Freedom to Roam: A Study of Mobile Device Adoption and Accessibility for People with Visual and Motor Disabilities

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ABSTRACT

Mobile devices provide people with disabilities new opportunities to act independently in the world. However, these empowering devices have their own accessibility challenges. We present a formative study that examines how people with visual and motor disabilities select, adapt, and use mobile devices in their daily lives. We interviewed 20 participants with visual and motor disabilities and asked about their current use of mobile devices, including how they select them, how they use them while away from home, and how they adapt to accessibility challenges when on the go. Following the interviews, 19 participants completed a diary study in which they recorded their experiences using mobile devices for one week. Our results show that people with visual and motor disabilities use a variety of strategies to adapt inaccessible mobile devices and successfully use them to perform everyday tasks and navigate independently. We provide guidelines for more accessible and empowering mobile device design.

Categories and Subject Descriptors: H.5.2 [**Information Interfaces and Presentation**]: User Interfaces – *input devices and strategies, voice I/O.* K.4.2 [**Computers and society**]: Social issues – *assistive technologies for persons with disabilities*.

General Terms: Design, Human Factors.

Keywords: Accessibility, blindness, low vision, motor impairment, mobile phones, mobile devices, diary study.

1. INTRODUCTION

Mobile phones increasingly play a central role in the everyday lives of people around the world. Whereas mobile phone ownership was once a luxury, mobile phones have become a necessity for most adults. A recent Pew study [8] showed that 75% of adults in the United States currently have a cell phone, and most of those feel that it would be very difficult to give up their phone. Mobile phones are increasingly used to keep families in touch [7,18] and to access information while on the go [25].

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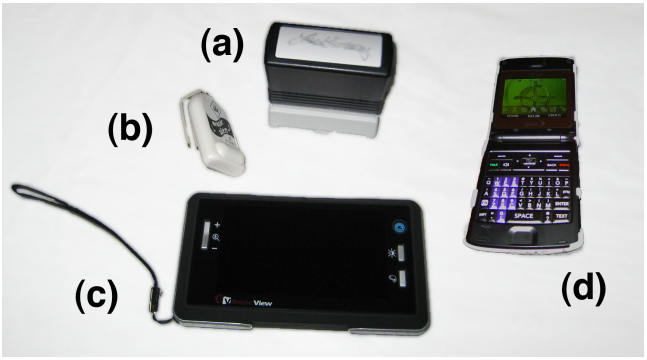

Figure 1. The devices a visually impaired participant carries with her frequently: (a) signature stamp, (b) water-level sensor, (c) CCTV magnifier, and (d) mobile phone.

For people with disabilities and older users, mobile phones and other mobile devices can provide increased freedom by allowing users to act independently while remaining in contact with friends, family, and caregivers [1]. Mobile devices can also be used to implement assistive software for people with special needs [14].

However, mobile device interfaces are often inaccessible to people with visual and motor disabilities due to problems such as small form factors, small or undifferentiated keys, and tiny on-screen text [7,10,11,28]. Despite having awareness of these problems, mobile device manufacturers continue to develop smaller and thinner devices and to adopt new interaction methods without considering accessibility problems. While companies have attempted to fill this void through the creation of specialized technologies for blind users (e.g., the PAC Mate accessible note taker,[1] Mobile Speak screen reader[2]) and older users (e.g., the Jitterbug phone[3]), such technologies have their own limitations, including increased price and reduced features [6,21]. Faced with these problems, people with disabilities continue to use both these specialized devices and general purpose devices [10]. Examples are shown in Figure 1.

Although the accessibility problems of mobile devices are known, less is known about how people with disabilities choose mobile devices, adapt them to their needs, and use them in their everyday lives outside the home. To better understand the day-to-day problems of mobile device users with disabilities and their

[1] http://www.freedomscientific.com/products/pacmate-hq.asp
[2] http://www.codefactory.es/en/
[3] http://www.jitterbug.com

strategies for working with mobile devices, we interviewed 20 people with visual and motor disabilities about their use of mobile devices, and conducted a diary study in which 19 participants recorded accessibility problems that they experienced when using their mobile devices outside their home.

We found that people used both mainstream mobile devices and devices designed specifically for people with disabilities, often in combination. Most participants encountered accessibility problems with these devices, and these problems were exacerbated when using the devices in certain environments. Participants used a variety of adaptation strategies to overcome mobile device accessibility problems, including memorizing device functions, customizing their devices, and using multiple devices in concert to overcome the limitations of a single device. From these findings, we present recommendations for increasing the accessibility of mobile devices, including increasing the options for device customization and automatically adapting user interfaces to environmental changes.

2. RELATED WORK

We draw on prior research on the accessibility of mobile devices for people with a variety of disabilities. In addition, we draw on research methods used in prior studies of mobile information use.

Prior studies have examined accessibility problems with the design of current mobile phone hardware and software. Bhachu et al. [3] asked elders in a focus group to examine a variety of mobile devices and consider their usefulness for health care applications. Massimi et al. [15] asked seniors to critique current smartphones, and to redesign existing smartphones to meet their needs. Leonard et al. [12] asked sighted and visually impaired participants to perform tasks with a mobile device, and analyzed differences in performance between the two groups. Plos and Buisine [22] surveyed users with visual or hearing impairments about their mobile phone accessibility needs. Tomioka et al. [27] asked focus groups with visual and motor disabilities to identify accessibility problems with current mobile phone hardware. Watanabe et al. [28] surveyed blind mobile phone users about accessibility problems with current mobile phones. These studies identified many overlapping concerns, including small device size, small buttons, screens with text that is difficult to read, and complicated device menus. These studies largely focused on the design of mobile phone hardware and software, and did not consider mobile device use in everyday life, as we do here.

Other studies have examined how people with disabilities currently use mobile phones. Kurniawan [11] performed a multi-method study that explored older people's use of mobile phones, their concerns with current mobile phone designs, and their desire for future devices. She found that users were most interested in mobile phones for handling emergencies, and experienced difficulties with the form factor of existing phones. Dawe [7] interviewed young people with cognitive impairments and their families about their current and desired use of mobile phones, finding that these young people could use their mobile phones to act more independently, but struggled with the complexity of current mobile devices. In a prior study [10], we interviewed blind smartphone users about their use of mobile devices, and found that users chose devices with familiar layouts, tactile buttons, and speech. This paper combines interviews and diary studies to extend our understanding of how people with visual and motor disabilities use their mobile devices in everyday life.

Prior research has used diary studies to better understand the activities that mobile device users perform while on the go. Sohn et al. [25] conducted a study in which participants used text messages to record information needed while on the go, finding that participants' information needs were strongly influenced by their location and activity. Other research has used voicemail [19] or combined text messaging with web surveys [4] to capture mobile experiences. This study adopts these methods to capture accessibility problems experienced on the go.

3. STUDY METHODS

To understand how people with motor and visual disabilities use mobile devices "in the wild," we interviewed 20 people about their use of mobile devices. Following this, 19 participants completed a diary study in which they reported accessibility problems that they experienced when using their mobile devices.

3.1 Interview

3.1.1 Participants

We recruited 20 subjects (13 female, 7 male) between the ages of 19 and 66 (average age 34.9). We recruited participants using e-mail lists for people with disabilities, by contacting local disability service organizations, and by contacting participants from prior studies who were interested in participating in additional research. All participants used personal mobile devices daily. We recruited participants with a range of abilities, including those with total blindness, low vision, and motor impairments. Information about our participants is summarized in Table 1.

We interviewed participants with different types of disabilities to inform the universal design of future mobile devices. Although it is important to identify accessibility issues within specific populations, such as blind users, our research shows that people with visual impairments, motor impairments, and multiple impairments often use devices designed for the general population.

3.1.2 Procedure

Each participant partook in a 60 to 90 minute semi-structured interview. The interview covered four topics: (1) mobile devices used by the participant, including how they acquired the device, what they used the device for, and any accessibility problems they encountered when using the device; (2) how participants used these devices in their everyday activities outside the home; (3) participants' information needs while on the go; and (4) participants' wishes for improving their current mobile devices and for future devices. Interviews were conducted either in person or via telephone. When possible, we obtained photographs of participants' devices (see Figure 1).

3.1.3 Analysis

We analyzed transcribed interviews and our notes to identify mobile device accessibility problems, adaptation strategies, use of mobile devices to access information, and wishes for future devices. We used open and axial coding to analyze responses [26].

3.2 Diary Study

Following the interview, we conducted a diary study to capture accessibility problems that occurred in the daily lives of our participants, but that were not captured during the interview. For example, one participant reported difficulty typing on her laptop due to fatigue felt during the busy week after her interview.

Table 1. Participants and the mobile devices that they carried at least once per week.

#	Sex	Age	Disability	Mobile devices	#	Sex	Age	Disability	Mobile devices
1	F	57	MI*	phone, paper calendar, paper address book	13	F	37	LV	smartphone, music player, game console, magnifier
2	F	41	LV*	phone	14	F	–	LV, MI	phone, music player
3	M	52	MI	phone, music player, GPS, tape recorder	15	F	23	Blind	smartphone, laptop, note taker, scanner, music player, GPS, cane
4	F	36	LV	phone, CCTV, water sensor, music player, cane	I1	F	24	LV	phone, magnifier
5	M	25	MI	phone	I2	F	34	MI	phone
6	M	52	Blind	smartphone, laptop, book reader, music player, compass, cane	I3	F	24	Blind	smartphone, laptop, book reader, note taker, cane
7	M	47	LV, MI	phone, audio recorder, cane	I4	M	66	LV, HI	smartphone, cane
8	M	25	Blind	smartphone, laptop, audio recorder, cane	I5	M	19	Blind	phone, note taker, music player, cane
9	F	34	Blind	phone, note taker, music player, scanner, pedometer, audio Bible	D1	M	24	Blind	smartphone, laptop, note taker, music player, audio recorder, cane
10	F	24	Blind	smartphone, laptop, book reader, cane	D2	M	26	MI	smartphone, laptop, music player
11	F	20	LV, HI*	phone, laptop, note taker, FM transmitter, cane	D3	F	21	Blind	phone, laptop, note taker, music player, cane
12	F	23	MI	phone, laptop, music player	D4	F	47	LV	phone, laptop, magnifier, cane

*LV = Low vision, HI = hearing impaired, MI = motor impaired. Participants I1-15: Interview only. D1-D4: Diary study only.

3.2.1 Participants

Nineteen people (7 male, 12 female) between the ages of 20 and 52 (average age 34.1) participated in the diary study (Table 1). Fifteen participants (1-15) were recruited from the interview study, and four (D1-D4) were recruited separately.

3.2.2 Procedure

Participants made a series of diary entries about their daily experiences with mobile devices. Participants were asked to report the following events as often as they occurred: (1) accessibility problems when using a mobile device; (2) accessibility problems related to travel and transportation; (3) information they accessed using a mobile device; (4) information that would be useful in a situation, but that was unavailable to them; and (5) other accessibility problems experienced while away from home.

Participants submitted diary entries by email, text message, voice mail, or via a web survey. Participants were asked to complete diary entries for 7 days, and were given additional incentive for submitting at least 7 diary entries during the week. Participants were able to submit entries anonymously.

3.2.3 Analysis

We received a total of 85 diary entries (63 web reports, 18 email, and 4 voicemail). We copied diary entries into a single table, and analyzed them along with the interview data to create a single list of mobile device accessibility problems.

4. RESULTS

4.1 Choosing and Using Mobile Devices

Participants shared their strategies for choosing mobile devices and described their frequently carried devices.

4.1.1 Researching and Acquiring Mobile Devices

Participants used a variety of strategies for learning about new mobile devices, including asking friends and family, discussing devices on mailing lists, performing web research, listening to podcasts, and trying out devices in stores.

As expected, participants used a combination of specialized and commodity devices. Only six interview participants used mobile phones that provided accessibility features. Those who used commodity devices were typically aware that more accessible devices existed, but thought that they were too expensive. Five participants cited cost as a reason for choosing a commodity device over a specialized device. Even more tech-savvy participants sometimes chose less-than-optimal solutions to reduce cost. For example, two of the seven smartphone users in our interview study did not have a roaming data plan, allowing them to use the Internet only when near a wireless access point.

4.1.2 Frequently Carried Devices

In all, 24 participants described a total of 90 mobile devices that they carried with them at least once per week. Commonly carried devices included phones or smartphones (24), music players (12), laptops (11), and GPS devices (2). Participants also carried portable accessibility devices such as canes (13), magnifiers (3), portable CCTVs (1), and Braille compasses (1).

4.2 Mobile Device Accessibility Challenges

Participants reported that they experienced a variety of accessibility and usability issues with their devices.

4.2.1 Findings from Prior Research

Prior research has identified many accessibility problems in current mobile devices [7,10,11,28]. Our interviews confirmed the

continued existence of these problems. Seven participants mentioned issues with on-screen text that was too small or had too low contrast. In some cases, text on a mobile device was partially visible, but was not visible on all screens or in all applications. Twelve participants also identified key size and nine participants identified overall device size as problems. Five participants complained about thin, flip-type phones that had recessed buttons, rather than exposed tactile buttons [24].

Three participants noted that, rather than becoming more accessible, their newer phones were less accessible than previous models they had used. For example, one participant had chosen a phone because it was easy to grasp. However, when she purchased an upgraded version of the phone, she found that it was thinner and made of different material, making it more difficult to grasp.

4.2.2 Situational Effects on Use

Mobile device use can be affected by environmental conditions in their varied usage contexts. These so-called *situational impairments* [23,29] have been shown to impair performance when using a mobile device [2,13,16,17]. Participants reported several situational factors that had a negative effect on their ability to use their mobile devices.

Crowded Spaces. Five participants described difficulties when using mobile devices in crowded areas, such as on the street or on a bus. One participant mentioned that it was difficult to physically interact with a device when on a moving vehicle. Another participant with low vision had difficulties navigating crowded spaces, and could not use a mobile device while doing so.

Lighting and Weather. Environmental factors such as daylight and weather also had a negative effect on participants' ability to use mobile devices. Five low vision participants mentioned that their mobile device screens were readable under ideal lighting conditions, but not in very bright or very dim light. One participant noted in a diary entry that it was difficult to hold her phone on a cold day:

> It was difficult using my phone with gloves on to keep my hands warm enough to not hurt (hard to hold it and the keys were too small to move easily).

Use while Walking. Using a mobile device while walking presented a challenge to some participants, either by reducing their motor control or their situational awareness. For blind and visually impaired participants, using a talking device or phone while walking made it difficult or impossible to hear sounds in the environment. One blind participant stated that she would use the phone while walking, but would mute the phone while she crossed the street. Another blind participant stated that she would use the phone when walking, but only when in a familiar area:

> [If someone called] I would probably ignore the call, or I would wait until I got somewhere that I wouldn't be worried about losing direction, and then I would call them back ... I don't want to have anything impeding my ability to know where I am.

Interruptions. Exacerbating the difficulties of using mobile devices while moving around, participants were prompted to use their mobile devices when receiving phone calls or text messages. Attempting to respond to these messages while on the go could be difficult and could reduce situational awareness. Stopping to answer a phone call could address these issues, but could cause other difficulties. For example, one participant in a wheelchair mentioned that he sometimes stopped to answer a call, but often blocked the sidewalk while doing so.

These examples show that using a mobile device while moving can present considerable challenges to people with disabilities. While prior research has shown that using while moving can reduce performance, these effects may be more drastic for people with disabilities by making it impossible to use a device while walking, or by reducing their situational awareness.

4.2.3 Fatigue and Changing Abilities

In addition to environmental effects, some participants described changes in their health or capabilities that affected their ability to use a mobile device. These changes typically took two forms: temporary changes in ability and ability changes from degenerative conditions.

Four participants described having conditions for which their visual or motor skills varied over time, based on stress, fatigue, weather, medication, or other factors. Two participants experienced variable pain in their hands, which occasionally made it difficult to use a mobile device.

Four participants also had progressive conditions that reduced their visual or motor abilities over time. Of these, three participants described how they could no longer use some mobile device that they previously used. For example, one participant previously enjoyed taking photographs with her camera, but no longer could due to her reduced motor control. Another participant became too weak to carry his laptop, and thus was no longer able to use it in mobile settings and instead used an audio recording device to take notes.

4.2.4 Device Failure and Maintenance

Five participants also mentioned having significant difficulties with mobile device reliability, including device failures. These difficulties included software bugs affecting a specific device feature, device lock-ups or restarts, or permanent device failures. For example, one participant experienced a software bug on her Braille note taker that caused the device to lock up whenever she edited multiple documents simultaneously. No fix was available for the bug, and so the participant had to remember not to edit multiple documents at once on the device.

Minor problems could often be addressed by restarting the device. In case of a complete device failure, participants needed to repair or replace the device. For more expensive items, participants had to send their devices away for repair. Devices designed for people with disabilities were typically more expensive, and were thus more likely to be repaired than replaced.

4.3 Adaptive Strategies

Despite the accessibility problems that they encountered, our participants were quite successful at performing tasks with devices that were often ill-matched to their abilities. Participants revealed multiple strategies for working with hard-to-use devices.

4.3.1 Modifying Devices

When possible, participants adjusted the settings of their device to make it more accessible. Seven of our low vision participants reported increasing the text size of their screen on at least one of their devices. However, even then, participants reported that the settings did not usually provide enough flexibility to meet their needs.

Other participants installed access software on their mobile devices. Seven participants installed screen reader software on a

laptop or smartphone. Thirteen of the interview participants had mobile phones that did not allow the user to install additional applications, such as a screen reader. Even participants who had compatible devices sometimes could not afford access software. However, some non-accessibility features could be appropriated to overcome accessibility problems. For example, one participant could not see the caller ID information on her phone screen, and so used a customized ringtone for each person who frequently called so she would know who was trying to reach her.

Participants did not typically modify their mobile device hardware to improve accessibility, but it did happen. One participant with a motor impairment had installed a wrist strap on her mobile phone, and two participants with low vision used magnifiers that attached to their mobile phones. Another two participants with motor impairments relied upon a holster, bag, or other carrying device to keep a mobile phone within reach (Figure 2). No other participants used accessibility modifications with their mobile devices.

4.3.2 Adapting to Devices

Some participants were able to use their phones successfully only by holding the device in an unconventional pose. For example, one participant with a motor impairment was capable of using his mobile phone by placing it in his lap (Figure 2). While this allowed him to use the phone effectively, it required him to stop moving and place the phone on his lap to use it.

Two visually impaired participants said that they sometimes used a mobile device while walking by wearing a headphone in only one ear, keeping the other ear clear to sense situational cues. Another participant used her phone's speakerphone feature to maintain situational awareness while walking, but stated that this was not always possible due to privacy concerns.

Figure 2. (left) Participant with motor impairment carries his phone on a hip holster; (right) Participant holds phone in his lap to dial.

4.3.3 Using Multiple Devices

Several participants described using multiple mobile devices to resolve potential accessibility problems. Using multiple devices protected against failure, maximized usability, and compensated for inaccessible features on a single device.

Owning multiple devices with redundant features provided some security in the event a device failed. Four participants stated that they owned backup versions of their devices in case of failure. These were typically devices that they previously used, although one participant purchased several copies of a device she liked when she found out that it was being discontinued. One blind participant carried both a mobile phone with integrated GPS and a dedicated GPS device, and justified this based on reliability concerns:

> If something happens to my phone, I'd still want to be able to have my [GPS]. If my [GPS] breaks, I still want to be able to have my phone.

As shown in our previous study [10], mobile device users also carry devices with redundant functions when one device is better suited for a certain function. For example, two participants carried a separate talking book reader device, even though their laptop or mobile phone could play audio books.

Finally, participants sometimes used multiple devices together in order to overcome an accessibility barrier found in a single device. For example, participants whose mobile phones did not provide accessible address books used other devices to store phone numbers. Two blind participants stored phone numbers on their accessible note taker device, and referenced them when they wished to make a phone call. Another participant carried a paper address book (Figure 3). Three participants carried no address book, and instead memorized numbers they frequently called.

Figure 3. A participant augments her mobile phone with a paper calendar and address book.

4.3.4 Learning a Device Offline

An additional strategy that our participants used to work with inaccessible devices was to practice using a device at home in order to learn how to use it. Two participants used a large magnifier or CCTV at their home to practice using a new device.

One of these participants, who had low vision, described in detail how she learned to use her new mobile phone. The text on the phone's screen was difficult to read, and so she practiced using the device at home using a magnifier, and memorized the button presses needed to perform tasks:

> When I got the phone, I would just use my magnifying glass, and then I could see everything on the phone ... So then I would just read it, read everything I need to read, and memorize it. So that way, if I'm out somewhere and I need to look up a phone number or something, I would know how to do it just by memory.

4.4 Accessing Information on the Go

One significant benefit of using mobile technology is the ability to access information while on the go. Participants shared how they currently used their mobile devices to access information while away from home. Participants also described how they used information to make plans before leaving home.

4.4.1 Calling Others for Assistance

Seventeen participants described instances in which they used their mobile device to coordinate with others, such as to arrange a meeting, or to request a ride. Three participants reported calling ahead to a restaurant or store to enquire about accessibility.

Two participants recounted calling a family member by phone and asking that family member to look up information on the Internet relevant to their current situation, such as directions or nearby attractions. In one case, the participant was visiting a new place, and the participant's family member had found a map of that location in case the participant called for navigation assistance.

All of our visually impaired and blind participants encountered some difficulties in navigating and finding items while running errands, especially in new places. If alone, participants most often asked strangers or store clerks for assistance. Because asking for help was not always easy, seven participants stated that they preferred to perform errands with a sighted friend or family member.

4.4.2 Using Automated Services

Although only five of our interview participants used a mobile device with a roaming data plan, five additional participants described using their mobile devices to access information services on the go through voice-based services or text messaging.

The most common information accessed using these services were phone numbers of local businesses, bus schedules, and weather information. Seven participants also reported using a GPS device, either on foot or in the car, to discover nearby points of interest. Our blind participants were particularly fond of this kind of location-based service, as it provided them with increased awareness of their surroundings. One participant stated:

> With the GPS, you can just strike out and go. I need that GPS to give me a little bit of assurance. Without GPS, I'd travel a lot less.

4.4.3 Planning Trips

When visiting a place for the first time, participants often made plans at home before leaving the house. This preparation included looking up directions, printing out maps, checking bus schedules, and calling ahead to ask about accessibility features. This task often required pulling together various pieces of information before leaving. For example, one participant, when visiting our research lab for her interview, printed out two maps: an accessible route map and a larger, easier to read copy of the standard campus map. Because the accessible map was not easily readable when printed, the participant was required to correlate the information between the maps to navigate to her destination.

4.5 Attitudes about Mobile Device Use

During interviews, participants offered many strong opinions about the mobile devices they use. Although these attitudes cannot be described fully here, we present some of the strongest themes that emerged from these discussions.

4.5.1 Use of Mass-Market vs. Specialized Devices

In total, nine of our interview participants frequently used a specialized mobile device that was specifically designed for people with disabilities. The most commonly used devices in this category were accessible note takers and talking book readers.

Participants offered a number of reasons both for and against using devices designed for people with disabilities. Such devices are typically more usable and accessible. One participant also praised a device because it was designed in collaboration with people with disabilities. Sometimes, however, participants gravitated instead toward commodity devices designed for a mass-market audience. Five participants noted that devices designed for people with disabilities could be expensive. Five participants mentioned some reliability problems with these devices and one said he no longer wished to rely on these specialized devices:

> I wanted to dispense with a lot of the proprietary blindness devices. You are completely reliant on the manufacturers to come out with new software ... I wanted something that I could use ... if I'm giving a presentation, I want to be able to hook my device up to the projector and show what I'm doing, and I just want it to be more commercial than adaptive.

None of the participants with motor impairments used mobile devices specifically designed for people with disabilities. One reason for this is a mismatch between available devices and the abilities of our participants. One participant, who had trouble typing accurately on her PC with a standard keyboard, found that she could type accurately using a keyboard designed for children. This participant was aware of more accessible phones, but was not interested in mobile devices marketed to children or the elderly.

4.5.2 Privacy

All of our participants sometimes used their mobile devices in public spaces. In some cases, using the device in public created tension between accessibility needs and perceived privacy.

Participants who used talking devices or speakerphone mode to increase accessibility found that they could not easily use these features in public due to environmental noise or privacy concerns:

> I would be in a setting that is a little loud ... like on a bus or something. And it would just be a little awkward to be yelling into your phone. So I usually just use the speed dial.

One participant used her phone with a portable magnifier, but disliked doing so in public because it drew too much attention. Instead, she tended to use the magnifier at home only, and so was unable to fully read text on her phone screen when in public:

> Sometimes it's a little socially awkward to, you know, use my magnifying glass with my cell phone. I'm sure it looks a little odd ... People are always like, "What is that girl doing?"

4.5.3 Independence

Participants expressed both positive and negative views about how their mobile devices affect their independence. On the positive side, mobile devices increased independence and safety. One participant referred to her mobile phone as a "security blanket." Another participant, who was blind, believed that his use of a mobile phone significantly increased his independence:

> It's a whole different world for a blind person. A cell phone is not a necessity at this point in society, but for a blind person it really is. Because for safety alone, it gives you more options. You don't have to worry about being completely stranded out there.

However, this increased independence from other people could also create dependence on the mobile devices themselves. If a mobile device failed, the user could be stranded. When asked what might happen if she lost her phone, one participant said:

> I wouldn't have my calendar or any way to call people when I was out, so I wouldn't travel as much. I wouldn't have entertainment when I was on the road, I wouldn't be able to text... It would not be good.

4.6 Desired Features

We asked participants about how their mobile devices could be improved to better support their needs. As expected, participants requested a variety of features. Many of the features requested by participants were available on other mobile devices, but were too expensive. Table 2 contains the features in which the participants were most interested. Less-frequently requested features included automatic volume and brightness adjustment, touch screens, a barcode reader, a currency recognizer, and facial recognition, each requested by only one participant.

Table 2. Most commonly requested device features.

Feature	# Participants
Screen reader	9
Voice input	8
Large buttons	7
Screen magnification	6
Smaller device	5
Optical character recognition	3
Improved screen contrast	3
Backlit keys	2
Music player	2
User-installable applications	2

We also asked participants about the types of additional information that they would like to access from their mobile devices. Participants were most interested in accessing information about local resources, such as restaurants and landmarks, and information about accessible routes in their area.

5. IMPLICATIONS FOR DESIGN

Although this study has focused largely on existing uses of mobile devices, our findings provide insight for the design of future accessible mobile devices. In addition to our participants' feature requests, we have identified additional opportunities for increasing the overall accessibility of mobile devices.

5.1 Access Methods on Commodity Devices

Many of the participants in our study used mass-market mobile devices, either in addition to or instead of devices designed for people with disabilities. Therefore, increasing the accessibility of existing mobile device hardware platforms using software should remain a high priority. While many of the current entry-level devices do not permit user-installable software, we expect that entry-level mobile devices will allow this feature in the future. Even now, many personal digital assistants (PDAs) and other portable devices allow for user-installable applications, and can connect to wireless networks without a monthly service fee.

5.2 Increased Configurability

While all of our participants used devices with some adjustable settings, the allowable ranges for these settings were often limited. For example, some devices allowed users to increase the text size, but only to a certain point. Mobile devices should be designed to be configurable to arbitrary settings. Thus, for instance, text should be scalable to an arbitrary size, activating scrolling, zooming, or rapid serial visual presentation [30] as necessary. Although increased configurability can result in additional interface complexity, we found that our participants were willing to spend time configuring a device at home before using it, suggesting that some configuration can occur offline with the help of the user's PC or another more accessible device.

5.3 Contextual Adaptation

Many of our participants described experiences in which their devices became more difficult or impossible to use under certain environmental conditions. These environmental effects were not only detrimental to performance, but could make a device unusable or place the user in an unsafe situation. This problem could be addressed by using a mobile device's on-board sensors to detect a user's location and activity, and adapt the user interface to increase accessibility [9]. In particular, these interfaces should provide the ability to switch between different input and output methods, or should provide a "minimal attention" mode [20] for use in cases where maintaining situational awareness is important. Since situational impairments affect users of all abilities, mobile devices that can adapt to contextual effects can benefit all users.

5.4 Integrating Assistive Devices

In addition to their mobile devices, twelve of our interview participants carried single-use accessibility devices, such as magnifiers, water level sensors, and compasses. As mobile devices gain increased sensing capability, they present the opportunity to replicate many of these features on a single device. For example, a mobile device camera can be used to magnify text or identify colors in an image, while an integrated GPS can provide navigational support.

6. FUTURE WORK

This investigation illustrates how some people with visual and motor disabilities use mobile devices in their everyday lives. Naturally, the study was limited in both population size and scope. It would be beneficial to extend this investigation to include additional participants, and to increase the diversity of participants in terms of age, disability, technology use, and geographic region. Although we found the interview methods useful for this early-stage research on improving access, tools with a broader reach, such as surveys, may also be beneficial.

Another opportunity is to extend the diary study used here to additional participants. The diary study was useful in revealing additional mobile accessibility problems in the lives of our participants. However, all but one of the participants recorded diary entries at home, and not while out. When asked why they did not submit more diary entries while on the go, twelve participants stated that using the web or email from home was more accessible. Extending these methods, either by providing more accessible diary techniques, or by incorporating new methods such as experience sampling [5], would allow us to better observe accessibility issues in everyday life.

7. CONCLUSION

We have presented a qualitative two-method study of how people with visual and motor disabilities currently acquire, adapt, and use mobile devices. Confirming prior research, we found that users with visual and motor disabilities experience a variety of accessibility problems when using mobile devices. Our results show that many of these problems persist and, perhaps surprisingly, that people with disabilities continue to choose commodity phones, even when they are aware of specialized access options. Despite these barriers, our participants were capable of using their mobile devices for a variety of uses, and of

supporting their activities outside the home. Combining interview techniques with a diary study about mobile use has allowed us to gain an understanding of how people with visual and motor disabilities use mobile devices in their everyday lives.

It is clear that mobile devices present opportunities for people with disabilities to live more independently. While we have seen advances both in commercial accessible mobile devices and in the research community, accessibility barriers are likely to remain. By better understanding the everyday experiences of mobile device users, we can approach the difficult research goal of improving mobile device accessibility for all users on the go.

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