Addressing Physical Safety, Security, and Privacy for People with Visual Impairments

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ABSTRACT

People with visual impairments face a variety of obstacles in their daily lives. Recent work has identified specific *physical privacy* concerns of this population and explored how emerging technology, such as wearable devices, could help. In this study we investigated their *physical safety and security* concerns and behaviors by conducting interviews (N=19) with participants who have visual impairments in the greater San Francisco metropolitan area. Our participants' detailed accounts shed light on (1) the safety and security concerns of people with visual impairments in urban environments (such as feared and real instances of assault); (2) their behaviors for protecting physical safety (such as avoidance and mitigation strategies); and (3) refined design considerations for future assistive wearable devices that could enhance their awareness of surrounding threats.

1. INTRODUCTION

Maintaining privacy, security, and safety in both physical and online domains are major challenges that almost everyone faces. For certain populations, however, these challenges are especially acute. For example, people with visual impairments (ranging from complete blindness to an inability to read a book when wearing corrective lenses [45]) may not be able to perceive their surroundings as easily as sighted people and are thus less able to effectively monitor for potential privacy, security, and safety risks.

Recent work has begun to study the unique concerns of people with visual impairments. Most of this work has focused on privacy and security related to technology, especially in using online services [7, 33, 42]. Other recent work, like that of Ahmed *et al.* [2], has studied this population's privacy concerns in more general settings, including in the physical world (e.g., eavesdropping on conversations). As these concerns and risks are better understood, the next logical step is to develop assistive devices to help people address them, potentially using new technologies like wearable cameras and other sensors.

As a first step in this direction, we initially set out to study design considerations for potential assistive technologies by conducting interviews focusing on key privacy related scenarios identified by past work [2]. However, as we began our interviews, we were surprised to discover that a recurring major theme that nearly every participant mentioned was physical safety and security, whereas Ahmed *et al.*'s study revealed significant privacy concerns but little concern about physical safety and security. We believe this difference arose because our study significantly broadened the target population; while Ahmed *et al.* conducted their interviews in a small, relatively safe college town (Bloomington, IN with a crime index of 229.8 versus the U.S. average of 294.7),[1] ours was conducted in a major metropolitan area (greater San Francisco, with an average crime index of 497.9). Statistically, our participants are probably right to be concerned given that people with visual disabilities in the U.S. have a higher risk of victimization than the overall population (17.8 versus 14.0 per 1,000 as of 2013) [25].

In this paper, we report on this broader understanding of the safety, security, and privacy concerns of people with visual impairments in an urban context and report design considerations for assistive wearable technology for addressing them.[2] Our findings on physical privacy concerns and behaviors largely confirm previous studies, but they give new insight into the physical safety and security challenges of people with visual impairments. Our findings also shed new light on design considerations for potential technological solutions for all three types of challenges (safety, security, and privacy).

Specifically, we focus on the following three research questions:

R1: *What are the privacy, safety, and security concerns of people with visual impairments in urban environments?* In particular, we seek to identify concerns in contrast or in addition to those expressed in the study of the small college town.

R2: *How do people with visual impairments manage their privacy, safety, and security in urban environments?* We seek to understand the behaviors and coping mechanisms of people with visual impairments in this broader environment.

R3: *How could wearable cameras and sensors address privacy, safety, and security concerns of people with visual impairments?* We aim to identify more detailed design considerations than previous studies through more focused questions on several key scenarios.

[1] http://www.city-data.com/crime/

[2] In our context, we mean 'security' to refer not only to protecting information, but also to physical protection of personal property and spaces. We do not offer a precise definition of the difference between safety *vs.* security, but informally we mean 'physical safety' to refer more to protection from bodily harm (e.g., being assaulted), and 'physical security' to refer to protection from less violent harm (e.g., theft of one's smartphone or ATM passcode).

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To answer these questions, we conducted semi-structured interviews with a diverse group of people with visual impairments (N=19) living in the greater San Francisco metropolitan area, including people with a range of impairments and of different ages. Using scenarios from Ahmed *et al.*, our participants described significant physical safety and security *concerns* not reported earlier, e.g., in public transit, at automated teller machine (ATM) booths, and even in private spaces that sighted people may consider safe. We identified various coping *behaviors* that people with visual impairments currently use to address these concerns, such as avoidance, repositioning, and technology use. The interviews revealed several new and refined design *considerations* for assistive devices that could provide alternatives for addressing the behaviors. For instance, a majority of our participants described wanting to know about the presence and intentions of other people in their immediate physical vicinity, as well as an ability to collect forensic evidence (e.g., imagery to share with law enforcement) of a physical assault.

2. BACKGROUND

Before describing work related to our study, we begin by introducing background related to visual impairments in general, including key terminology and a brief overview of existing assistive devices.

2.1 Key Terminology

The estimated 285 million people living with visual impairments worldwide experience a variety of difficulties with their sense of sight [46]. Clinically, 'visual impairment' is defined as a "visual acuity of 20/70 or worse in the better eye with best correction, or a total field loss of 140 degrees" [4]. 'Severe visual impairment' usually implies a corrected visually acuity of 20/200 or worse. 'Low vision' is sight "that may be severe enough to hinder an individual's ability to complete daily activities such as reading, cooking, or walking outside safely, while still retaining some degree of usable vision" [4]. Finally, 'total blindness' describes a person's inability to see anything with either eye.

Visual impairments also come in a variety of forms. The most common causes of visual impairment stem from the inability to correct refractive issues (43% of cases) and diseases including cataracts (33%) and glaucoma (2%) [46]. Other cases are caused by accidents, other diseases, or a reduction in vision or vision processing such as the loss of central vision, peripheral vision, contrast sensitivity, or depth perception [3]. Only about 15% of people with visual impairments are totally blind, while the majority (65%) of people are over age 65 and live in developing countries (90%) [46].

2.2 Current Assistive Technology

There are many assistive technologies currently available to aid people with visual impairments in their daily activities. Hersh and Johnson [27] provide a comprehensive discussion of these technologies, e.g., for tasks such as personal care (e.g., Braille labels for clothing[3]), reading (e.g., with video magnifiers [5]), navigation (e.g., Miniguide[4]), financial management (e.g., Note Teller[5] for currency detection), healthcare monitoring (e.g., talking bathroom scales[6]), and food preparation (e.g., talking microwave ovens[7]).

Smartphones and PCs are popular with people with visual impairments [37] in part because they have helped them achieve greater independence [14], but they introduce their own challenges since modern visual mouse and touch based user interfaces are often not accessible to people with visual impairments. Blind people generally use audio screen reading software, such as JAWS (Job Access with Speech),[8] Window-Eyes,[9] and VoiceOver,[10] all of which generate synthesized speech to relay information from the screen. People with low vision often use screen magnifying software, such as ZoomText[11] and MAGic,[12] to enlarge a part of the screen to make it more readable. Some people use refreshable Braille displays, although the use of this technology is becoming less common because the number of people who read Braille is decreasing [44] (e.g., only 10% of blind children are learning Braille [43]).

The ubiquity of smartphones and other portable computing devices has motivated research into more advanced assistive devices that can better help people sense their environment for tasks such as identifying and finding objects [8], taking photographs [24, 31], and navigating new spaces [16] and transportation networks [6, 13]. Although some of this work has explored using automated computer vision techniques, other projects such as VizWiz [8] and GoBraille [6] leverage crowdsourcing where remote users view photos taken by people with visual impairments and help identify content in the scene. Crowdsourcing has also been applied to let people with visual impairments take photos and share them on social media [53, 55]. Recently, assistive technology research has shifted towards wearable devices [22, 51] as wearable cameras are becoming more affordable and practical in the form of Google Glass,[13] Orcam,[14] and Narrative Clip[15] [56, 58].

3. RELATED WORK

We now summarize research work related to ours, specifically in better understanding the concerns, coping behaviors, and potential solutions for the security, safety, and privacy of people with visual impairments.

3.1 Privacy, Security, and Safety Concerns

While certain types of concerns like online security have been studied extensively, the physical safety and security concerns of people with visual impairments has not yet been adequately researched. Shinohara and Wobbrock [52] study how assistive devices may attract unwanted attention from friends and colleagues, possibly making users even more conspicuous to potential attackers. Azenkot *et al.* [6] report on the safety concerns of blind and deaf participants in unfamiliar locations in the context of designing a navigational tool. Cassidy *et al.* [15] design a haptic feedback mechanism for using ATMs in order to make assistive devices less obvious to potential attackers. Ahmed *et al.* [2] focus on the privacy concerns of people with visual impairments but also mention safety to the extent that feeling "safe from intrusion" in the home is an important aspect of privacy. Our work focuses on better understanding physical safety and security concerns, and adds significantly to this existing body of knowledge.

Recent work has also addressed the privacy and security concerns of people with visual impairments in the context of electronic device use [7, 20, 33, 42, 56], but again, it has not focused on security and safety in the physical world. Ahmed *et al.* [2] report on privacy

[3] www.labelsp.com/braille
[4] www.gdp-research.com.au
[5] www.brytech.com/noteteller/
[6] www.maxiaids.com/talking-bathroom-scale
[7] www.maxiaids.com/talking-microwave-oven
[8] www.freedomscientific.com/JAWS
[9] www.gwmicro.com/window-eyes/
[10] www.apple.com/accessibility/osx/voiceover/
[11] www.zoomtext.com
[12] www.freedomscientific.com/MAGic
[13] www.google.com/glass/start/
[14] www.orcam.com
[15] getnarrative.com

concerns expressed by people with visual impairments in both the virtual and physical worlds, but their study did not reveal significant concerns related to physical safety and security, which we believe to be an artifact of the fact that their participants all lived in a small, safe college town. In our work, we confirm their findings related to privacy and shed new light on physical safety and security issues, which our urban participants identified as their key concerns.

3.2 Coping Mechanisms

Caine [9] reports three categories of privacy behaviors across technology and age groups including 'avoidance', 'modification', and 'alleviatory'. Our study found evidence of these among our population in addressing not only privacy but also security and safety concerns. We found the 'avoidance' and 'modification' behaviors to be especially prominent, but our study also identifies several additional behaviors, such as 'adaptation' and 'acceptance', that occur specifically because of our participants' visual impairments (see Section 6). In addition, we further categorize the modification coping behaviors ('repositioning', 'mitigation', and 'human assistance') because of their prevalence and importance with a visually impaired population. We did not find any current coping behaviors that would fall under Caine's 'alleviatory' classification. This is likely due to our participants' inability to know if they had been victims of certain behaviors (eavesdropping) and inability to easily identify perpetrators of other crimes (assault).

Both Ahmed *et al.* [2] and Azenkot *et al.* [7] discuss strategies used by people with visual impairments to protect themselves from other people eavesdropping on their devices, including using headphones and screen occlusion software. We report similar defensive strategies but go beyond behaviors related to eavesdropping and report the coping strategies that people with visual impairments use to address privacy, security, and safety concerns.

3.3 Proposed Solutions

Several researchers have addressed the safety concerns of people with visual impairments in the context of navigation and transportation, especially through using mobile and wearable devices. Both Azenkot *et al.* [6] and Campbell *et al.* [13] introduce mobile device applications that provide information about buses and bus stops. Some researchers have addressed the navigational concerns of people with visual impairments through tools that can detect obstacles [18], help cane users with a wearable camera [22], and provide haptic feedback through a wristband [56] among others [17, 32]. We explore these safety concerns as well as others beyond navigational and transportation safety, although our work may also shed light on the design of such devices in the context of physical safety.

Other related work has explored using cameras to help people better monitor their surroundings. Wang *et al.* [54] consider how to alert sighted people who may be distracted by their mobile phones of potentially dangerous situations (e.g., while crossing the street). Abboud *et al.* [1] use sensory substitution device (SSD) cameras in their 'EyeMusic' prototype to convey an image in the form of music. Our work is complementary, and our findings could inform the future design of these devices.

4. METHOD

We interviewed visually impaired participants in an urban setting to investigate their physical safety and security concerns and behaviors, and to understand considerations for addressing their concerns through wearable technologies. The interviews were semi-structured and conducted either in person or by phone, and were conducted individually except when two participants were living with each other and consented to a joint interview (more information is provided in Section 4.3). We included both participants in the same interview in these cases because they were often able to improve their partner's recall of concerns and experiences. Participants were allowed to choose the location of the interview, including the option to be interviewed over the phone.

4.1 Interview Protocol

Our interviews consisted of two parts. First, we presented three hypothetical scenarios derived from the findings in Ahmed *et al.* [2] (in which a person with a visual impairment may experience security and privacy concerns because of people around them). We then introduced potential technological solutions to gather participant feedback and to inform future design choices.

Privacy and Safety Scenarios

We framed our interview discussion around three scenarios related to physical safety, security, and privacy [2]: (1) sharing health history at a doctor's office, (2) reading email in a public place, and (3) typing a password into a computing device or a PIN into an ATM. During the first several interviews, participants reported much greater concern about entering ATM PINs than about entering passwords on a personal computer and, in particular, on the safety aspects of ATM use (e.g., physical assault while withdrawing cash). We therefore tailored the third scenario to consider only ATMs in subsequent interviews in order to obtain more insight into physical safety concerns.

For some interviews, we skipped one or more scenarios depending on the specific impairment of our participants. For example, one participant was able to see nearby people, so we skipped the ATM scenario in her case. Some participants mentioned that they kept their computer screens off during use, so we did not ask them any further questions for the reading email scenario.

Deriving Design Considerations

We next interviewed participants about potential technological solutions to address their concerns. Ahmed *et al.* [2] presented several technology ideas that may possibly address the privacy concerns of people with visual impairments but discussed that we need further research to understand their requirements. Our goal here was to better understand the design considerations for such technologies. We specifically focused on camera based and wearable devices since progress in lightweight, low-cost mobile technology and computer vision has shown promising potential to assist people with visual impairments [2, 56]. Of course, any real-world devices will have to strike a trade-off between various factors, including accuracy, utility, cost, convenience, weight, and so on. We give additional insight into the preferences and behaviors of our participants, which we aggregate into design considerations, and which may form the input into an eventual functional analysis for more formal design requirements.

Our interviews first discussed the use of cameras to analyze the surroundings and help assess the environment for people with visual impairments. We then asked participants: (1) how such a system might help them; (2) how they would prefer such a system to relay feedback to them; (3) what information about the surroundings they would like to receive; and (4) what devices (e.g., wearable first-person cameras or stationary third-person cameras) would be most suitable. For participants unfamiliar with the concept, we gave a brief introduction to wearable camera technology.

We purposely adapted our interview questions when a participant indicated a strong desire for an assistive device that could enhance their safety. When this occurred, our follow-up questions sought to better understand their safety concerns and how assistive devices might be useful.

4.2 Study Procedure

Recruitment and Enrollment
To recruit participants, we contacted various organizations for people with visual impairments and asked them to distribute our recruitment email to their members and other organizations. Our recruitment process ran from February through August, 2015, although most of the interviews were conducted in July and August, 2015. We also used snowball sampling, by asking our participants to notify others about our study.

Ethical Considerations
Indiana University's institutional review board (IRB) approved our study. To obtain informed consent, we provided our information sheet via email so that participants could use accessibility tools to read the study sheet; we read the information aloud if needed. Participants could skip any question, and we recorded interviews only after obtaining verbal or written consent.

Compensation
In-person participants received $15 in cash (interviews lasted at most 100 minutes), and those participating over the phone received a $15 Amazon.com eGift Card.

4.3 Participants

During the six-month study period, we interviewed a total of 19 participants, including 11 in person and eight over the phone. Table 1 summarizes their demographic information. We categorized our participants into three groups based on the nature of their impairment and their personal history. Congenitally blind participants are denoted by 'T', congenitally low-vision participants are denoted by 'L', and late visually impaired participants are denoted by 'X'. The group included nine men and 10 women and a diverse age range from 18-to-65. A majority of our participants lived in either the greater San Francisco or greater Los Angeles metropolitan areas. Four participants were from small cities of relatively equal crime rates (Sonoma and Santa Rosa, California and Bloomington, Indiana). Our participants included two couples (one of which was married) of which both partners were visually impaired; these participants chose to have their interviews jointly. The interviews lasted between 25 and 100 minutes with most lasting about 35 minutes. In-person participants (N=11) chose where to be interviewed with most (N=6) choosing a public place. Others picked their home (N=3) or office (N=2).

4.4 Analysis Approach

All but one of the interviews were conducted by a single researcher (the other was conducted by a second researcher). The interviews were audio-recorded and transcribed. The transcribed interviews were later analyzed and coded using an iterative coding procedure with open coding where two researchers separately developed a list of concepts based on the interview transcripts [48, 49]. Later they created a codebook by combining the lists of concepts, and re-coded one interview. As the agreement (Cohen's κ=0.38) was not satisfactory on that interview, they again discussed and refined the codes. When agreement reached a satisfactory level (κ=0.79 with SD=0.04) on five re-coded interviews, the researchers divided the rest of the transcripts into two sets and re-coded the interviews based on the refined codebook. The final codebook had seven groups of concepts: 'Safety Concerns', 'Privacy Concerns', 'Feelings', 'Coping Behavior', 'Design Attributes', 'Desired Information', and 'Feedback Preference'.

5. FINDINGS: CONCERNS

In this section, we discuss our findings related to *concerns* of people with visual impairments. In Section 6 we report on their *coping behaviors* before discussing the *design considerations* revealed by our study in Section 7.

As mentioned above, we were surprised to find that physical safety and security were recurring themes of our interviews despite rarely arising in Ahmed *et al.*'s study. We attribute this difference to the fact that their study was conducted in a small, safe town, whereas ours was conducted in a major metropolitan area. We thus begin by describing these new findings related to physical safety and security concerns. We also more briefly discuss our findings related to physical privacy concerns, which largely mirror the findings of past studies, in Section 5.2.

5.1 Physical Safety and Security Concerns

Fifteen participants described at least one scenario in which they were concerned about their safety or security, and eight of these described more than one such scenario. In this section we report on these personal safety and security scenarios, which fell into four main groups: on the street, in public transit, in ATM booths, and in private spaces.

On the Street
Although safety on the street is a universal concern, people with visual impairments are at particular risk because they cannot fully assess their surroundings and cannot always recognize (un)safe situations. Moreover, in the case of an encounter such as assault or theft, they cannot describe the visual characteristics of their assailant to police officers, making them particularly attractive targets. Several of our participants expressed such concerns during our interviews.

One participant (T2) expressed heightened concerns about being followed at night, whereas another (T7) expressed a general sense of helplessness about not being able to assess the safety of her environment:

> *When I go for walks, I have been followed. And so basically because of how society is today, I don't go for walks with my guide dog because I don't know who is around me and I think that is much more debilitating for me than anything that we have discussed. Not knowing my environment, not knowing who is around me and if something happened to me I would not be able to tell anyone.* *(T7)*

Some participants described actual scenarios where such fears were realized. One participant (X6) shared a story about an attacker who tried to steal his guitar after a chase that lasted over five minutes. Another (X1) had been a victim of theft only a few days before the interview. Another participant relayed a story about not being able to flee from an unsafe situation:

> *I was across the street from a shooting once. So, I heard the shots — everybody sort of freaked out, of course. And I looked up and went "those weren't firecrackers, right?"*

ID	Sex	Age Group	Impairment type	History	Technology Usage	Interview Method	Participant's Location	Crime Index[†]
T1	F	24–30	Totally Blind	Since Birth	iPhone	In person	Oakland, CA	970.6
T2	F	24–30	Blind in one eye, light perception in other	Since Birth	iPhone, Laptop	Phone	San Pablo, CA	426.7
T3	F	30–35	Totally Blind	Since Birth	Windows Phone, Regular and Braille Laptop	Phone	Santa Rosa, CA	193.4
T4	F	30–35	Totally Blind	Since Birth	iPhone, Portable Braille Computer	Phone	Santa Rosa, CA	193.4
T5	F	35–40	Blind with Light perception	Since Birth	iPhone, Laptop	In Person	San Leandro, CA	405.0
T6	F	40–50	Totally Blind	Since Birth	Android	In person	Oakland,CA	970.6
T7	F	50–65	Totally Blind	Since Birth	iPhone	Phone	San Bernardino,CA	554.0
T8	F	50–65	Blind with Light perception, can see shapes	Since Birth	Regular phone, Laptop	In person	Berkeley, CA	387.9
L1	F	18–24	Low Vision	Since Birth	iPhone, Laptop	In person	Bloomington, IN[‡]	229.8
L2	M	18–24	Low Vision	Since Birth	iPhone, Laptop	In person	Berkeley, CA	387.9
L3	M	30–35	Low Vision	Since Birth	iPhone, Laptop	In person	Oakland, CA	970.6
L4	M	50–65	Low Vision	Since Birth	Smartphone, laptop	Phone	San Leandro, CA	405.0
L5	M	50–65	Low Vision	Since Birth	Regular phone, iPad, Laptop	Phone	San Bernardino, CA	554.0
X1	M	24–30	Low Vision	Last 5 years	iPhone, Laptop	In person	Oakland, CA	970.6
X2	M	30–35	Totally Blind	Last 11 years	iPhone, iPad, Macbook	In person	San Leandro,CA	405.0
X3	F	30–35	Totally Blind	Last 7 years	Android Smartphone, Tablet, Laptop	In person	El Cerrito, CA	377.3
X4	M	40–50	Blind in one eye, low vision in other	Last 3 years	Android Smartphone, Laptop	In person	El Cerrito, CA	377.3
X5	M	40–50	Blind with Light perception, can see shapes	Since childhood	Android Smartphone, Laptop	Phone	San Francisco, CA	487.9
X6	M	50–65	Totally Blind	Since 1963	iPhone	Phone	Sonoma, CA	192.9

[†]2013 city-data.com crime index (Higher means more crime, U.S. average=294.7)

[‡]This was the first study interview, conducted in the researchers' home city.

Table 1: Demographic information for our study participants. ID Key: T-congenitally blind; L-low vision; X-late visually impaired

> *And everybody is so freaked out they can't talk to me... I am standing on the corner and trying to figure out: What's going on?* (T6)

Public Transit

Most of our participants were heavily dependent on public transport, which gave rise to several safety concerns. One participant expressed concern about waiting for public transit for extended periods of time:

> *What I would like to see is more public transportation run more frequently because when you have public transportation running more frequently you are not standing out there waiting a long time period for help. Because when the bus comes nobody wants to mess around. They want to catch the bus. But if you are standing outside for a half hour to 45 minutes waiting for a bus, a lot of things can happen.* (L5)

Another participant had experienced suspicious activity while waiting for a van:

> *I was in a waiting spot to get a paratransit van, and somebody came into this area. I thought there was someone there but I wasn't sure, and then someone else came up and said: "Did he do anything?" And I was like "What?!" And so I was right and there was someone there.* (T7)

Another participant expressed similar concerns with handling money at transit stations:

> *Another big one that you need to consider especially in big cities: I am standing at a bus stop and I am about to pull out my wallet to get my bus fare ready. Is it safe to do that? Because there might be no one around and it might be okay or there might be 5 or 10 other people around and the minute you pull out your wallet they are going to pounce... I think that is a big, big one you cannot leave out. It is so important.* (T4)

ATM Booths

Although accessible ATMs enable people with visual impairments to perform banking more easily, the overt nature of using an ATM puts them at risk. This concern was expressed by a majority (N=10) of our participants. Some of them also expressed similar concerns for point-of-sale transactions where PINs must be entered and can be observed by others. One participant emphasized this threat when asked about shoulder surfing in the context of laptops, saying that theft of ATM PINs was a greater concern:

> *When I am at an ATM, like I am entering my PIN, those numbers are huge so I am wondering how to mitigate that somehow. Or if I am like at the cash register and I am buying groceries, because that is more of me putting information out in a public place. For me that is more of a concern — going*

to an ATM, person behind me, going to a grocery store and entering my PIN in. *(X1)*

Another participant highlighted the fact that many people with visual impairments cannot drive and cannot use drive-up ATMs that offer more security than the walk-up stations on the street:

I don't think it is safe to use ATM. We walk, so I can't get into a car. If I use an ATM to get $ 20, I could walk down the street and get mugged. So why should I go to an ATM showing everybody that I am getting money or if I am making a deposit? *(L5)*

As Cassidy *et al.* [15] reported, although headphone jacks are available at many ATMs to try to enhance privacy, using headphones can actually put people with visual impairments at greater risk by muffling their hearing and further impairing their ability to sense the surroundings [23, 39, 35]. T7 noted this issue, reporting that they need to be so engaged in the transactions that they tend to lose their focus on the surroundings.

Private Spaces

As noted by Ahmed *et al.* [2] in the context of privacy, people with visual impairments can have heightened safety and security concerns in enclosed spaces, including even in their own homes and offices. The main concern expressed during the interviews was an inability to identify others entering their personal space. At home, the safety risk can be reduced by installing home security systems, but these systems trade off security for convenience, as described by one participant:

I want to know who is coming up to my front door. I hate not knowing that because I feel very vulnerable when people knock at my door at home. We have a home security system on at night but we don't have it on, you know, all the time. That would be horrible to have to unset it to go out and in. We have motion detectors but that hasn't been very optimal either, and I would just like to be warned when somebody is coming up to my porch. *(T7)*

Although office spaces tend to be safer because of better security and the presence of coworkers, people with visual impairments cannot always rely on their coworkers to announce their presence:

There was one time when I was at my office and there was someone walking around. I assumed it was somebody that needed to be there, but the person refused to identify themselves. And they were kind like of creeping around in the middle of the night and stuff. And I think I knew who it was but they wouldn't tell me and it was kinda creepy. *(T5)*

Participants mentioned similar concerns arising in other enclosed spaces, including hotel lobbies (T1) and libraries (L1, L2).

5.2 Physical Privacy Concerns

Both Ahmed *et al.* [2] and Azenkot *et al.* [7] reported 'eavesdropping' and 'shoulder surfing' as concerns of people with visual impairments. To further explore these concerns and in order to inform the design of defensive technologies, we gave our participants the above-mentioned three scenarios in which eavesdropping and shoulder surfing concerns may arise. Our findings mostly confirm what was found by Ahmed *et al.* [2], so we provide only a brief summary here.

Eavesdropping Concerns

Ten of our participants reported that they would feel uncomfortable verbally sharing their health history with a staff member in the waiting room of a medical facility out of concern that others in the waiting room may overhear the information. Fourteen of our participants said that they had experienced similar situations. Two other participants mentioned that generally they do not feel uncomfortable in these situations, but it depended on the type of information requested, and that sharing Social Security or bank account numbers would make them feel uncomfortable. Two participants said that they felt embarrassed when they had to share their weight. As one participant put it:

It's not that I have anything to hide but I don't really want everybody in the waiting room thinking 'Oh she has this, or she has that.' It's nobody's business. *(T6)*

Participants also reported similar concerns while filling out forms at the bank (X4, T8), sharing personal information in an office (T3), having personal conversations with others (X4), or having to share their PIN when needing assistance at an ATM (X4).

Shoulder-Surfing Concerns

In response to our second and third scenarios, most participants (N=13) reported that they have shoulder-surfing concerns while using an ATM, and six reported concerns when using their laptops in public places. Two participants indicated that they are uncomfortable when they send text messages on their smartphones. One participant was a victim of shoulder surfing where her confidential information was stolen by one of her coworkers:

I was at work doing [sic] receptionist, sitting down, and a gentleman, a coworker, stood behind me reading my information and I was on the Internet at the time researching information about the company. And he stands behind me and reads off what I was researching on for the company, which was confidential... I felt a little embarrassed and then I had to talk to my manager about it because he took everything that he saw and basically ran with it and got credit for it and I didn't. *(X3)*

T7 expressed her concern about shoulder surfing as she has to deal with other people's medical information, and other people are put at risk by her lack of awareness of the actions of people around her. These concerns differed across people depending on their specific type of visual impairment; although people with total blindness may not need to turn their screens on, people with visual impairments often use the screen with text rendered in a large font, making them particularly vulnerable to shoulder surfing.

6. FINDINGS: COPING BEHAVIORS

Our participants reported various strategies to address their safety, security, and privacy concerns. We organized these strategies into seven different categories: 'avoidance', 'repositioning or relocation', 'mitigation', 'use of technology', 'help from an acquaintance', 'adaptation', and 'acceptance'.

Avoidance

Fifteen of our participants reported simply avoiding certain situations as a major coping mechanism. Examples of this behavior ranged from avoiding walking on the street when possible (T7), to avoiding the use of ATMs (L5), to sharing personal health information over the phone before a medical visit in order to avoid having to discuss it in the waiting room:

> *What I often do is that I tell doctor's staff before I even go into the office that I won't do things right in the waiting room. So, either we can do that over the phone so that there is a level of confidentiality that way or pull me into the examination room.* *(T6)*

A common strategy to avoid shoulder surfing as well as device theft was to not use devices outside of the home. Eight participants said that they try to avoid using their laptops outside of their home. One participant (X4) reported that he was advised not to use his phone outside his home to avoid theft, while Participant X6 turns off his devices (or features) to try to avoid using them excessively:

> *The way I address the concerns is just to refrain from using them. I tend to keep the WiFi disabled [on my iPhone], and I just listen to the music or let it be completely off, you know, where it is on standby mode or my laptop is turned off as I am carrying it around. It is in its container and it's off. And I only use them when I feel safe... When I have reservations about the safety of my behaviors, my default choice is just turn the device off. That way no one can have access to it. Because I am not even really using it.* *(X6)*

Relocation

Fourteen participants said they typically address their eavesdropping and shoulder-surfing concerns by changing their location. They indicated that if they could sense their environment, they might change their location as needed. One participant with low vision who is able to assess the environment usually moves to the corner of a room when sending text messages:

> *Usually I talk and then stop and go to a corner by myself and send it. Before doing magnification I usually sit somewhere or won't take [the text] right away – I will wait until I am by myself and at the same time put myself back-against-the-wall, so that I am holding my cell phone when I read the text, so that I can see everyone walking around.* *(L3)*

Repositioning was quite common in medical settings: 10 of the 19 participants reported that they had felt uncomfortable at the doctor's office and asked receptionists if they could move to a different room.

Mitigation

Fifteen participants mentioned various mitigation techniques to address safety, security, and privacy concerns. For the health information scenario, L2 reported trying to talk quickly so that only the receptionist could understand him, while some whisper or give their information in a softer voice (L3, T7, and T8), and others lean close to the counter (T1).

Our participants' most common defensive strategy to address shoulder surfing concerns at ATMs was to cover their hands so that others could not see their keypresses (T3, T6, and X5). One participant tries to confuse people who may be shoulder surfing:

> *With the phone password, sometimes I intentionally make mistakes so that my passwords are little bit secured. I will hit the keys, I will hit more keys, I will be hitting delete in rapid succession so that it's not easy to understand what the password was. I will be going back and forth between the actual password and use extra letters and numbers, and hitting delete quickly – eventually the password is put in but if it's a four character password, I actually typed 10 characters including the deletions.* *(X5)*

When asked how she addresses security concerns about her personal possessions, one participant shared her frustration in finding a solution for her phone, as a specific example:

> *I don't know what's safe and what is not. I don't know when it's safe to pull out my phone or not. I have been trying to figure out protocols so that I can kind of barely pull the speaker part of my phone out of my purse.* *(T6)*

Most of our participants addressed their shoulder surfing concerns either by turning off the screen or by lowering the laptop lid. However, some low-vision participants struggle with these defensive strategies, as they need to have bright lighting in order to see the keyboard and screen. A common solution for eavesdropping is to use headphones, although these have the disadvantage that they can interfere with the person's ability to monitor the environment. One participant (X2) reported using bone-conduction headphones, which allow him to continue listening to his surroundings as his ears are not obstructed by the headphones.

Help from Others

Ten participants said that they generally seek help from their acquaintances, especially for filling out paperwork (L1, X4), conducting transactions at ATMs (X6), or being aware of their surroundings (L2, L3). However, they reported some frustration on having to rely on friends' availability:

> *In our college campus, I was doing the financial aid information thing with a friend. We have to disclose like tax information or birth date or other information that's needed for financial aid. So, I was trying to discuss that information because someone was helping me fill out the information. We are like in the cafeteria type of setting. That was really uncomfortable trying to do that. That was the person's only time that they had to do that. And I pretty much didn't have a choice.* *(X4)*

Our interviews revealed that people with complete blindness are often helped by friends who themselves have low vision. Meanwhile, since blind people tend to have a better sense of hearing [23, 39, 35], the low-vision helpers sometimes rely on their blind friend. L3, who often helps guide his blind friend on the street, mentioned:

> *Since I have more friends who are totally blind, I usually am the one who is watching over everything else. A couple of*

times I had some scenarios with friends, I had friends who are totally blind, I am the one who is seeing them because I am guiding them. I am also the one who is usually watching around. Because they can hear, they have good hearing, before I see it they already heard it, but the majority of the time, I usually will be the eyes and they are also the ones who will be the ears. (L3)

Adaptation

Many participants reported developing strategies that use their sense of hearing to assess their environment. Six participants reported that they use their hearing or echo location to sense their surroundings. One participant described this as using his 'facial vision' to prevent shoulder surfing at ATMs and grocery store checkouts:

> *I will stop typing if anyone comes closer than three or four feet from me if I am in the grocery store. People tend to stand six or eight feet away from me, but if they approach close to me then I will stop my work and ask them what they are doing. I can tell that because they start to bump into me. I have like a territorial bubble around me and I hear people's footsteps and I hear the activities that are going on behind me. If anyone's presence is near then they are blocking the sound that I can hear from behind them. It's my 'facial vision,' they call it, when I hear the echoes. The person's presence blocks the ambient noise.* (X6)

Others also described similar types of hearing senses. L3 said that he always tries to feel the situation and if he does not feel it is right to perform some activity, then he does not do it. Both T3 and T6 reported that they can "always" tell what others are doing based on the sounds people make.

Acceptance

Participants reported sometimes feeling that a situation was outside of their control and they had very little choice other than to accept the risks. Nine participants indicated such acceptance, for example, having no other choice than to get help from others:

> *Whenever we have difficulties we have to call someone in and that invades our privacy. We can't read my mail, don't even know who it is from. Most of the time [automatic scanning] doesn't work. Most of the time if you are trying to read bills, scan doesn't work. It works fine for block text, but if you are trying to read tables or anything like that so you are reading any of your personal material or bills, then no. So our privacy... we don't have any privacy.* (T7)

Three participants expressed how they have come to accept their lack of privacy and have to always assume they are being eavesdropped upon. For example, one participant said:

> *I guess over my lifetime I have developed an assumption that someone is there. I kind of say to myself, "if I walk out my front door someone can hear me."* (T6)

Those who feel uncomfortable sharing their health history in a waiting room sometimes have to do so unwillingly. One participant (X5) said that he had to do so in the interest of time.

7. FINDINGS: CONSIDERATIONS FOR DESIGN OF ASSISTIVE DEVICES

As the above findings show, people with visual impairments face considerable challenges in maintaining their physical safety, security, and privacy in everyday life, and they cope with these challenges in a variety of ways. Although some of these coping behaviors are effective and do not affect the quality of life, others (like avoidance and acceptance) either continue to put people at risk, or prevent people from realizing the same opportunities that fully-sighted people can enjoy.

Given these findings, a logical next step is to identify potential technological solutions that could help people with visual impairments better manage their physical safety, security, and privacy in various settings. Mobile or wearable devices could use cameras and other sensors to help perceive the environment around the user and then report information about potential threats nearby. Of course, before trying to design or implement such a system, we need to understand the preferences and requirements of people with visual impairments. To do this we asked our participants for feedback about what they would like to see in such devices, including what capabilities would be most important to them, what types of devices they would prefer, and what the important design considerations would be. We first report on the types of information people would like from such devices, and then on the important design considerations for these devices.

7.1 Desired Information

A key goal of our study was to identify what type of information people would like from an assistive device in order to enhance personal safety, security, and privacy. Our interviews uncovered that most participants were interested in answers to a small set of questions:

How Many People are in my Vicinity?

Most participants (N=14) thought it would be useful to know how many people were nearby, as this information would help them assess their security and privacy and act accordingly. Although one participant (L4) already uses his hearing (adaptation) to infer the number of people around him, he indicated that higher quality information would help him better identify any suspicious activity. Two participants (X3 and X4) added that this information would help with navigation in general.

How Close are People to me?

Most participants (N=13) also wanted information about how close people in their vicinity were to them in order to better assess their surroundings. Several participants used the term "bubble" to mark the territory of their private space and a desire to know when people enter this bubble. The radius of the bubble varied between participants, e.g., 5–10 feet (T4), 5–15 feet (T1), 6 feet (X6), and 10 feet (L3). The size of the bubble depended on the situation, e.g., in public places the bubble was smaller than in private places, while X2 and T6 reported that they wanted to know in general if other people were within earshot.

Who is in my Vicinity?

Almost all participants (N=18) said it would be useful to know if any friends or acquaintances were nearby. This information could help them address their privacy concerns in private spaces or at an ATM by relying on trusted individuals. One participant (L2) specifically wanted to know this information to prevent shoulder surfing by specific people. Another participant (L4) said this information could help him in the office to differentiate between strangers and trusted coworkers. T7 reported wanting to know the general properties of a person, like their age, gender, and other visual characteristics.

What are the People in my Vicinity Doing?

Most participants (N=16) mentioned a desire to know what others around them are doing, and especially if anyone is paying attention to them or looking at them. For example, T1 wanted to know if people are being "nosy" and looking at her. X1 mentioned wanting to know if people are holding up a camera to capture or record his ATM interactions, while T5 wanted to know if someone was trying to hear her personal conversations. One participant suggested a way to provide this information:

> *Maybe a lot of people aren't paying attention to me at all. The device could say that you have a person two feet away from you watching TV or texting on their cell phone.* *(T4)*

Knowing what others are doing can be useful at the bus stop, in the doctor's office, or in public places. One participant (X3) reported that having this information would also help her maintain the privacy of other people, since she could avoid disturbing someone who was busy or engaged in a private activity.

Six participants mentioned that they would like information to help them infer people's *intentions*, since knowing their intentions would help address nearly all of the concerns that were reported by our participants. T3 wanted to know if someone is about to reach toward him, e.g., trying to touch him or trying to steal from him. L2 would like to know if someone is trying to read his texts, and if so, whether they seemed to be doing so on purpose or incidentally (e.g., out of boredom).

Forensic Capture: Who was Around me?

The interviews revealed an interesting application of cameras that we did not anticipate: four of the participants indicated a desire to record and preserve a video record of their interactions with other people in order to have evidence when their safety or others' safety was compromised. For example, one participant shared a recent incident on a train where this record would have been helpful:

> *I witnessed a scuffle. I witnessed at least a couple guys beating up a third guy. I went to my house, and I called 911 and said that I heard this. I described it as best I could, but I could not – they want visuals. If I would have a camera on me anyway, I would want control of that camera. If I could just get off the train and I would like to give my phone to the station master and say that here is my camera you can have it.* *(T6)*

This forensics capability identified in our interviews was always mentioned in the context of the visually impaired person's safety. One participant indicated a potential use of their body camera to witness potential tampering with her items when she is separated from them:

> *Every time I go through security I have to take my shoes off and put my computer in like separate bins. It would be helpful to have a camera like that is looking out for me to see, especially looking out for my [belongings] going through the security checkpoint.* *(T7)*

Finally, one participant had a novel idea regarding the use of cameras and enhancing their personal safety, expressing the desire to know *where* cameras are located:

> *I would like to know as a blind person, when other cameras are about. There are cameras on [public transit], at bus stops, and intersections. I would like to know where those cameras are because, for example, if I thought I was in kind of an icky neighborhood and I need to make a phone call or do something on my phone, if I know there is a camera up ahead at the corner, I would do whatever I did by the camera so that a cop could – if I was robbed – have a chance of figuring out who that person was. I will use those cameras as my friend.* *(X2)*

7.2 Design Considerations

During our interviews we presented participants with several scenarios that involved the use of camera technology to give them better awareness of their surroundings. They reflected on the technologies, interpreted how they could be used in their everyday lives, and often offered further suggestions and refinements. We performed a bottom-up coding of their responses, which resulted in three categories of design attributes they used to describe these technology preferences: 'Discreet', 'Wearable', and 'Forensic Considerations'. Our identification of these three categories provides some insight into design preferences for a potential system, but we note that this is just a starting point; more rigorous future work is required (including functional decomposition, requirements analysis, and prototyping) to derive formal design requirements.

Discreet

As Shinohara and Wobbrock reported, people with visual impairments do not want to be marked as different, so they prefer less noticeable assistive devices and are particularly sensitive about others' reactions towards them [52]. Similarly, most of our participants (N=12) mentioned they would prefer something discreet as they do not want to look "weird" (L1, L2, X1, T5, T7) or draw attention to themselves (T4, T6). Often the discreet and wearable design considerations were brought up together:

> *I like the idea of having something on your clothes because it is less noticeable... because people will start to wonder why is he wearing this weird eyeglass thing. If you want to do stuff low key, then you do it that way.* *(L2)*

Although many participants imagined a subtle and discreet device to avoid embarrassment, one particular user equated discretion with safety and security:

> *Clip on camera, something I could clip on my glasses or clip on to my cap or collar. Not too visible because it would make me an easy target to someone who might want to steal my camera. They might try to get my camera and knock me over. (X4)*

In order to maintain discretion, many of the participants expressed a desire for subtle feedback from the system:

It would need to be something that is not obvious to sighted people, like an app that would vibrate and not let a sighted person know of the alert. It would be very helpful if the notification was discreet. (T4)

Wearable

Most participants were already familiar with the concept of head-mounted wearable cameras (e.g., Google Glass and Orcam), and we also gave a brief introduction to wearable devices to further familiarize them with the concept. Most of our participants (N=16) indicated a preference for wearable cameras over other types of devices for a variety of reasons: wearable devices are small and less noticeable (L2, T4, L3), they are more convenient as they do not require deliberate pointing like a smartphone camera (T3), and may require less time to activate compared to other mobile devices (L4). One participant (X2) suggested that the camera could be wearable as an earring and another (L5) suggested a lapel pin which could be attached to coats, shirts, or hats, similar to a broach.

Participants had mixed feelings about head-mounted wearable cameras. Some preferred them since they could be worn like sunglasses (X2) and would not affect their natural movement (T8). But most participants felt that these cameras would be more noticeable than other wearable cameras, and would prefer the more discreet devices.

Forensic Considerations

Some participants gave us specific design considerations about forensic capture, such as maintaining their own control of the camera in order to preserve documentation of an extreme situation (such as assault). In particular, one participant told us:

I'd like the notification tone and at that point, maybe when it gives that tone, start taking 30- or 15-second interval pictures of who is around. When the police do decide to help, they ask "oh well you didn't see them," we can't describe them. We'd have these pictures in every five, ten, fifteen or thirty seconds intervals of who is around at that point. (T5)

By mentioning control of the camera, T5 differentiated the camera state from its normal operating mode supporting privacy awareness as posed by the interview questions. Indeed, the other participants who mentioned a forensics capability also desired a way to explicitly change the camera operating mode, either by a specific request from the user or automatically based on a policy specified by the user ahead of time (e.g., in certain predefined scenarios).

8. DISCUSSION

Our interviews yielded new information about visually impaired people's concerns and behaviors regarding physical safety and security, and confirmed past findings about physical privacy. In addition, the interviews explored their thoughts, perceptions, and preferences toward design concepts involving wearable cameras to enhance physical safety, security, and privacy. These findings represent a first step toward designing new assistive devices, and could provide useful input into future formal requirement processes including functional analysis. We term them "considerations" as they should be considered as user feedback much like use-case feedback available during the design process. Although these considerations are not complete, our study group identified them as major themes that could positively influence any potential design. Of course, as with the design of any new technology, there will be competing requirements, including practical limitations on device size, power usage, and cost, and some of the design considerations expressed by our participants conflict with one another (e.g., discreet but with the capability to accurately sense the whole environment). Nevertheless, our study is a starting point for future, more rigorous design processes.

Safety and Privacy Bubble

Although all people share some concern about their private space, our target population of people with visual impairments were clear that their concerns extended beyond their immediate space (for example, within an arm's reach) to several feet away. Their concerns were largely motivated by wanting to sense the presence and intentions of others around them so that they could take action or modify their behavior to avoid risks to their personal safety, security, and privacy. Our interviews also made clear that participants' privacy concerns were preempted by any safety concerns until the latter were satisfied. However, the design considerations for a bubble to enforce safety also apply to protecting privacy, so the potential exists for assistive technology to satisfy both concerns.

Offering Adequate Coping Mechanisms

In terms of supporting coping strategies, we hope our work could help shed light on how to create technologies that prevent people with visual impairments from having to completely avoid activities or completely accept their risks. Wearable cameras combined with computer vision techniques offer the hope of helping people with visual impairments become more aware of their physical surroundings, including when people enter their security and privacy "bubble." Knowing who and how many people are in the vicinity, how close they are, and what they are doing could help better assess and manage safety and security. This information combined with knowledge of the layout of a physical space may allow users to better 'reposition' themselves to avoid shoulder surfing, or to adopt 'mitigation' strategies (such as speaking softly) to avoid eavesdropping.

Feasibility of Assistive Technology

After many years as just a research curiosity, wearable cameras such as GoPro Hero,[16] MeCam,[17] and Narrative Clip are already available on the consumer market. Some of these devices even give a near 360 degree view of the wearers' surroundings [40]. Head-mounted cameras like Orcam, Google Glass, and Microsoft HoloLens[18] are also on or nearing the market and may soon be more mainstream. Cameras that can sense in three dimensions (by measuring or estimating depth information), including Google's Project Tango[19] and dual- and multiple-lens sensors [50, 41], are likely to soon appear on these wearable devices. Low-cost infrared imaging sensors like FLIR One[20] may also be useful to more easily detect and recognize people based on their thermal signatures. All of this new camera technology is progressing rapidly and is likely to significantly improve a device's potential to monitor the area surrounding a user.

Meanwhile, impressive advances in computer vision technology

[16] gopro.com
[17] mecam.me
[18] www.microsoft.com/microsoft-hololens/
[19] www.lenovo.com/projecttango/
[20] www.flir.com/flirone/

have occurred over the last few years, driven in large part by deep learning [38], which can allow hundreds of objects to be accurately detected in near real-time [47], sometimes rivaling or even outperforming human accuracy [26]. Currently these techniques are computationally intensive and are not easy to implement on low-power, resource-constrained devices like wearable computers, but mobile processors are developing rapidly, and we expect deep learning will become feasible on mobile devices in the next few years. In the meantime, devices could rely on lower-cost, less accurate vision algorithms, or could send images off-board to remote cloud computing resources, or some combination of the two. Further work is needed to assess how well assistive devices based on current technology could perform given limitations on cost, weight, and power.

Wearable Cameras for Capturing Forensics

The use of cameras to monitor and record incidents of interest has begun to expand, most notably in the form of police officers wearing body cameras. Our work shows that people with visual impairments are also interested in the forensic collection of imagery to improve their physical safety and security. Kientz *et al.* [34] presented a system called CareLog which allows caregivers of autistic children to "document and analyze specific, unplanned incidents of interest" through the use of a wireless trigger. In the case of CareLog, the video and audio are archived for later review. Our research suggests such systems may be extended for people with visual impairments, as one participant suggested:

> *A device like that, to be honest, I think would help me to be less dependent on sighted people. That would be nice. It would allow me to do more things by myself.* *(T3)*

Networked Cameras

An interesting design consideration directly linked to forensics is *where* the record is maintained. If wearable cameras record and retain the video locally, then an assailant need only steal the visually impaired person's camera. If the record is preserved separately from the device, e.g., in the cloud, then stealing the camera does not destroy the forensics but raises questions about who may have access to private details captured by the camera. An alternative option might create a live video feed from a visually impaired person's camera to a trusted individual such as a friend or 911 operator, similar to current live-broadcasting smartphone apps like Meerkat[21] and Periscope.[22] As one possible design template, LiveSafe's smartphone app for campus safety[23] provides direct connection to campus public safety, audio and video recording, discreet initiation, geo-position reporting, and geo-boundary control (to work only within the campus limits). Duncan *et al.* [21] describe networked cameras that monitor activity in residences to allow trusted agents to monitor elderly persons. Complementary to the concept of forensics is whether knowledge of the presence of a camera could be a suitable deterrent and is another interesting direction for future work.

Safety Risks to the Camera Wearer

Although we hope wearable cameras could enhance safety and security, participants expressed concerns that these devices themselves may draw additional attention and actually increase the risk of assault. The safety risks to the camera wearer need to be key design considerations for a camera-based solution. Designing wearable devices to be as discreet as possible, combined with forensic capture capabilities, may help to reduce this risk. Additionally, the cost of the sensor may contribute to the risk of theft. Based on input from our participants, assistive devices should be low cost and also incorporate features such as store and forward of images, and perhaps technology that renders the device useless if separated from its authorized owner.

Privacy Risks to the Camera Wearer

The implications of wearable cameras to privacy in a visually impaired person's home should be considered. Caine and others explored this subject in the context of senior citizens being monitored in their own homes [10, 12], and we expect similar privacy concerns may apply to people with visual impairments. Hoyle *et al.* [30, 29] study the privacy concerns of people wearing cameras with automatic data collection ("lifelogging") and discuss impression management issues as being a major privacy concern for the wearer. People with visual impairments may find it even more difficult to filter the images captured by such devices, requiring careful thought to where the images are stored and how and with whom they are shared.

The use of cameras also puts people with visual impairments at risk of accidentally sharing images or information with the wrong people, which Caine calls a "misclosure" [11]. One participant (P12) mentioned an embarrassing incident in which her friend accidentally shared a naked photo of herself while using the VizWiz app [8] to try to differentiate between conditioner and shampoo. Such incidents underscore the requirement for the camera and recorded data to be under the review and control of the visually impaired person or their trusted surrogate during normal operations. Alternatively, as computer vision continues to improve, automatic algorithms could be employed to scan for potentially sensitive information in images and alert the user accordingly [36].

Privacy Risks to Bystanders

Given that a system might include an outward-facing camera to detect people within the visually impaired person's 'bubble' of personal space, designers also need to take the privacy of bystanders into consideration. Although a future system may or may not store and forward images, the expectation of bystander privacy must be honored, or at a minimum, managed. Denning *et al.* [19] studied the reactions of bystanders towards a wearable augmented reality cameras and proposed several design axes for privacy mediating technologies to respect the bystanders' privacy. Another suitable analogy for this design implication is found in lifelogging. Hoyle *et al.* [28] describe the legal difficulties in conducting user studies involving wearable devices because of bystander expectations of privacy. Taking a proactive approach such as privacy by design could help mitigate bystander privacy concerns. Ye *et al.* [57], for instance, detail the use of privacy by design in lifelogging applications. In the case of storing and forwarding images to facilitate forensic capture, the tension between bystander privacy and preserving the image record would require appropriate attention from designers. For example, the transition to store and forward from merely object detection could imply a system state change that might be indicated to bystanders in some manner such as a flashing light. We leave managing this tension to future work.

[21] meerkatapp.co

[22] www.periscope.tv

[23] www.livesafemobile.com

Beyond Cameras
We also suggest that cameras could be used in conjunction with other rich sensing modalities. One participant (X1) mentioned the possibility of scanning for nearby cell phone signals to identify who was entering their privacy "bubble." It is possible to scan the local area for Bluetooth devices and make camera state decisions and user alerts based on received signal power, reported device type and unique ID. It may also be possible to monitor WiFi traffic to make inferences about the people (such as number and distance) carrying those devices nearby. Input from these non-visual sensors could then be used in combination with camera data, for instance, by turning on the camera when a new person is detected nearby.

Concerns Related to Impairment Types
Our participants had different types of visual impairments, and we grouped them based on their impairment history in order to observe any correlations between impairment type and security, privacy, and safety behaviors or concerns. One trend we observed is that the majority of the safety and security concerns we report were given by the congenitally blind participants, whereas only one low vision participant was extremely concerned about safety. However, given the small number of participants and the fact that our study did not investigate this correlation further (e.g. by asking follow-up questions), this observation would need to be confirmed in a future study. However, our interviews did strongly suggest that concerns are correlated with one's own personal history and experiences. For example, the fact that L5 was the only congenitally low vision participant that was extremely concerned about personal safety is likely due to them having actually experienced a robbery in the past. It is left to future work to understand any correlations between attitudes towards safety and participant demographics, impairments, and personal experiences.

9. CONCLUSIONS
In order to gain an understanding of the physical safety and security concerns of people with visual impairments, and how technological solutions such as wearable cameras can address such concerns, we conducted semi-structured interviews with 19 participants. Our sample was predominantly urban, represented a wide range of ages and visual impairments, and had a balanced gender distribution. We reported on various *concerns* that people with visual impairments have about their physical safety and security, their *coping mechanisms* to address these concerns, and *desired information and design suggestions* in the context of assistive solutions to address safety and security.

We found that people with visual impairments have significant concerns about their physical safety in the context of crime, as they feel not only vulnerable but also unable to fully assess their environment. People with visual impairments, as a result, must develop several coping mechanisms that range between, and include, the extremes of complete acceptance of risk and the complete avoidance of performing certain activities. In addition to finding wearable cameras as a helpful tool to provide feedback about the environment, our participants indicated that the forensic collection of imagery would be helpful in the case of assault. We hope that the results of this study will help illuminate the unique concerns, behaviors, and needs of people with visual impairments in the context of physical safety and security, and will motivate further research to address their needs.

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11. REFERENCES
[1] Sami Abboud, Shlomi Hanassy, Shelly Levy-Tzedek, Shachar Maidenbaum, and Amir Amedi. 2014. EyeMusic: Introducing a "visual" colorful experience for the blind using auditory sensory substitution. *issues* 12, 13 (2014), 14. DOI: http://dx.doi.org/10.3233/RNN-130338

[2] Tousif Ahmed, Roberto Hoyle, Kay Connelly, David Crandall, and Apu Kapadia. 2015. Privacy Concerns and Behaviors of People with Visual Impairments. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems (CHI '15)*. ACM, New York, NY, USA, 3523–3532. DOI: http://dx.doi.org/10.1145/2702123.2702334

[3] American Academy of Ophthalmology. 2010. What is Low Vision? (2010). http://www.aao.org/eye-health/diseases/low-vision

[4] American Foundation for the Blind. 2008. Key Definitions of Statistical Terms. (2008). http://www.afb.org/info/blindness-statistics/key-definitions-of-statistical-terms/25

[5] American Foundation for the Blind. 2016. CCTV/Video Magnifier. (2016). http://www.afb.org/info/living-with-vision-loss/for-job-seekers/careerconnect-virtual-worksites/retail-worksite-for-low-vision-users/cctv-video-magnifier/12345

[6] Shiri Azenkot, Sanjana Prasain, Alan Borning, Emily Fortuna, Richard E. Ladner, and Jacob O. Wobbrock. 2011. Enhancing Independence and Safety for Blind and Deaf-blind Public Transit Riders. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '11)*. ACM, New York, NY, USA, 3247–3256. DOI:http://dx.doi.org/10.1145/1978942.1979424

[7] Shiri Azenkot, Kyle Rector, Richard Ladner, and Jacob Wobbrock. 2012. PassChords: Secure Multi-touch Authentication for Blind People. In *Proceedings of the 14th International ACM SIGACCESS Conference on Computers and Accessibility (ASSETS '12)*. ACM, New York, NY, USA, 159–166. DOI:http://dx.doi.org/10.1145/2384916.2384945

[8] Jeffrey P. Bigham, Chandrika Jayant, Hanjie Ji, Greg Little, Andrew Miller, Robert C. Miller, Robin Miller, Aubrey Tatarowicz, Brandyn White, Samual White, and Tom Yeh. 2010. VizWiz: Nearly Real-time Answers to Visual Questions. In *Proceedings of the 23Nd Annual ACM Symposium on User Interface Software and Technology (UIST '10)*. ACM, New York, NY, USA, 333–342. DOI: http://dx.doi.org/10.1145/1866029.1866080

[9] Kelly Caine. 2009a. *Exploring everyday privacy behaviors and misclosures*. Ph.D. Dissertation. Georgia Institute of Technology. http://hdl.handle.net/1853/31665

[10] Kelly Caine, Selma Sabanovic, and Mary Carter. 2012. The effect of monitoring by cameras and robots on the privacy enhancing behaviors of older adults. In *HRI*, Holly A. Yanco,

Aaron Steinfeld, Vanessa Evers, and Odest Chadwicke Jenkins (Eds.). ACM, 343–350. DOI: http://dx.doi.org/10.1145/2157689.2157807

[11] Kelly E. Caine. 2009b. Supporting Privacy by Preventing Misclosure. In *Extended Abstracts on Human Factors in Computing Systems (CHI EA '09)*. ACM, New York, NY, USA, 3145–3148. DOI: http://dx.doi.org/10.1145/1520340.1520448

[12] Kelly E. Caine, Celine Y. Zimmerman, Zachary Schall-Zimmerman, William R. Hazlewood, Alexander C. Sulgrove, L. Jean Camp, Katherine H. Connelly, Lesa L. Huber, and Kalpana Shankar. 2010. DigiSwitch: Design and Evaluation of a Device for Older Adults to Preserve Privacy While Monitoring Health at Home. In *Proceedings of the 1st ACM International Health Informatics Symposium (IHI '10)*. ACM, New York, NY, USA, 153–162. DOI: http://dx.doi.org/10.1145/1882992.1883016

[13] Megan Campbell, Cynthia Bennett, Caitlin Bonnar, and Alan Borning. 2014. Where's My Bus Stop?: Supporting Independence of Blind Transit Riders with StopInfo. In *Proceedings of the 16th International ACM SIGACCESS Conference on Computers & Accessibility (ASSETS '14)*. ACM, New York, NY, USA, 11–18. DOI: http://dx.doi.org/10.1145/2661334.2661378

[14] Pete Carey. 2015. Smartphones, apps are liberating the blind and visually impaired. (2015). http://www.mercurynews.com/business/ci_28641561/smartphones-apps-are-liberating-blind-and-visually-impaired

[15] Brendan Cassidy, Gilbert Cockton, and Lynne Coventry. 2013. A Haptic ATM Interface to Assist Visually Impaired Users. In *Proceedings of the 15th International ACM SIGACCESS Conference on Computers and Accessibility (ASSETS '13)*. ACM, New York, NY, USA, Article 1, 8 pages. DOI: http://dx.doi.org/10.1145/2513383.2513433

[16] Hsuan-Eng Chen, Yi-Ying Lin, Chien-Hsing Chen, and I-Fang Wang. 2015. BlindNavi: A Navigation App for the Visually Impaired Smartphone User. In *Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems (CHI EA '15)*. ACM, New York, NY, USA, 19–24. DOI: http://dx.doi.org/10.1145/2702613.2726953

[17] James Coughlan and Roberto Manduchi. 2007. Color Targets: Fiducials to Help Visually Impaired People Find Their Way by Camera Phone. *J. Image Video Process.* 2007, 2 (Aug. 2007), 10–10. DOI: http://dx.doi.org/10.1155/2007/96357

[18] D. Dakopoulos and N.G. Bourbakis. 2010. Wearable Obstacle Avoidance Electronic Travel Aids for Blind: A Survey. *IEEE Transactions on Systems, Man, and Cybernetics* 40, 1 (Jan 2010), 25–35. DOI: http://dx.doi.org/10.1109/TSMCC.2009.2021255

[19] Tamara Denning, Zakariya Dehlawi, and Tadayoshi Kohno. 2014. In Situ with Bystanders of Augmented Reality Glasses: Perspectives on Recording and Privacy-mediating Technologies. In *Proceedings of the 32Nd Annual ACM Conference on Human Factors in Computing Systems (CHI '14)*. ACM, New York, NY, USA, 2377–2386. DOI: http://dx.doi.org/10.1145/2556288.2557352

[20] Bryan Dosono, Jordan Hayes, and Yang Wang. 2015. "I'm Stuck!": A Contextual Inquiry of People with Visual Impairments in Authentication. In *Eleventh Symposium On Usable Privacy and Security (SOUPS 2015)*. Ottawa, 151–168. https://www.usenix.org/conference/soups2015/proceedings/presentation/dosono

[21] John Duncan, L. Jean Camp, and William R. Hazelwood. 2009. The Portal Monitor: A Privacy-enhanced Event-driven System for Elder Care. In *Proceedings of the 4th International Conference on Persuasive Technology (Persuasive '09)*. ACM, New York, NY, USA, Article 36, 9 pages. DOI: http://dx.doi.org/10.1145/1541948.1541995

[22] Alexander Fiannaca, Ilias Apostolopoulous, and Eelke Folmer. 2014. Headlock: A Wearable Navigation Aid That Helps Blind Cane Users Traverse Large Open Spaces. In *Proceedings of the 16th International ACM SIGACCESS Conference on Computers & Accessibility (ASSETS '14)*. ACM, New York, NY, USA, 19–26. DOI: http://dx.doi.org/10.1145/2661334.2661453

[23] Frederic Gougoux, Franco Lepore, Maryse Lassonde, Patrice Voss, Robert J. Zatorre, and Pascal Belin. 2004. Neuropsychology: Pitch discrimination in the early blind. *Nature* 430, 6997 (15 07 2004), 309–309. http://dx.doi.org/10.1038/430309a

[24] Susumu Harada, Daisuke Sato, Dustin W. Adams, Sri Kurniawan, Hironobu Takagi, and Chieko Asakawa. 2013. Accessible Photo Album: Enhancing the Photo Sharing Experience for People with Visual Impairment. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '13)*. ACM, New York, NY, USA, 2127–2136. DOI: http://dx.doi.org/10.1145/2470654.2481292

[25] Erika Harrell. 2015. *Crime Against Persons with Disabilities, 2009–2013 - Statistical Tables*. Technical Report. Bureau of Justice Statistics. http://www.bjs.gov/content/pub/pdf/capd0913st.pdf

[26] Kaiming He, Xiangyu Zhang, Shaoqing Ren, and Jian Sun. 2015. Delving Deep into Rectifiers: Surpassing Human-Level Performance on ImageNet Classification. *CoRR* abs/1502.01852 (2015). http://arxiv.org/abs/1502.01852

[27] Marion Hersh and Michael A. Johnson. 2008. *Assistive Technology for Visually Impaired and Blind People* (1st ed.). Springer Publishing Company, Incorporated.

[28] Roberto Hoyle, Qatrunnada Ismail, David Crandall, and Apu Kapadia. 2015a. Challenges in Running Wearable Camera-Related User Studies. In *CSCW Workshop: The Future of Networked Privacy: Challenges & Opportunities*.

[29] Roberto Hoyle, Robert Templeman, Denise Anthony, David Crandall, and Apu Kapadia. 2015b. Sensitive Lifelogs: A Privacy Analysis of Photos from Wearable Cameras. In *Proceedings of The ACM SIGCHI Conference on Human Factors in Computing Systems (CHI '15)*. 1645–1648. DOI: http://dx.doi.org/10.1145/2702123.2702183

[30] Roberto Hoyle, Robert Templeman, Steven Armes, Denise Anthony, David Crandall, and Apu Kapadia. 2014. Privacy Behaviors of Lifeloggers using Wearable Cameras. In *Proceedings of the ACM International Joint Conference on Pervasive and Ubiquitous Computing (UbiComp)*. 571–582. DOI: http://dx.doi.org/10.1145/2632048.2632079

[31] Chandrika Jayant, Hanjie Ji, Samuel White, and Jeffrey P. Bigham. 2011. Supporting Blind Photography. In *The Proceedings of the 13th International ACM SIGACCESS Conference on Computers and Accessibility (ASSETS '11)*. ACM, New York, NY, USA, 203–210. DOI: http://dx.doi.org/10.1145/2049536.2049573

[32] Alekhya Jonnalagedda, Lucy Pei, Suryansh Saxena, Ming Wu, Byung-Cheol Min, Ermine A Teves, Aaron Steinfeld, and M Bernardine Dias. 2014. *Enhancing the Safety of Visually Impaired Travelers in and around Transit Stations*. Technical Report CMU-RI-TR-14-28. Robotics Institute, Pittsburgh, PA. https://www.ri.cmu.edu/publication_view.html?pub_id=7815

[33] Shaun K. Kane, Chandrika Jayant, Jacob O. Wobbrock, and Richard E. Ladner. 2009. Freedom to Roam: A Study of Mobile Device Adoption and Accessibility for People with Visual and Motor Disabilities. In *Proceedings of the 11th International ACM SIGACCESS Conference on Computers and Accessibility (ASSETS '09)*. ACM, New York, NY, USA, 115–122. DOI:http://dx.doi.org/10.1145/1639642.1639663

[34] Julie A. Kientz, Gillian R. Hayes, Tracy L. Westeyn, Thad Starner, and Gregory D. Abowd. 2007. Pervasive Computing and Autism: Assisting Caregivers of Children with Special Needs. *IEEE Pervasive Computing* 6, 1 (Jan. 2007), 28–35. DOI:http://dx.doi.org/10.1109/MPRV.2007.18

[35] Andrew J. Kolarik, Silvia Cirstea, Shahina Pardhan, and Brian C.J. Moore. 2014. A summary of research investigating echolocation abilities of blind and sighted humans. *Hearing Research* 310 (2014), 60 – 68. DOI: http://dx.doi.org/10.1016/j.heares.2014.01.010

[36] Mohammed Korayem, Robert Templeman, Dennis Chen, David Crandall, and Apu Kapadia. 2016. Enhancing Lifelogging Privacy by Detecting Screens. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI '16)*.

[37] Liat Kornowski. 2012. How the Blind Are Reinventing the iPhone. *The Atlantic* (May 2012).

[38] Alex Krizhevsky, Ilya Sutskever, and Geoffrey E. Hinton. 2012. ImageNet Classification with Deep Convolutional Neural Networks. In *Advances in Neural Information Processing Systems*. 1097–1105.

[39] N. Lessard, M. Pare, F. Lepore, and M. Lassonde. 1998. Early-blind human subjects localize sound sources better than sighted subjects. *Nature* 395, 6699 (17 09 1998), 278–280. http://dx.doi.org/10.1038/26228

[40] Mandy Mandelstein. 2016. Kodak's New 4K Camera Captures Beautiful 360 Video For the Price of a GoPro. (2016). http://gizmodo.com/kodaks-new-4k-camera-captures-beautiful-360-video-for-t-1751390086

[41] Tim Moynihan. 2015. How This Magical 16-Lens Camera Will Actually Work. (2015). http://www.wired.com/2015/10/light-l16-camera/

[42] Maia Naftali and Leah Findlater. 2014. Accessibility in Context: Understanding the Truly Mobile Experience of Smartphone Users with Motor Impairments. In *Proceedings of the 16th International ACM SIGACCESS Conference on Computers & Accessibility (ASSETS '14)*. ACM, New York, NY, USA, 209–216. DOI: http://dx.doi.org/10.1145/2661334.2661372

[43] National Federation of the Blind. 2016a. Braille Readers are Leaders. (2016). https://nfb.org/braille-campaign

[44] National Federation of the Blind. 2016b. Braille Usage. (2016). https://nfb.org/braille-usage-toc

[45] U.S. Department of Veterans Affairs. 2002. *Visual Impairment and Blindness*. Technical Report. Department of Veterans Affairs. http://www.publichealth.va.gov/docs/vhi/visual_impairment.pdf

[46] World Health Organization. 2014. Visual impairment and blindness, fact sheet 282. (2014). http://www.who.int/mediacentre/factsheets/fs282/en/

[47] Joseph Redmon, Santosh Kumar Divvala, Ross B. Girshick, and Ali Farhadi. 2015. You Only Look Once: Unified, Real-Time Object Detection. *arXiv* abs/1506.02640 (2015). http://arxiv.org/abs/1506.02640

[48] Marcus Renner and Ellen Taylor-Powell. 2003. *Analyzing Qualitative Data*. Technical Report. University of Wisconsin-Extension., Cooperative Extension, Madison Wisconsin, USA. http://learningstore.uwex.edu/assets/pdfs/g3658-12.pdf

[49] Johnny Saldana. 2009. *The Coding Manual for Qualitative Researchers*. Sage, Los Angeles, California.

[50] Vlad Savov. 2016. Dual-camera phones are the future of mobile photography. (2016). http://www.theverge.com/2016/4/11/11406098/lg-g5-huawei-p9-two-camera-smartphone-trend-apple

[51] Roy Shilkrot, Jochen Huber, Connie Liu, Pattie Maes, and Suranga Chandima Nanayakkara. 2014. A Wearable Text-reading Device for the Visually-impaired. In *CHI '14 Extended Abstracts on Human Factors in Computing Systems (CHI EA '14)*. ACM, New York, NY, USA, 193–194. DOI:http://dx.doi.org/10.1145/2559206.2579520

[52] Kristen Shinohara and Jacob O. Wobbrock. 2011. In the Shadow of Misperception: Assistive Technology Use and Social Interactions. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '11)*. ACM, New York, NY, USA, 705–714. DOI: http://dx.doi.org/10.1145/1978942.1979044

[53] Violeta Voykinska, Shiri Azenkot, Shaomei Wu, and Gilly Leshed. 2016. How Blind People Interact with Visual Content on Social Networking Services. In *Proceedings of the 19th ACM Conference on Computer-Supported Cooperative Work & Social Computing, CSCW 2016, San Francisco, CA, USA, February 27 - March 2, 2016*. 1582–1593. DOI: http://dx.doi.org/10.1145/2818048.2820013

[54] Tianyu Wang, Giuseppe Cardone, Antonio Corradi, Lorenzo Torresani, and Andrew T. Campbell. 2012. WalkSafe: A Pedestrian Safety App for Mobile Phone Users Who Walk and Talk While Crossing Roads. In *Proceedings of the Twelfth Workshop on Mobile Computing Systems & Applications (HotMobile '12)*. ACM, New York, NY, USA, Article 5, 6 pages. DOI: http://dx.doi.org/10.1145/2162081.2162089

[55] Shaomei Wu and Lada A. Adamic. 2014. Visually Impaired Users on an Online Social Network. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '14)*. ACM, New York, NY, USA, 3133–3142. DOI:http://dx.doi.org/10.1145/2556288.2557415

[56] Hanlu Ye, Meethu Malu, Uran Oh, and Leah Findlater. 2014a. 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)*. ACM, New York, NY, USA, 3123–3132. DOI:http://dx.doi.org/10.1145/2556288.2557085

[57] Tengqi Ye, Brian Moynagh, Rami Albatal, and Cathal Gurrin. 2014b. Negative FaceBlurring: A Privacy-by-Design Approach to Visual Lifelogging with Google Glass. In *Proceedings of the 23rd ACM International Conference on Conference on Information and Knowledge Management, CIKM 2014, Shanghai, China, November 3-7, 2014*.

2036–2038. DOI:
http://dx.doi.org/10.1145/2661829.2661841

[58] Yuhang Zhao, Sarit Szpiro, and Shiri Azenkot. 2015. ForeSee: A Customizable Head-Mounted Vision Enhancement System for People with Low Vision. In *Proceedings of the 17th International ACM SIGACCESS Conference on Computers & Accessibility (ASSETS '15)*. ACM, New York, NY, USA, 239–249. DOI:
http://dx.doi.org/10.1145/2700648.2809865