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An Empirical Investigation of the Situationally-Induced Impairments Experienced by Blind Mobile Device Users

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ABSTRACT

In this paper, we describe a study specifically focusing on the situationally-induced impairments and disabilities (SIIDs) which individuals who are blind encounter when interacting with mobile devices. We conducted semi-structured interviews with eight legally-blind participants, and presented them with three scenarios to inspire discussion relating to SIIDs. Nine main themes emerged from analysis of the participant interviews, including the challenges faced when using a mobile device one-handed while using a cane to detect obstacles along the intended path, the impact of using a mobile device under inhospitable conditions, and concerns associated with using a mobile device in environments where privacy and safety may be compromised (e.g. when using public transport). These were found to reduce the quality of the subjective interaction experience, and in some cases limiting use of mobile technologies in public venues. Insights from our research can be used to guide the design of future mobile interfaces to better meet the needs of users whose needs are often excluded from the design process.

CCS Concepts

• **Human-centered computing→Accessibility→Empirical studies in accessibility**

Keywords

Accessibility; Blind; Mobile; Mobile Screen Readers; Situational Impairments.

1. INTRODUCTION

Advances in mobile technologies enable users to undertake a variety of tasks while on-the-go. Situationally-induced impairments and disabilities (SIIDs) may be encountered when using a mobile device while in motion or in a noisy environment, as the situation itself places demands on the user's attention, vision, and motor ability [15,18]. For example, ambulatory mobile device users may attempt to navigate through an environment (e.g. crossing a street) when attempting to divide attention between the mobile interface and the path ahead. Lack of awareness regarding obstacles or hazards can lead to poor decision making (e.g. walking into the path of traffic), resulting in accident or injury, in addition to impeding the mobile task. In contrast to Health Induced Impairments and Disabilities (HIIDs) [18], SIIDs are experienced by any user regardless of ability, who may not be able to use their mobile device as expected. Much of the prior research examining issues associated with SIIDs relates to the needs of young healthy individuals. The needs of individuals with disabilities (e.g. individuals who are blind) who experience encumbrances or difficulties due to situational, environmental or contextual factors impacting their tasks have yet to be examined in detail.

Mobile devices, such as smart phones, play an important role in the daily lives of individuals who are blind. Assistive technologies either built into these devices or installed on them as third-party applications can be used to support mobile interaction [22]. Common examples include screen readers (e.g. Apple VoiceOver[1], Google Talkback[2]) which provide an accessible representation of visual content from the interface. Wayfinding applications (e.g. ClickAndGo[3], Wayfindr[4]) can be used to assist users to navigate independently of others, while crowdsourced object recognition software (e.g. VizWiz[5]) can provide awareness of photographed items on a journey (e.g. signposts). While these technologies offer valuable assistance to individuals who are blind, SIIDs can negatively impact the user experience. A common example is walking through a noisy shopping mall when auditory feedback from the device is masked by ambient sounds present [9]. While a sighted user may be able to notice the screen flashing or detect a graphical icon on the screen indicating the presence of a notification, the same may not be possible for individuals who are blind, who may in turn miss an important incoming message.

When attempting to design a solution to meet the needs of users with SIIDs, there are instances where blind mobile user needs are more complex than those of sighted users. As an example, consider the needs of a blind pedestrian navigating an unfamiliar route. To do this, a long cane would be swiped with the dominant hand to detect obstacles along the intended path[6]. At the same time, the user may be interacting with his/her phone to try and obtain directions through a wayfinding application. The phone

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[1] Voiceover - https://www.apple.com/accessibility/osx/voiceover/
[2] Talkback – http://www.google.com
[3] Click and Go - http://www.clickandgomaps.com/
[4] Wayfindr - http://www.rlsb.org.uk/campaigns/wayfindr
[5] VizWiz - http://www.vizwiz.org/
[6] "Swiping a cane" is the act of swinging a long cane from side-to-side to identify the type of terrain being traversed and to detect the presence of obstacles in front of the user which may otherwise impede their journey.

may be held in the user's non-dominant hand. The user would need to divide attention between swiping the cane and accessing the mobile device, to ensure that neither task is negatively impacted. Undertaking both tasks at once (termed: a parallel task) can be a cognitively demanding process.

Our research aims to examine the issues faced by individuals who are blind using a mobile device, when impaired by the situation, context or environment. Interviews were undertaken with eight blind mobile device users. This paper presents the strategies and workarounds commonly used by our participants to address these barriers. The long term goal of the research is to examine ways that technologies can be developed to better address a community whose needs are often excluded from the design process.

2. RELATED WORK

Researchers have examined ways to address situational impairments encountered by ambulatory users. Examples include studies by Goel et al. [6] and Kane et al. [8] where common situational impairments were described, and solutions for more accurate text entry and target acquisition while walking were examined. Mizobuchi et al. [11] reported that walking adversely affects text-input speed and error rate. Additionally, findings from their study suggested that text-entry tasks affect mobility tasks. Schildbach and Rukzio [17] studied target selection tasks within a navigation course. They reported that cognitive load increases when walking while target selection performance decreases.

Mobile users commonly experience SIIDs when objects are carried while interacting with a mobile device. Through a sequence of studies, Ng et al. [12,13,14] investigated the effects of encumbrance on mobile interaction while walking. The researchers examined the performance of a target acquisition task on a touch screen in a range of settings. These included carrying other objects in one or both hands while either walking or standing still, and interacting with the touch screen while walking with one shopping bag in each hand using three common input postures. Findings from the studies suggested that walking while encumbered decreased target accuracy and increased error rate and selection time. It also prevented participants from walking naturally. Mobile interaction performance was found to decrease when the dominant hand was encumbered [14]. The researchers suggest that mobile users may not be able to pay the necessary attention to their surroundings to perform multiple tasks due to the increased level of cognitive workload experienced.

Studies have also been conducted examining the accessibility challenges encountered by individuals who are blind when using mobile devices. SIIDs may occur when auditory output from the mobile device conflicts with the environmental noise in crowded spaces. Inclement or inhospitable conditions are also known to impact mobile interactions [9,22]. To facilitate text entry in noisy environments, techniques have been proposed by researchers to better support the user [2].

Researchers have examined ways through which eyes-free mobile device interaction can be facilitated. For example, leveraging alternative channels such as the sense of touch can help users perceive cues which are missed due to the SIIDs or HIIDs encountered. Yatani et al. [21] investigated the efficacy of haptic feedback presented on the back of a touch screen mobile device. By generating different patterns of vibration (e.g. moving from left to right or top to bottom), they examined how accurately users could distinguish different cues, helping to support eyes-free touch screen interaction. However, cues would need to be designed in such a way that they could be perceived and discerned under inhospitable conditions or challenging social settings. Li et al. [10] developed an interaction technique called 'Virtual Shelves'. This technique takes advantage of the sense of position and orientation of one's body parts with respect to each other. The researchers developed a mobile prototype using an accelerometer and a gyroscope to help individuals who are blind to access application shortcuts more easily. While these solutions have been valuable, further study is needed to determine the extent of challenges faced by individuals who are blind when encountering SIIDs to ensure that technologies are able to support users in a wider range of scenarios.

In this paper, we describe an empirical study undertaken specifically examining the range of issues encountered when individuals who are blind attempt to use mobile devices while situationally-impaired. We also present common workarounds used by participants, along with insights from our research which can be used by interface designers to better match the needs of individuals who are blind who may encounter SIIDs.

3. UNDERSTANDING THE IMPACT OF SIIDS ON MOBILE USE

Interviews were conducted with individuals who are blind, to identify instances where SIIDs have been experienced when using mobile devices. Questions were semi-structured in nature, covering areas such as solutions which have been developed to address SIIDs, and the role of third parties in supporting users when constrained by the situation, context or environment.

Table 1. Participant demographic details

#	Age	Sex	Experienced Blindness	Mobility Aid	Living Area
P1	23	F	Congenitally blind	Cane	Suburban
P2	32	M	Congenitally blind	Cane	Urban
P3	23	F	Congenitally blind	Cane	Suburban
P4	49	M	Blind since 31, due to RP	Guide Dog or Cane	Urban
P5	24	F	Congenitally blind	Cane	Urban
P6	20	F	Congenitally blind	Cane or Guide Dog	Suburban
P7	29	M	Blind since 18, due to an accident	Cane or Guide Dog	Suburban and Rural
P8	34	M	Blind since 28, gradual vision loss	Cane	Urban and Suburban

3.1 Participants

Using snowball sampling, eight participants who identified themselves as legally-blind were recruited for the study (four male, four female, aged from 20 to 49, average: 29.25) (Table 1). All eight stated that they could not rely on their residual vision. Five of the participants were congenitally blind. The rest became blind later in life, due to illness or accident. Five of the participants used a long cane for purposes of object identification and wayfinding. P4 used a service animal (guide dog) as his primary mobility assistant and an identification cane for situations in which the guide dog could not help effectively (e.g. identifying the position of a stool in the locker room). Two other participants, P6 and P7 mentioned that if going out with others, they would prefer to use their canes for orientation and wayfinding, favoring leaving their service animals at home. Service animals would be used to support independent exploration, particularly for unfamiliar areas.

All eight participants were iPhone users and used Apple's VoiceOver screen reader to access content from the mobile interface. When asked about the reason they have chosen the iPhone over competing products, all mentioned that they perceived the device to be the best in supporting accessibility among individuals with visual impairments. P8 benefited from a dedicated GPS device for navigation. All participants stated that they used their mobile device on a daily basis. Seven considered themselves to be expert users (able to use apps, use email/web/social media, calendar functionality, and GPS on the phone, etc.). Five used their mobile devices frequently, relying on the device and its features for independent living. Seven used their phones regularly to listen to audio books or read books and news using their mobile screen reader. Commonly accessed functionality among participants varied from obtaining transportation using UBER[7] or LYFT[8] applications, using GPS functionality for wayfinding and orientation, the built-in camera to take photos (though taking and checking photos was found to be a complex task), communicating through social media apps such as Facebook and Twitter, and applications for blind users including color identifiers.

3.2 Interview Protocol

Interviews were conducted by phone and using video conferencing technologies. Three pre-defined scenarios relating to SIIDs were presented to each participant, based on an approach used by Qian et al. [16]. The scenarios were informed using data gathered from an earlier pilot study, where the experiences of blind mobile device users had been examined. Adhering to the categorization by Cooper [4], daily and necessary use scenarios were presented.

After the scenarios were presented, participants were asked about similar situations that they have faced, and the strategies or workarounds employed to address these situations. The scenarios presented were not intended to cover an exhaustive range of situations which would be encountered by individuals who are blind. They were thought to provide a means of inspiring discussion, and provide an opportunity to reflect upon personal experiences where mobile interaction was impacted due to the situation, context or environment. This was anticipated to result in suggestions for design.

The following three scenarios were presented:

1. **Shopping (Necessary use scenario):** John is a 30 year old blind adult who uses a cane for wayfinding. He regularly goes shopping, taking a bus to the grocery store from his home. After shopping, he walks back to the bus station with bags in his hands. While walking to the bus station, he finds it difficult to use his mobile phone in order to reply to a message, make a phone call or check the bus schedule.
2. **Using public transportation (Daily use scenario):** In order to get to work, John first catches a bus to the metro station, and then takes a train which stops near his office. Both buses and trains are crowded during rush hour. The journeys can also be bumpy. Taking advantage of his commuting time, he likes to read the news using his mobile device. However, listening to his mobile screen reader is not always possible.
3. **Checking mobile notifications in a meeting (Necessary use scenario):** When John attends meetings at work, there are situations where he likes to check the time or respond to urgent messages or emails using his mobile device. However, he is not always able to do this because he thinks that his mobile screen reader may distract others in the meeting.

In order to analyze the data gathered, interviews were first transcribed, and then coded and reviewed by the authors. The main themes emerging from the coded data are presented in Section 4 and Table 2.

Table 2. Themes identified relating to SIIDs

Index of Themes	SIID Scenario / Experience	Number of Participants Experiencing this SIID
1	Using the phone while walking with a cane	7
2	Using public transportation	6
3	Using mobile devices under inhospitable conditions	5
4	Using a mobile device when the hands are occupied	6
5	Attempting to multitask	3
6	Using apps for navigation	6
7	Focusing attention on the environment	8
8	Social events or crowded locations	6
9	Using a mobile phone camera to take good quality photographs	4

4. RESULTS AND DISCUSSION

Nine main themes relating to SIIDs emerged from the data (Table 2). Three of these themes were directly extracted from the discussions relating to the three pre-defined scenarios presented to participants (themes: 2, 4, 8). The remaining six themes were either highlighted in discussions relating to the pre-defined scenarios (themes: 1, 5, 7), or were mentioned in discussions relating to participants' personal experiences (themes: 3, 6, 9).

4.1 Using the Phone while Walking with a Cane

As described in 3.1, five participants used their cane for orientation and wayfinding (i.e. using the cane to swipe for obstacles, and tapping the end of the cane on the ground to identify surfaces). When asked about the practicalities of using the phone while ambulatory, P1 stated, "I keep my phone in my purse as I prefer to keep my hands free to use the cane when walking. I

[7] UBER - https://www.uber.com/
[8] LYFT- https://www.lyft.com/

can then swipe the cane to identify obstacles in my path while navigating." P2, who lives in a crowded city, highlighted that due to the volume of pedestrians rushing to work, he had been jostled many times while en-route to his work place. As a result, it was difficult for him to concentrate on navigating towards his office while using the phone. He feared being pushed over in a crowded area. As his work necessitated that he should take calls even when out of the office, he made the conscious decision to only accept urgent work calls while in transit. Although it would require considerable cognitive effort to attend to the call, while navigating in a busy environment, he felt that there was no other option available to him. Other participants stated that to better concentrate on the call, they had to wander away from their intended path to a quieter place and remain stationary to use the phone to complete an urgent mobile task. This would alleviate some of the worries about being distracted using the phone, and navigating into the path of traffic or other hazards.

P2, P4 and P7 were aware that sighted users often performed one-handed interactions with a mobile device, especially if encumbered (i.e. holding a shopping bag in the other hand). The participants felt that these actions were challenging to perform by individuals who are blind. The encumbrance resulting from holding a cane or service animal leash in one hand, combined with performing VoiceOver screen reader gestures (e.g. two or three finger and multi-tap gestures) compared to the simpler gestures made by sighted users to interact with the touch screen, were stated as causes of this frustration. As workarounds, more experienced participants had strategically repositioned their favorite application icons on the interface, making it easier to target those icons using the thumb of their free hand. This would in turn help to guarantee success of accessing the desired application when on-the-go.

4.2 Using Public Transportation

Six of the participants described situations in which they would prefer not to use their phones for routine tasks when in public. Four participants addressed safety concerns as the main reason of their frustration, especially on packed buses or trains. Concerned about not being able to visually perceive the intentions of people around them, they did not want to take the risk of their phones being stolen. Furthermore, there was a worry that conversations made when using the phone could be overheard, compromising both privacy and security.

The second challenge related to entering text. Four participants stated that when riding a bus, entering text on a mobile device while using VoiceOver touch typing mode would result in a range of spelling errors. Characters would be unintentionally entered due to the bumpiness of the journey causing their fingers to move away from the intended targets on the screen. Using dictation as a text entry alternative was considered frustrating because of the inaccuracy resulting from the ambient noise. Using the auto-correct functionality was a partial solution for participants, although incorrect terms could be generated using this feature. As a result, participants felt that more time needed to be invested to verify the meaning of text message and email content while on-the-go, to avoid recipients misconstruing the information received.

Three participants mentioned that in some situations, loud ambient noise masked the output from their mobile devices, even when volume settings for the phone were maximized (e.g. when riding an underground train). Participants were aware that playing sounds at a loud volume could pose dangers to their own levels of hearing. P4 addressed a serious situation where he had missed urgent notifications while traveling, as these had been masked by ambient sounds. He stated that he would often end-up postponing responding to messages on his phone until after exiting the subway. He would then be able to fully concentrate on the task, as the environment is generally quieter away from the subway station. Participants mentioned that they would sometimes forget about these messages, particularly if time has passed since receiving the message. Unlike sighted users, who are able to visually-scan through their inbox to identify the presence of messages which have yet to be addressed, blind users are forced to listen to information sequentially, making the process of checking an inbox more time consuming.

4.3 Using Mobile Devices under Inhospitable Conditions

Individuals often wear protective clothing such as gloves in inclement weather. However, selecting icons on a touch screen device or pressing tactile buttons on a phone can be a challenging experience for any mobile user if the hands are covered. Sounds can be attenuated when wearing hats that cover the ears, making it more difficult for blind individuals to perceive both their surroundings and auditory output from their mobile screen reader. Five of the participants stated that windy weather would impact their interaction with their phone by either blocking their hearing capability or adding too much distortive noise when they used their phone's microphone for dictation. This could lead to more time being spent checking content for errors.

4.4 Using a Mobile Device when the Hands are Occupied

Six participants stated that it would either be impossible or challenging to interact with their phones when carrying other objects in their hands. For example, P2 emphasized that using the phone while gripping the handles of shopping bags was extremely difficult for him to do, forcing him to ignore non-urgent calls when returning home after grocery shopping. He explained that in urgent situations the only solution would be stopping in a quiet spot along his journey, putting the shopping bags on the ground and taking the call. However, if the ground was wet or muddy, he would rethink taking the call to avoid getting the bags dirty. For P3, handling the cane and shopping bags at the same time seemed to be so cumbersome that she said she felt the need to take a taxi when returning home from a shopping excursion. This was to ensure her personal safety, as she worried that she may accidently stray into traffic while using the phone. The process of assessing hazards (e.g. traffic patterns) while using a cane to examine obstacles along the user's intended route is known to be demanding when vision is not available [7]. Participants favored loading items into a backpack which would free the hands to interact with the cane. As a result, some participants felt that they would need to plan trips in advance to stores, ensuring that they had a backpack with them at all times.

Suggestions were made that voice-based interaction could offer considerable potential for interacting with mobile devices, particularly when the hands were occupied limiting the user's ability to interact with a touch screen. While many participants had accessed Siri[9] and other voice-interaction apps while on the go, this was to varying degrees of success. It was clear from

[9] Siri - http://www.apple.com/ios/siri/

discussions with participants that these technologies would need to improve in fidelity to be used by ambulatory mobile users who may be encumbered.

4.5 Attempting to Multitask

Some participants had tried numerous ways to multitask. For example, P3 managed her shopping list on the phone. She explained, "While in the grocery store, I have a shopping assistant who pulls the cart and I follow the cart holding a cane. At the same time, I have to interact with a shopping list of items present on my phone." Performing both tasks at the same time, led the participant to walk much slower than she ordinarily would. She was aware that she was slowing down shoppers behind her when traversing the aisles. As a workaround, she would give her phone to her assistant to go through the list and delete the items already placed in the cart.

Due to safety and privacy concerns, the participant had recently stopped giving her phone to assistants in the store. She had heard stories of thefts of mobile devices and information stored on the phone (e.g. passwords, security details). As a new workaround, she would place the phone in her jacket pocket, and would listen to the items from the list using earphones extending from the pocket. Only one earphone would be used, to ensure that the other ear could be kept free to identify hazards in the surrounding area. She would interact with the phone using one hand. The process of paying attention to her surroundings while walking through aisles and listening to the shopping list at the same time required a great deal of cognitive effort.

Holding the phone in the palm of her free hand, and swiping on the screen to manage the list of items using the same hand without any earphones, was her third attempt to tackle this challenge. Finding this third approach also risky, cumbersome and impractical, she indicated the following laborious procedure as her fourth partial solution to this challenge: taking her phone out of her jacket pocket, reading some items from the list, putting the cellphone back in her pocket, finding and putting the items in the cart, and repeating the same procedure until all items were successfully obtained. She would also attempt to strike through items from the list once these had been placed in the cart.

The second challenge for P3 related to requesting transportation to return home after a shopping trip. Her preference was to call for a taxi using a mobile application (UBER) while waiting in the checkout line, allowing her to take her shopping home without needing to wait with her bags for long periods of time outside the store. However, she would not go with this option because she was not able to estimate the number of people ahead of her in the checkout line, nor the number of items in their carts to guess her waiting time. If the taxi arrived prior to her completing the checkout process, she worried that she would either be charged extra for the ride, or the driver may tire from waiting and leave. Using the app during checkout did not work either because different steps of this process required attention (e.g. handling the cart, placing the items on the conveyer belt, listening to each item being scanned, making the payment, and putting the shopping bags back in the cart). As a partial, yet not optimal solution, she stated she would use the app exactly after finishing up at the checkout and before leaving the grocery store while placing her bags in the cart. This was preferable to holding bags for prolonged periods while waiting for a taxi, which could be painful if items in the bags were heavy.

P5 and P6 mentioned that would sometimes look up information about a brand or an item (e.g. the calorie counts, etc.) by using barcode reader applications on their phones. They worried that assistants accompanying them around a grocery store might think that they were not conducting tasks related to shopping while using the phone (e.g. checking email). As a result, these participants wanted to keep interactions with a mobile device brief, as to not offend others around them.

4.6 Using Apps for Navigation

Although interested in taking advantage of navigation and location finding apps such as Google Maps and Yelp, P2, P3, P5 and P6 found interaction with such applications to be time-consuming and even inaccurate in certain situations. These types of app were thought to be of use when searching for the location of restaurants/stores near where the user was present. P2 emphasized the difficulty of one-handed interaction with such interfaces and the required cognitive load, alongside their inaccuracy in detecting the exact location of buildings, especially in built-up areas. P6 pointed out that she would not trust navigation apps because in her experience of using such technologies, delays in presenting information about the user's location had led to confusion. When individuals who are blind navigate multiple times to the same destination, a mental map is gradually developed where non-visual cues experienced on different parts of the route are committed to memory. P6 stated that when individuals who are blind want to visit a new location and want to take advantage of a navigation app, they should be able to trust the accuracy of that app. It was clear from the interviews that participants did not want to rely upon sighted peers or strangers for assistance to help with navigation and orientation. The ability to conduct tasks independently was paramount. However, certain situations dictated that third party help would be vital to accomplish tasks quickly.

The process of accessing apps with a screen reader, was described in detail by participants. First, a button on the phone should be pressed to hear whether the screen is in "locked" mode. If so, it should be unlocked using swiping and double-tapping gestures. Following that, several swiping gestures are needed along with a double-tap, to browse content on the phone and select the desired app. Locating a particular item or piece of information within the app may also require several steps. The process was found to be cognitively demanding, particularly when the user is on the move. When asked about ways to improve interaction, P2 suggested that a reliable and easy to use navigation interface with planning features would be helpful for his daily commute. Ideally, it would require "minimal interaction with a touch screen" which would be helpful when dividing attention between the interface and the path ahead. Commenting on accessibility issues with mobile applications, P7 stated that if blind software experts could join the development teams, many of these applications had the potential to better serve blind individuals, as the actual accessibility requirements could be understood more clearly. This highlighted a general problem with interface design, that technologies are often developed without consideration of diverse populations who would benefit most from interacting with them.

4.7 Focusing Attention on the Environment

When on the go, individuals who are blind have to perceive as many audio cues as possible, while paying attention to spatial cues such as changes in landscapes (e.g. the presence of curbs and steps), slopes and pavement tile textures. All participants specified the need for focusing their attention on the environment as an essential requirement contributing to their health and safety while navigating. As reaching the destination safely is a priority for individuals who are blind, participants mentioned that it would be difficult to conduct a parallel task (i.e. using a phone while ambulatory). The main reason for this limitation was the cognitive effort they needed to capture their surroundings, especially if the environment was unfamiliar or terrain was slippery.

4.8 Social Events or Crowded Locations

Participants described several instances where they did not have expected access to their phones. Examples include attending meetings, conferences and social events (e.g. when at a movie theater, concert venue, restaurant, and library). In meetings or classroom environments, tasks such as checking time covertly using the phone was a common challenge. P2 stated, "Sighted users are able to glance easily at their phone to determine the time of day, without drawing undue attention from others. It is more complex when using a screen reader." He mentioned solutions to address this issue included wearing earphones to listen to auditory output from the screen reader, minimizing the screen reader volume, or putting his finger on his phone's speaker in meetings in order to attenuate output. Participants had concerns with using earphones, due to their visibility when donned. They did not like to be judged as being rude because others might think they were not paying attention to what was going on at the event.

Similar to the findings of Shinohara et al. [20], participants in our study did not want to appear to be different from others. Choosing food from a restaurant menu was an example that P3 mentioned. She liked to choose entrees by herself similar to her friends. However, as restaurants rarely had accessible versions of menus, she was forced to either look at online versions of the menu using her phone while seated in the restaurant, or if she was able to plan ahead, she would examine the menu on the restaurant's web site while at home, and decide in advance what to order. The responses gathered from participants suggested that planning was essential prior to conducting tasks which others take for granted.

4.9 Using a Mobile Phone Camera to take Good Quality Photographs

Photos are often captured by individuals who are blind for a variety of reasons. Applications such as TapTapSee[10] provide information about the photo, along with feedback to indicate the direction of the shot. Aside from taking photos to share events with friends and family, some individuals who are blind benefit from apps such as VizWiz to acquire information about a visual scene, particularly in situations where the user is lost and needs to orient their position. Three of the participants described situations where they needed to take advantage of this feature on their phones.

Using a scanning application on his phone to read notecards and printed documents, P4 indicated situations in which the scanning process would fail because of the lack of appropriately accessible feedback from the app about the optimal lighting and angling conditions. He would try to conduct the task again using guesswork (e.g. angling the phone in a different direction, or steadying the phone with his other hand after putting the cane down on the ground to free the hand). Similar to P6 and P7, P4 needed this feature for note-taking in classes and project meetings to have equal access to information like his sighted classmates or colleagues. The participant mentioned that he would sometimes be provided with an accessible version of the notes from a class. However, there would be a lag between the class and when these notes would be made available, which made it difficult to study. Participants had tried taking photos using the camera on their mobile devices, but were unaware of whether glare from the whiteboard or the legibility of handwriting on the board would be acceptable when photographed. Furthermore, while technology could provide a representation of content in accessible form (e.g. Text Detective[11]), apps could not always accurately convert complex content from the board (e.g. mathematical equations, etc.) into an accessible format.

4.10 Suggestions for Future Mobile Interaction

Participants offered several practical ideas to address SIIDs on mobile devices. Common suggestions included:

- **Provide Hands-Free Interaction.** Voice input technologies should improve to better capture information from the user, even if background sounds are present. It was suggested that some type of artificial intelligence could be used to learn from prior voice commands that had been made by the user. This was thought to reduce the number of errors that would be made when voicing further commands on-the-fly. It was also suggested that voice commands could help the user when touch screen interaction was not an option (i.e. when encumbered).
- **Present Immediate Feedback to the User.** Feedback should be presented earlier to the user, to avoid time being wasted in the mobile interaction process. For example, applications should communicate non-optimal lighting conditions for taking photos to the user when focusing the camera, rather than only after taking the photograph.
- **Understand User Context.** The accelerometer, gyroscope and other sensors within the phone can be used to detect movement while encumbered and the presence of ambient sounds. The mobile device can consequently provide the situationally-impaired user with more enhanced feedback.
- **Leverage Multi-Modal Input.** Multiple modalities should be used to ensure that information from the mobile device can be perceived by the user. Meaningful tactile feedback can complement auditory cues, helping the user to better discern a notification, compared with one form of feedback alone.

5. INSIGHTS FROM THE RESEARCH

Interface designers rarely consider the unique needs of diverse user groups (e.g. individuals with HIIDs) when developing mobile solutions. Even fewer consider the difficulties faced by these users when constrained by the situation, environment or context (SIIDs). Findings from our data gathering study offer an insight into the considerations that can be made when designing interfaces to better match the abilities of blind individuals who experience SIIDs. While some of these findings confirm results mentioned in previous research, the availability of touch screen devices as well as new applications of mobile devices in recent years make these insights worthy of consideration by interface designers, with a view to making mobile interfaces more universally and equally accessible.

[10] TapTapSee - http://www.taptapseeapp.com/

[11] Text Detective - http://blindsight.com/textdetective/

- **Consider Interaction Modes (themes 1, 5, 6).** Gestures made using a screen reader (e.g. VoiceOver) on a smartphone, were thought to be more complex compared to the gestures made by sighted users when interacting with the phone (i.e. interaction using two or three fingers). This would limit one-handed use of the phone, making it difficult to conduct tasks in parallel (e.g. walking while texting). The ability to interact more effectively with touch screen interfaces using one hand, in addition to enhanced voice input capabilities, were thought to offer considerable potential to blind mobile device users.
- **Reduce Encumbrances (themes 4, 5).** Participants felt encumbered using a smartphone when holding a cane or leash for a service animal. In contrast to sighted users who can visually assess whether items carried by hand can be safely or temporarily left on the floor (e.g. shopping bags), individuals who are blind may not easily be able to make assessments or judgments about the environment. This may impact mobile usage behavior.
- **Limit Errors (themes 2, 7).** When impaired by the situation, context or environment, errors could be made when using the phone while ambulatory. This caused users to spend more time checking content and relying on features such as autocorrect. To ensure that ambient sounds such as the noise of traffic could be heard, participants favored wearing only one earphone. However, even when using this workaround, processing simultaneous channels of audio still proved to be challenging.
- **Evaluate under Realistic Conditions (themes 2, 3, 7).** Participants felt that mobile technologies had not been designed with blind users in mind. Furthermore, it was obvious that these technologies had not been tested with distracters. For example, ambient sounds which are an everyday occurrence can mask auditory feedback from the phone, impacting the interaction. Similarly, when in motion, tactile cues presented via the device in the trouser pocket can be attenuated. This makes the process of identifying notifications challenging. Participants felt that feedback should be discernable under these conditions.
- **Preserve User Privacy (themes 2, 5).** SIID instances may occur because users may modify their behavior when using a mobile device, due to the fear of being overheard or observed by strangers. While privacy and security have been discussed by researchers in the past [1,3,9,22], workable solutions are still needed to support individuals who are blind.
- **Provide Discretion (theme 8).** Similar to sighted users, blind users are faced with scenarios where they need to discreetly obtain information from the mobile interface (e.g. number of missed calls and unread texts) without drawing undue attention to themselves. Feedback would be needed to be presented covertly to the user.
- **Maintain Social Norms (themes 8, 9).** Participants in our study highlighted that they did not want to be viewed differently to their sighted counterparts. Assistive technologies for mobile devices should be designed taking into account that mobile users do not want to "stand out".

6. CONTEXTUALIZING FINDINGS

Recent advancements in mobile technologies have led to mobile devices being used in a variety of contexts. This has introduced new types of challenges to all users regardless of ability. Our research is unique in focusing on SIIDs encountered by blind mobile users, and confirms and extends previous research (e.g. [9]). Kane et al. [9] examined the needs of individuals who experience low levels of vision or identify with motor impairments. They addressed the ways in which mobile technologies are adopted by users, as well as accessibility challenges that individuals with disabilities face using these devices. Among challenges, they mentioned environmental and contextual factors including "crowded spaces", "lighting" (not necessarily applicable to individuals who are blind), and "the weather." In our study, we specifically focused on individuals with no or limited functional vision who also use a mobility aid (e.g. long canes). This allowed us to focus on challenges that are faced when encumbered (i.e. with one hand holding the cane or leash for service animal, restricting the use of the same hand to interact with the mobile device).

In contrast to other studies, we have focused on one-handed interactions with touch screens for individuals who are blind, and in certain cases, the issues faced when using the device while ambulatory. Gestures which need to be undertaken to interact with a screen reader (e.g. VoiceOver) can sometimes pose challenges to conduct one-handed, as multiple fingers are needed to interact with the interface. We found that individuals who are blind are interested in using voice interfaces to complement touch screen interaction when situationally impaired. However, participants felt augmentation of voice interfaces including supporting personalized commands would be beneficial, if the SIID being experienced was particularly limiting.

7. LIMITATIONS OF THE STUDY

The process of recruiting individuals with disabilities to participate in research is not without its own challenges. Geographical location combined with busy schedules can affect the ability to participate. In our study, we recruited eight participants who identified as legally-blind. While, research suggests that undertaking studies with smaller numbers of individuals with disabilities is not uncommon [19], a larger sample would have been preferable to obtain a more detailed picture of the issues faced by individuals who are blind.

8. CONCLUSION AND FUTURE WORK

We conducted an empirical study to identify instances of SIIDs experienced by blind individuals when using their mobile devices. The investigation revealed difficulties using phones (including interacting with touch screens using one hand and voice interfaces recently available on mobile devices) while on the move, and other situations which may not impact their sighted counterparts. Our participants expressed concerns about social factors such as safety, privacy, and not wanting to look different from others or to appear rude. Findings from our study can be used to inform designers who may not be aware of the issues faced by individuals who are blind. The method described in this paper, can also be used by interface designers to interact with individuals with other disabilities, to help inform the design of a more inclusive solution.

The next step to expand this study will be to observe blind users encountering SIIDs in the wild. Participants will be observed using mobile devices over a long term period. Video footage of mobile interaction will be played back to participants. Through a series of retrospective think-alouds, participants can provide more detailed descriptions of difficulties faced. Task analyses of the footage will also be conducted to identify areas for improvement. These future steps will help to more strongly support the validity of the findings of this current work. A participatory-design approach, similar to [5], can then be adopted to examine ways in which technologies can be developed to better support blind mobile users who experience SIIDs.

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