] between the phones for portable usage and the Echo for home, we can read virtually all our books anywhere." (P13)*

Finally, the theme of independence was mentioned by four participants—that is, enabling tasks that had previously required assistance from others. Tasks mentioned included being able to shop, play games, and control the home environment. For example, P5 said that she could order online without having to ask her brother for help, while P10 described needing less help from her husband:

> *"It used to be there were nights I went to bed with the light on until my husband got home from work because I couldn't turn it off. [It also] saves me having to get up and turn on my CPAP [sleep apnea machine]." (P10)*

Accessibility Challenges and Device Limitations

Accessibility challenges arose primarily due to the device's ecosystem, that is, elements of the system beyond voice-based interaction. As found in Study 1, half of the participants mentioned problems with the paired smartphone app. Ten participants also reported that device setup was difficult, either on initial purchase or whenever the device got disconnected from the internet. Finally, the physical design caused issues for two participants. P12, who had low vision, had trouble reading the physical controls due to poor color contrast between the symbol and button, while P2 could not see the orange indicator light that comes on with the Echo during setup (note: recent releases also provide audio feedback to address this issue).

Two other limitations point to the need for richer voice interaction: the difficulty of discovering unknown features, and the limited features of Echo's voice-based apps compared to smartphone apps. P16, for example, compared the implementations of Alexa (Echo) apps for ride sharing (*e.g.*, Uber, Lyft) to comparable smartphone apps, concluding that the voice-based apps were lacking. For discoverability, eight participants either reported difficulty in learning about the existence of features or mentioned that they desired a particular feature that already existed—demonstrating the problem itself. As an example, P14 said:

> *"There are so many skills [Alexa apps] available that I know I'm missing out on some things that I would probably like to do, but don't even know that's possible." (P14)*

Input Modalities

The primary input modality preference was voice, but many people (*N*=9) also wanted other means such as a remote, smartphone, smartwatch, in-air gestures, or direct touch for controlling the device. Alternative options could deal with noisy environments, not wanting to disturb other people, or wanting to control the device from a distance. For example, P15 mentioned that it could be easier at times to use their watch as a manual remote control than to yell across the room, since *"I will almost always have the watch on."*

Current and Desired Smart Home Use

Although only four participants had connected smart home appliances to their IPA, all participants wanted their house to be automated. As shown in Table 5, current smart home appliances included lights, thermostat, TV, and switches. For the 12 participants who did not own smart appliances, the most common reasons were policies at their current residence (*e.g.*, a rental unit) (*N*=5) and cost (*N*=4).

The most common *desired* smart appliances, when posed to all 16 participants, were thermostats (*N*=14) and lights (*N*=10). Less common requests included the oven, dishwasher, security system, stove, garage door, washer, dryer, vacuum cleaner, TV, fans, blinds, and refrigerator. For example, P16 felt that voice control would be more accessible than his current thermostat, while P15 mentioned the general need for an accessible alternative to flat touch controls on appliances, *"which are very difficult as a blind person"*. P4 also said: *"I often forget to either turn lights on so that people know we're home or turn them off, because I don't need them."*

Some participants' experience points to the need for a wider range of appliances to be smart-enabled. P10, in particular, had a mobility impairment and used a smart switch for her CPAP (sleep apnea machine) and had wanted to do so for her oxygen compressor as well. But, she said:

> *"But unfortunately, compressors are, if the electricity dies, it sets off an alarm so the smart switches won't work for something like that. If I turn off my oxygen using it, it just sets off an alarm." (P10)*

When asked to envision an ideal smart home without having to take into account current capabilities, almost everyone wanted *all* appliances to be automated (*N*=14). Two participants wanted a personal assistant like Amazon Echo or Google Home to make emergency broadcasts and calls, connect with scales and fitness trackers, and pay bills. One participant also wanted to monitor her pets remotely by audio, as a more accessible alternative to a "pet cam" (P11).

Security and Privacy

Although security has been called out as an important issue for IPAs [43], only four participants raised security concerns, such as cloud-based services being hacked. For privacy concerns, participants were evenly split. Half believed that their conversations were not sensitive enough to cause any harm to them, with one participant even mentioning that the 'always on' feature can be positive:

> *"I guess the biggest thing was when there was the murder case which they wanted to subpoena the Echo. And I realized, gee, if somebody's killing me, the smartest thing to do would say, "Alexa, so and so had just stabbed me." Because she would actually record it and the police would be able to get that later on." (P10)*

Of the eight participants who were concerned, however, the two main issues were the device always listening and recording (*N*=6), and personal information being collected (*N*=6). Concerns affected device usage for five participants, for example, not using calendars, doing financial transactions or online shopping, or using applications that asked for location details. To avoid conversations being recorded, P16 turned off the microphone during sensitive discussions, while P1 unplugged it. Although not as common, a few people mentioned privacy concerns related to being overheard by other people in the home, or other people controlling their device (*e.g.*, for shopping, banking, for which reason security codes were used).

Summary

This study confirmed many of the findings from Study 1, emphasizing that IPAs have replaced many disparate devices, and improved efficiency and independence for a variety of tasks. Particularly important for blind and visually impaired users, issues related to the device ecosystem arose, along with a desire for more feature-rich voice-enabled applications. Although smart home appliance adoption is currently low, participants expressed enthusiasm about smart home appliances and their potential to address accessibility issues in the physical world.

DISCUSSION

Our studies demonstrate the immense potential of voice-controlled IPAs to provide inclusive, accessible interaction for people with a range of disabilities. At the same time, this formative research highlights directions for future work and accessibility issues that should be addressed, such as the limited control over speech output settings for users with hearing loss (Study 1), issues with paired smartphone apps (in Studies 1 and 2), and visual accessibility problems with the physical device design (Study 2). Here, we discuss generalizability of the findings and some of the more promising opportunities we identified for future work.

Subpopulations of users. Study 1 captured use by users with a broad range of disabilities, but some subpopulations were disproportionately represented. Almost two thirds of the reviews included a user with a visual or motor impairment, which means that our findings may be more likely to apply to these two groups. Study 2 findings are specific to users with visual impairments, although addressing the issues that arose there could be more widely beneficial.

Perhaps most unexpectedly, Study 1 included adoption by users with speech impairments and hearing loss—two subpopulations for whom voice-based IPAs are not obviously accessible. This finding may be partly due to sampling bias: users with more severe impairments may not have thought to try the device and thus to write a review. Still, most reviews in Study 1 that included users with speech impairments were positive, showing that conversational interaction even supplemented speech therapy for some users. While more formal computerized speech therapy is an active area of research (*e.g.*, [30]), it will also be important to study the utility of emerging conversational interfaces for these goals.

Mobile vs. home-based IPAs. Home-based IPAs offer different affordances than smartphone IPAs (*e.g.*, Siri), and, at least at the time of study, offered greater functionality. The largely positive findings from our studies contrast work with smartphone-based IPAs, where participants *without* disabilities considered the IPA to be *"entertaining / gimmicky"* [24]. This difference may reflect the differences of home-based devices compared to a purely mobile, smartphone option and/or the preferences of users with disabilities. Further work should explore these possibilities.

Discoverability. Discoverability of commands is a long-standing problem with voice interaction [41]. This issue arose in Study 2, where some users with visual impairments found it difficult to discover apps and advanced commands. Adaptive and contextualized learning may enhance learnability and discoverability in voice interfaces [12,19], and has been recently used for voice-based interaction for users with motor impairments [12]. Typically, however, the voice input is paired with visual output. Improving discoverability for *purely non-visual interaction* will likely offer benefits not only for blind users but also for others.

Rich voice-only app design. A related issue found in Study 2 is the limited nature of many voice-based apps compared to mobile or desktop counterparts. While sighted users may not mind switching to a visual interface for in-depth tasks (indeed, Amazon recently released an IPA with a visual display), understanding how to better support rich interaction through a voice-only interface is important for accessibility, particularly for users with visual impairments. While existing auditory interface interaction techniques should prove useful (*e.g.*, Spearcons [39]), new advances are needed to support complex information access.

Smart home adoption and perception. Smart home appliance adoption is occurring, with 15% of reviews and 25% of interview participants mentioning at least one smart home appliance. In terms of barriers to adoption, Brush *et al.* [8] have identified cost, inflexibility, management overhead, and security. Our visually impaired participants in Study 2 also cited cost, but mentioned policies in housing units, and, for some, worries about the accessibility of purchase and setup; security and privacy were not top concerns. Of course, other subpopulations of users with disabilities may have different concerns. Many of the smart home appliances desired by participants already exist, although there were still new opportunities (*e.g.*, the oxygen compressor). It will be important to revisit adoption rates in a few years to assess how adoption is changing.

Memory support. Users with memory loss in Study 1 sometimes encountered difficulties in remembering commands. Adaptive interaction may address this problem, for example, by learning a user's usage patterns to efficiently prompt actions. At the same time, we observed broad use of the IPAs for aiding memory: setting reminders, tracking calendars, and other memory-related tasks. As such, IPAs may be a promising platform for extending existing work on memory support (*e.g.*, prompting systems [11]) and to explore new possibilities for more explicitly supporting independent living for users with memory loss.

Limitations of the Study Method

For Study 1, we used verified reviews because they are more credible than otherwise [1], but there is still the possibility that some reviews were misleading (*e.g.*, ads for third-party features). Second, the dataset is likely biased toward users who are early adopters, have the resources to purchase an IPA, and are largely able to use the device. Third, the third-person perspective reviews (two thirds of our dataset), may not be as accurate as first-person reviews in reflecting the experience of users with disabilities. Finally, the reviews only include what review authors chose to mention, which means that frequency counts in Study 1 should be considered a minimum. Study 2 addresses this lattermost problem, but only focuses on one user group (users with visual impairments), and participants may have been relatively tech-savvy and socially connected since they were recruited through Facebook. Future work requires similar in-depth studies on IPA usage by other user groups.

CONCLUSION

With the increasing adoption of voice-controlled conversational interfaces and home-based IPAs, including people with disabilities in the design of these technologies is critical. To understand current use, we analyzed 346 Amazon Echo reviews that mentioned a user with a disability and interviewed 16 blind and visually impaired participants who owned a home-based IPA. The first study showed that users with a range of disabilities are using the Amazon Echo, including for unexpected cases such as speech therapy and support for caregivers. Study 2 provided a more in-depth analysis of one specific group—users who are blind or visually impaired—with findings reflecting the first study as well as emphasizing the efficiency of the devices for a variety of tasks, difficulties with discovering new functionality, and the desire for richer voice-only applications. However, accessibility challenges related to speech input and output still exist (Study 1), along with issues with the device ecosystem (both studies). As exploratory research, these findings should inform future work on accessible voice-based IPAs.

REFERENCES

1. Eric T. Anderson and Duncan I. Simester. 2014. Reviews Without a Purchase: Low Ratings, Loyal Customers, and Deception. Journal of Marketing Research 51, 3: 249–269. https://doi.org/10.1509/jmr.13.0209

2. Lisa Anthony, Yoojin Kim, and Leah Findlater. 2013. Analyzing User-Generated YouTube Videos to Understand Touchscreen Use by People with Motor Impairments. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI ’13), 1223–1232. https://doi.org/10.1145/2470654.2466158
3. Vikas Ashok, Yevgen Borodin, Svetlana Stoyanchev, Yuri Puzis, and I. V. Ramakrishnan. 2014. Wizard-of-Oz evaluation of speech-driven web browsing interface for people with vision impairments. In Proceedings of the 11th Web for All Conference (W4A ’14), 1–9. https://doi.org/10.1145/2596695.2596699
4. Shiri Azenkot and Nicole B. Lee. 2013. Exploring the use of speech input by blind people on mobile devices. In Proceedings of the 15th International ACM SIGACCESS Conference on Computers and Accessibility (ASSETS ’13), 1–8. https://doi.org/10.1145/2513383.2513440
5. James P. Barber and Kelley K. Walczak. 2009. Conscience and Critic : Peer Debriefing Strategies in Grounded Theory Research. In Paper presented at the Annual Meeting of the American Educational Research Association, San Diego, California, April 13-17, 2009.
6. Scott Beach, Richard Schulz, Julie Downs, Judith Matthews, Bruce Barron, and Katherine Seelman. 2009. Disability, Age, and Informational Privacy Attitudes in Quality of Life Technology Applications. ACM Transactions on Accessible Computing (TACCESS) 2, 1: 1–21. https://doi.org/10.1145/1525840.1525846
7. Virginia Braun and Victoria Clarke. 2006. Using Thematic Analysis in Psychology. Qualitative Research in Pyschology 3, 2: 77–101.
8. A J Bernheim Brush, Bongshin Lee, Ratul Mahajan, Sharad Agarwal, Stefan Saroiu, and Colin Dixon. 2011. Home Automation in the Wild: Challenges and Opportunities. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI ’11), 2115–2124. https://doi.org/10.1145/1978942.1979249
9. Erin Buehler, Stacy Branham, Abdullah Ali, Jeremy J. Chang, Megan Kelly Hofmann, Amy Hurst, and Shaun K. Kane. 2015. Sharing is Caring: Assistive Technology Designs on Thingiverse. In Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems (CHI ’15), 525–534. https://doi.org/10.1145/2702123.2702525
10. Zoraida Callejas and Ramón López-Cózar. 2009. Designing smart home interfaces for the elderly. ACM SIGACCESS Accessibility and Computing, 10–16. https://doi.org/10.1145/1651259.1651261
11. Clare Carroll, Catherine Chiodo, Xin Adena Lin, Meg Nidever, and Jayanth Prathipati. 2017. Robin: Enabling Independence For Individuals With Cognitive Disabilities Using Voice Assistive Technology. In Proceedings of the 2017 CHI Conference Extended Abstracts on Human Factors in Computing Systems (CHI ’17), 46–53. https://doi.org/10.1145/3027063.3049266
12. Eric Corbett and Astrid Weber. 2016. What can I say? Addressing User Experience Challenges of a Mobile Voice User Interface for Accessibility. In Proceedings of the 18th International Conference on Human-Computer Interaction with Mobile Devices and Services (MobileHCI ’16), 72–82. https://doi.org/10.1145/2935334.2935386
13. George Demiris, Marilyn J Rantz, Myra A Aud, Karen D Marek, Harry W Tyrer, Marjorie Skubic, and Ali A Hussam. 2004. Older adults’ attitudes towards and perceptions of “smart home” technologies: a pilot study. Medical Informatics and the Internet in Medicine 29, 2: 87–94. https://doi.org/10.1080/14639230410001684387
14. Jan Derboven, Jonathan Huyghe, and Dirk De Grooff. 2014. Designing voice interaction for people with physical and speech impairments. In Proceedings of the 8th Nordic Conference on Human-Computer Interaction: Fun, Fast, Foundational (NordiCHI ’14), 217–226. https://doi.org/10.1145/2639189.2639252
15. Mari Carmen Domingo. 2012. An overview of the Internet of Things for people with disabilities. Journal of Network and Computer Applications 35, 2: 584–596. https://doi.org/10.1016/j.jnca.2011.10.015
16. Stefania Druga, Randi Williams, Cynthia Breazeal, and Mitchel Resnick. 2017. “Hey Google is it OK if I eat you ?” Initial Explorations in Child-Agent Interaction. In Proceedings of the 2017 Conference on Interaction Design and Children (IDC ’17), 595–600. https://doi.org/10.1145/3078072.3084330
17. Aarthi Easwara Moorthy and Kim-Phuong L Vu. 2015. Privacy concerns for use of Voice Activated Personal Assistant in the public space. International Journal of Human-Computer Interaction 31, 4: 307–335. https://doi.org/10.1080/10447318.2014.986642
18. Susan Koch Fager. 2017. Speech Recognition as a Practice Tool for Dysarthria. Seminars in Speech and Language 38, 3: 220–228. https://doi.org/10.1055/s-0037-1602841
19. Anushay Furqan, Chelsea Myers, and Jichen Zhu. 2017. Learnability through Adaptive Discovery Tools in Voice User Interfaces. In Proceedings of the 2017 CHI Conference Extended Abstracts on Human Factors in Computing Systems (CHI’17), 1617–1623. https://doi.org/10.1145/3027063.3053166
20. Susumu Harada, Jacob O. Wobbrock, Jonathan Malkin, Jeff A. Bilmes, and James A. Landay. 2009. Longitudinal study of people learning to use

continuous voice-based cursor control. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '09), 347–356. https://doi.org/10.1145/1518701.1518757

21. Daniel J. Hruschka, Deborah Schwartz, Daphne Cobb St.John, Erin Picone-Decaro, Richard A. Jenkins, and James W. Carey. 2004. Reliability in Coding Open-Ended Data: Lessons Learned from HIV Behavioral Research. Field Methods 16, 3: 307–331. https://doi.org/10.1177/1525822X04266540
22. Shaun K Kane, Meredith Ringel Morris, Ann Paradiso, and Jon Campbell. 2017. "At times avuncular and cantankerous, with the reflexes of a mongoose": Understanding Self-Expression through Augmentative and Alternative Communication Devices. In Proceedings of the 2017 ACM Conference on Computer Supported Cooperative Work and Social Computing (CSCW '17), 1166–1179. https://doi.org/10.1145/2998181.2998284
23. Matthew L. Lee and Anind K. Dey. 2008. Lifelogging memory appliance for people with episodic memory impairment. In Proceedings of the 10th international conference on Ubiquitous computing - UbiComp '08, 44-53. https://doi.org/10.1145/1409635.1409643
24. Ewa Lugar and Abigail Sellen. 2016. "Like Having a Really bad PA": The Gulf between User Expectation and Experience of Conversational Agents. In Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI '16), 5286–5297. https://doi.org/10.1145/2858036.2858288
25. Michal Luria, Guy Hoffman, and Oren Zuckerman. 2017. Comparing Social Robot, Screen and Voice Interfaces for Smart-Home Control. In Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems (CHI '17), 580–592. https://doi.org/10.1145/3025453.3025786
26. Bill Manaris, Valanne Macgyvers, and Michail Lagoudakis. 2002. A Listening Keyboard for Users with Motor Impairments — A Usability Study ∗. International Journal of Speech Technology 5, 4: 371–388.
27. Alex Mihailidis, Amy Cockburn, Catherine Longley, and Jennifer Boger. 2008. The acceptability of home monitoring technology among community-dwelling older adults and baby boomers. Assistive technology 20, 1: 1–12. https://doi.org/10.1080/10400435.2008.10131927
28. Maia Naftali and Leah Findlater. 2014. Accessibility in context: understanding the truly mobile experience of smartphone users with motor impairments. In Proceedings of the 12th international ACM SIGACCESS conference on Computers and accessibility (ASSETS '14), 209–216. https://doi.org/10.1145/2661334.2661372
29. Gregor Pačnik, Karl Benkič, and Bojan Brečko. 2005. Voice operated intelligent wheelchair - VOIC. In IEEE International Symposium on Industrial Electronics (IEEE ISIE '05), 1221–1226. https://doi.org/10.1109/ISIE.2005.1529099
30. Rebecca Palmer, Pam Enderby, and Mark Hawley. 2007. Addressing the needs of speakers with longstanding dysarthria: computerized and traditional therapy compared. International Journal of Language & Communication Disorders 42, Sup1: 61–67. https://doi.org/10.1080/13682820601173296
31. François Portet, Michel Vacher, Caroline Golanski, Camille Roux, and Brigitte Meillon. 2013. Design and evaluation of a smart home voice interface for the elderly: Acceptability and objection aspects. Personal and Ubiquitous Computing 17, 1: 127–144. https://doi.org/10.1007/s00779-011-0470-5
32. Amanda Purington, Jessie G. Taft, Shruti Sannon, Natalya N. Bazarova, and Samuel Hardman Taylor. 2017. "Alexa is my new BFF": Social Roles, User Satisfaction, and Personification. In Proceedings of the 2017 CHI Conference Extended Abstracts on Human Factors in Computing Systems (CHI EA '17), 2853–2859. https://doi.org/10.1145/3027063.3053246
33. Frank Rudzicz, Rosalie Wang, Momotaz Begum, and Alex Mihailidis. 2015. Speech Interaction with Personal Assistive Robots Supporting Aging at Home for Individuals with Alzheimer's Disease. ACM Transactions on Accessible Computing (TACCESS) 7, 2: 1–22. https://doi.org/10.1145/2744206
34. Richard C. Simpson and Simon P. Levine. 2002. Voice control of a powered wheelchair. IEEE Transactions on Neural Systems and Rehabilitation Engineering 10, 2: 122–125. https://doi.org/10.1109/TNSRE.2002.1031981
35. Christoph Stahl and Pascal Laub. 2017. Maintaining multiple sclerosis patients' quality of life – a case study on environment control assistance in a smart home. In Proceedings of the 10th International Conference on PErvasive Technologies Related to Assistive Environments (PETRA '17), 83–86. https://doi.org/10.1145/3056540.3064943
36. Matthieu Tixier and Myriam Lewkowicz. 2015. Looking for Respite and Support : Technological Opportunities for Spousal Caregivers. In Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems (CHI '15), 1155–1158. https://doi.org/10.1145/2702123.2702563
37. Michel Vacher, Benjamin Lecouteux, Dan Istrate, Thierry Joubert, François Portet, Mohamed Sehili, and Pedro Chahuara. 2013. Experimental Evaluation of Speech Recognition Technologies for Voice-based Home Automation Control in a Smart Home. In 4th

Workshop on Speech and Language Processing for Assistive Technologies, 99–105.

38. Amber Wagner, Ramaraju Rudraraju, Srinivasa Datla, Avishek Banerjee, Mandar Sudame, and Jeff Gray. 2012. Programming by voice: a hands-free approach for motorically challenged children. In Proceedings of the 2012 ACM annual conference extended abstracts on Human Factors in Computing Systems Extended Abstracts (CHI EA '12), 2087–2092. https://doi.org/10.1145/2212776.2223757

39. Bruce N Walker, Jeffrey Lindsay, Amanda Nance, Yoko Nakano, K Palladino, Tilman Dingler, and Myounghoon Jeon. 2011. Spearcons (Speech-Based Earcons) Improve Navigation Performance in Advanced Auditory Menus. Human Factors 55, 1: 157–182. https://doi.org/10.1177/0018720812450587

40. Maria Klara Wolters, Fiona Kelly, and Jonathan Kilgour. 2016. Designing a spoken dialogue interface to an intelligent cognitive assistant for people with dementia. Health informatics journal 22, 4: 854–866. https://doi.org/10.1177/1460458215593329

41. Nicole Yankelovich. 1996. How Do Users Know What to Say? Interactions 3, 32–43. https://doi.org/10.1145/242485.242500

42. Hanlu Ye, Meethu Malu, Uran Oh, and Leah Findlater. 2014. Current and Future Mobile and Wearable Device Use by People With Visual Impairments. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '14), 3123–3132. https://doi.org/10.1145/2556288.2557085

43. Eric Zeng, Shrirang Mare, and Franziska Roesner. 2017. End User Security & Privacy Concerns with Smart Homes. In Symposium on Usable Privacy and Security (SOUPS '17).

44. VoiceOver for Mac: VoiceOver overview. Retrieved September 14, 2017 from https://support.apple.com/kb/PH22549?locale=en_US

45. JAWS Screen Reader - Best in Class. Retrieved September 14, 2017 from http://www.freedomscientific.com/Products/Blindness/JAWS

46. Dragon NaturallySpeaking - world's best-selling speech recognition software | Nuance. Retrieved September 14, 2017 from https://www.nuance.com/dragon.html