5-16-2022

Evaluation of the Accessibility of Touchscreens for Individuals who are Blind or have Low Vision: Where to go from here

Elizabeth Codick
emc6595@rit.edu

Evaluation of the Accessibility of Touchscreens for Individuals who are Blind or have Low Vision: Where to go from here

by

Elizabeth Codick

Thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Human Computer Interaction

Rochester Institute of Technology

B. Thomas Golisano College
of
Computing and Information Sciences

Department of Information Sciences and Technologies

May 16, 2022

Rochester Institute of Technology

B. Thomas Golisano College
of
Computing and Information Sciences

Master of Science in Human Computer Interaction

Thesis Approval Form

Student Name: Elizabeth Codick

Thesis Title: Evaluation of the Accessibility of Touchscreens for Individuals who are Blind or have Low Vision: Where to go from here

Thesis Committee

Name	Signature	Date
Elissa Weeden Chair		
Kristen Shinohara Committee Member		
Mingming Fan Committee Member		

Abstract

Touchscreen devices are well integrated into daily life and can be found in both personal and public spaces, but the inclusion of accessible features and interfaces continues to lag behind technology's exponential advancement. This thesis aims to explore the experiences of individuals who are blind or have low vision (BLV) while interacting with non-tactile touchscreens, such as smartphones, tablets, smartwatches, coffee machines, smart home devices, kiosks, ATM machines, and more. The goal of this research is to create a set of recommended guidelines that can be used in designing and developing either personal devices or shared public technologies with accessible touchscreens. This study consists of three phases, the first being an exploration of existing research related to accessibility of non-tactile touchscreens, followed by semi-structured interviews of 20 BLV individuals to address accessibility gaps in previous work, and finally a survey in order to get a better understanding of the experiences, thoughts, and barriers for BLV individuals while interacting with touchscreen devices. Some of the common themes found include: loss of independence, lack or uncertainty of accessibility features, and the need and desire for improvements. Common approaches for interaction were: the use of high markings, asking for sighted assistance, and avoiding touchscreen devices. These findings were used to create a set of recommended guidelines which include a universal feature setup, the setup of accessibility settings, universal headphone jack position, tactile feedback, ask for help button, situational lighting, and the consideration of time.

Acknowledgements

I would like to acknowledge my committee, Rochester Institute of Technology's Bridges to the Doctorate Program, and my friends and family that have supported me throughout my Master's education. I appreciate how much my committee has all helped me improve my thesis, especially with the length and the short time frame they had. I specifically want to thank my chair Elissa Weeden, who has helped me since the beginning of the project and helped guide me through this whole process.

I would also like to thank the RIT's Bridges to the Doctorate Program, whose members have provided me with a Deaf community of like minded Deaf/Hard of Hearing students and a well-rounded group of Rochester Institute of Technology and University of Rochester professors and faculty from which to learn and grow. They also provided me with the funding to support this thesis.

Lastly, I want to thank my friends and family who have supported me through the last two years. I especially want to thank my mother and my roommate/friend, Dymen Barkins. Both have provided me with an ear to listen to my ideas and have read through parts of my thesis to ensure that it made sense to people with fresh eyes.

Table of Contents

List of Tables and Figures

Tables

Figures

Introduction

Touchscreens are everywhere from the smartphone in your pocket and the coffee maker in your kitchen, to the soda machines and interactive maps in the mall. The need for proper accessible touchscreen interfaces is not a new concept and has been an enduring challenge when designing accessibility features of such devices (Buzzi et al., 2017; Grussenmeyer & Folmer, 2017; Guo et al., 2019; Huang, 2018; Khan & Khusro, 2019). Touchscreens are non-tactile, heavily visual based, and come in a variety of sizes, making it difficult for individuals who are blind or have low vision (BLV) to independently interact with the interfaces. Smartphones and tablets are known for their accessibility features such as their built-in screen readers like Talkback and VoiceOver, and the personal ownership of the technologies allows for customization to match the owner’s needs and preferences (Grussenmeyer & Folmer, 2017). However, not all touchscreen interfaces are set up with accessible features and many touchscreen interfaces are set up in public areas for use by multiple individuals. There are several challenges that present themselves while interacting with dynamic touchscreens by individuals who are BLV, especially in public places with unfamiliar technologies, which include the ability to read what is on the screen, to be able to explore the screen without triggering the system, and the ability to gain access to the system platform to enable available accessibility features (Guo et al., 2019).

The present challenges for the interaction with touchscreen interfaces could be addressed with a user-centered design approach that considers users that are BLV (Huang, 2018). For example, the need for better accessibility features on cell phones for BLV users has become more prevalent alongside advancements in cell phones that end up excluding different users because they cannot access these advances without some sort of accessibility accommodation or feature. However it is unclear that designers and developers are aware of the needs and preferences of BLV users. This study investigates current research and approaches to solutions for this problem through an exploration of existing research, followed by semi-structured interviews and a survey, to get a deeper understanding of what challenges are being faced, what approaches are being used, and what the BLV community is hoping for in future touchscreen technologies and solutions. The research design was reviewed and approved by Rochester Institute of Technology's IRB, the approval form can be seen in Appendix A. The ultimate goal of this research is to gain sufficient insight into the problem in order to present recommendations and guidelines for private and public domain touchscreen interface designers and developers that will help individuals who are BLV more effectively, confidently, and independently interact with touchscreen devices no matter the location, setting, or purpose. The following research questions have been identified to provide a progression towards the research goal:

RQ1: What current features exist to assist individuals who are blind or have low vision in independent interactions with touchscreens?

RQ2: What are the perceptions and experiences of individuals who are blind or have low vision in interactions with touchscreen interfaces?

RQ3: What are the conditions and/or constraints that are preventing individuals who are blind or have low vision from having effective interactions with touchscreens?

RQ4: What improvements could be made to touchscreen interfaces that could improve interactions and experiences with individuals who are blind or have low vision?

Review of Literature

Personal Devices

Most previous research conducted related to BLV accessibility to touchscreen devices focuses on personal touchscreen devices, such as smartphones, tablets, and smartwatches. Research has been conducted to evaluate the accessibility of QWERTY keyboards on touchscreen devices (Nicolau et al., 2015), the nagiavation throughout the device (Ferati et al., 2011; Kane et al., 2008), input modalities (Abdolrahmani et al., 2018; Branham & Roy, 2019; Buzzi et al., 2017; Ferati et al., 2011; Guo et al., 2019; Kane et al., 2008), and feedback (Csapó et al., 2015; Ferati et al., 2011; Grussenmeyer & Folmer, 2017; Hakobyan et al., 2013; Kane et al., 2008; Oh et al., 2013, 2015; Tennison & Gorlewicz, 2019; Vatavu, 2017).

Navigation throughout the device

Navigation is a key role when interacting with touchscreen devices and is necessary in order to complete the intended task the user sets out to accomplish. Not being able to navigate through a device easily and naturally can be frustrating to users. Traditional navigation on touchscreen devices is highly visually dependent and requires users to locate target items on the screen, which can include clicking buttons or icons to make selections to move about in the device, as well as reading and scrolling through the content of the screen to decide where they would like to go next. This creates a barrier for BLV users due to these interaction techniques being contingent on visual cues, and the inconsistencies of interface layouts leads to difficulty in learning each new layout of an interface in order to locate important objects on the screen (Ferati et al., 2011; Kane et al., 2008).

Shaun Kane, Jeffrey Bigham, and Jacob Wobbrock (2008) recruited eight blind participants and conducted 30-minute interviews to address what types of mobile devices were being used, and the challenges and approaches faced by their participants that related to touchscreens. Through their interviews they found people would put adhesive tactile dots or Braille labels on personal devices in the home to indicate target areas, while in public places they would try to memorize the layout of the screen but would most likely ask for help. Participants indicated that their main challenges and concerns included learning where the objects on the screen were located and accidentally activating certain features on the screen. Kane, Bigham, and Wobbrock (2008) used the information learned during the interviews to design a set of guidelines for their proposed solution. They proposed a set of audio-based multi-touch interaction techniques which they referred to as Slide Rule with the goal of enabling access to touch screen applications for blind users. The techniques were then put to the test with 10 blind participants who were asked to complete a few tasks with two different devices that were setup identically in terms of applications and with Mobile Speak Pocket: an Apple iPhone loaded with the Slide Rule and a Pocket PC device that had physical buttons for navigation and selection. Participant feedback was generally positive with the Pocket PC due to the physical buttons being more familiar and mixed with the Slide Rule device due to the intangibility of the device. However, participants did note that for flat touchscreen devices, the Slide Rule was more accessible to them than before (Kane et al., 2008).

Ferati, Mannheimer, and Bolchini (2011) designed and tested an auditory touchscreen interface, known as AEDIN (Acoustic EDutainment INterface), which was designed for educational purposes. The interface was designed as a bookshelf of essays with a grid structure. When the user taps on a square in the grid a sound effect would indicate where the user is currently located in the bookshelf, as well as the topic of the essay. The results showed a high rating of comfort and ease of use with the touchscreen technology (Ferati et al., 2011).

Input Modalities

User input on touchscreen devices is typically accomplished through gestures that are performed on the screen, including the most common: tap, swipe, and pinch. Most gestures are performed in the area of the target content. This would mean that the user would find the button that they are looking for and tap within the button's boundaries, or they would perform the pinch gestures over the area that they would like to zoom into or out of. Gestures performed on touchscreen device screens can be difficult for anyone, especially without visual cues, and this can include basic gestures or more complex gestures that involve several changes in direction and/or multiple finger movements.

A previous research paper investigated the preference and ease of correctly performing gestures on a smartphone by BLV individuals (Buzzi et al., 2017). They recruited 36 BLV participants and asked them to perform 25 gestures six times, where the categories of gestures included: swipe, pinch, letterlike, tap, rotor, angled, and to and fro. The participants started with a training phase, and if unsure about the shape of the gesture were given a cardboard cutout so they could feel and trace the gesture shape. The participants reported that the most difficult gestures to perform were to and fro, swipe, and rotor, including gestures that required several changes in direction and multiple finger movements. The to and fro swipe in this study was a swipe in one direction to the opposite direction in one movement and could include one, two, or three fingers placed on the screen performing the motion, for example, swipe down then up. The rotor swipes were either clockwise or counterclockwise, most commonly the pointer finger and thumb are placed on the screen with some distance between them and then the wrist is twisted. The participants' opinions of the gestures correspond with the data that was collected, shown through valid and invalid captures (Buzzi et al., 2017).

Kane et al.'s (2008) Slide Rule techniques previously mentioned consisted of 8 multi-touch gestures: one finger scan, flick up, flick down, flick left, flick right, sound-finger tap, double tap, and L-select. A one-finger scan was used to browse the information on the screen, flick gestures were used to flip between pages of items, sound-finger tapping was used for selection, double tap was used to pause music, and L-select was used to browse the information hierarchically (Kane et al., 2008).

Ferati et al.'s (2011) AEDIN system consisted of one finger taps, one finger double taps, and stroke shaped circles. The single tap activated the sound effect for the specific grid item, double tap was used for selection, and a left-to-right finger semi-circular swipe mixed up the items within the grid (Ferati et al., 2011).

Other research that addressed the use of gesture based inputs with touchscreen devices proposed different design solutions for better interactions including creating a simplified user interface (Khan & Khusro, 2019), use of gestural cues for input (Grussenmeyer & Folmer, 2017), and types of gestures used (Buzzi et al., 2017; Oh et al., 2015). Huang (2018) suggested placing common actions in the corners of the screen, after observing that most of the participants in their study touched or felt for the corners of the touchscreen.

In order to tackle the challenge of accidental input activation of touchscreens or misclicks, Guo et al., (2019) proposed a solution that they referred to as StateLens. StateLens scans the touchscreen interface and generates directions for navigating through the interface, in addition to the user wearing a 3D printed finger cap that allows them to explore without touching the screen or tilt their finger forward for selection (Guo et al., 2019).

Another form of input for touchscreen devices that is more commonly used by BLV users is a Voice-Activated Personal Assistant (VAPA). Some popular examples are Siri, Amazon Echo, and Google Assistant. VAPAs use voice input to control the touchscreen device, allowing the user to complete numerous tasks with voice controls. A few examples include the ability to create alarms, calendar reminders, search for information, start up music, ask for directions, and allow access to online shopping.

In 2018, Ali Abdolrahmani, Ravi Kuber, and Stacy Branham focused on the use, acceptability, and challenges for blind and low vision individuals when using VAPAs. They recruited 14 legally blind participants and performed semi-structured interviews that addressed their experiences with home and mobile VAPAs, inquiring about approaches, frequency of use, and challenges faced while interacting with their VAPA technologies. The participants discussed usability challenges, accuracy of platforms, use in public places, and privacy concerns. Some usability challenges that were discussed included identifying system status, missing visual cues, and the awkwardness and distractions associated with input and output of information in the public domain (Abdolrahmani et al., 2018).

One year later in 2019, Stacy Branham and Antony Roy published a paper that reviewed identified design guidelines for VAPAs, which revealed an interaction model that followed human to human conversation. The authors argued that approach was very limited for people with disabilities, including BLV users, as well as people in a variety of situations which were not expected or considered during the creation of the model (Branham & Roy, 2019).

Digital keyboards on touchscreen devices

The use of a traditional QWERTY keyboard on the touchscreen is highly dependent on visual cues, due to the lack of physical keys or tactile cues. In 2015, Nicolau et al. conducted an eight-week longitudinal study that focused on the use of QWERTY keyboard interaction on a touchscreen and the learning effect through situational usage. The participants within this study were experienced in using screen readers on a desktop, however none of the participants (N = 5) owned or had experience with using screen readers on their personal touchscreen devices. The study consisted of weekly sessions that were designed to follow the effects on typing performance for the new users, and the participants were also allowed to practice their keyboard skills outside of the weekly sessions. The results showed a slight increase in the average typing performance from the first week at 1.6 wpm and the eighth week at 4 wpm, which is about a 0.3 wpm increase per week (Nicolau et al., 2015).

There have been developments in software and even hardware devices with the goal to increase typing speed and allow for better interactions with touchscreens for

BLV people. Previous work has evaluated some of the new technologies developed including simplified QWERTY keyboards (Rakhmetulla & Arif, 2020; Yfantidis & Evreinov, 2006), as well as keyboards that take Braille into account such as Braille keyboards (Alnfiai & Sampalli, 2016; Li et al., 2017; Nicolau et al., 2014; Seim et al., 2014; Southern et al., 2012; Trindade et al., 2018), Braille key check software (similar to spell check) (Nicolau et al., 2014), and Braille games (Araújo et al., 2016; Milne et al., 2014). However, an important thing to note is that not all BLV individuals know or use Braille, thus excluding any accessible approaches including Braille for that sample. These past works also collected data from their BLV participants that take note about the hardships they face while using cell phones including low average typing speed (Alnfiai & Sampalli, 2016; Li et al., 2017; Nicolau et al., 2014; Rakhmetulla & Arif, 2020; Seim et al., 2014; Southern et al., 2012; Yfantidis & Evreinov, 2006), difficulties fixing typing errors (Li et al., 2017; Nicolau et al., 2015; Southern et al., 2012), and the distraction of audio feedback (Alnfiai & Sampalli, 2016; Li et al., 2017; Southern et al., 2012), as well as features they are looking for in future advancements. Figure 1 shows some examples of digital keyboards that were designed and tested for individuals who are blind or have low vision to use, an important note is these keyboards were designed with smartphone and tablets in mind.

Senorita is a simplified touchscreen QWERTY keyboard (seen in Figure 1a) that groups letters based on frequency of use and the reach of the thumbs (Rakhmetulla & Arif, 2020). Eight keys are positioned on the bottom of the screen, with the four on the left intended to be activated by the left thumb and the four keys on the right intended to be used by the right thumb. The eight keys are assigned a key that matches the most frequently typed English letters: ‘E’, ‘A’, ‘I’, ‘S’, ‘R’, ‘N’, ‘O’, and ‘T’. Underneath each of the main letters are four to five additional letters to be used. The keyboard is meant to be used as a chorded keyboard, meaning that a key on the right and a key on the left are to be clicked at the same time to produce a letter input. For example, on the keyboard underneath the ‘I’ key on the left side are the following letters ‘C’, ‘F’, ‘W’, and ‘X’, on the right side of the keyboard underneath the letter ‘N’ are the following letters ‘M’, ‘Y’, ‘W’ and ‘K’. If the user were to hit the ‘I’ and the ‘N’ at the same time the letter input would be ‘W’, because it appears in both of the keys. Rakhmetulla and Arif (2020) conducted three user studies evaluating the use of Senorita, the first study analyzing the use of Senorita on a smartphone, the second on a tablet, and the third with BLV participants. The smartphone user study was a longitudinal approach that had the participants return for 10 sessions of using the Senorita keyboard which revealed an average 14 wpm. The tablet study was not longitudinal and had an average 9.3 wpm. The last study that was conducted with the target audience of BLV users produced an average of 3.7 wpm for blind users, and 5.8 wpm for low vision users (Rakhmetulla & Arif, 2020).

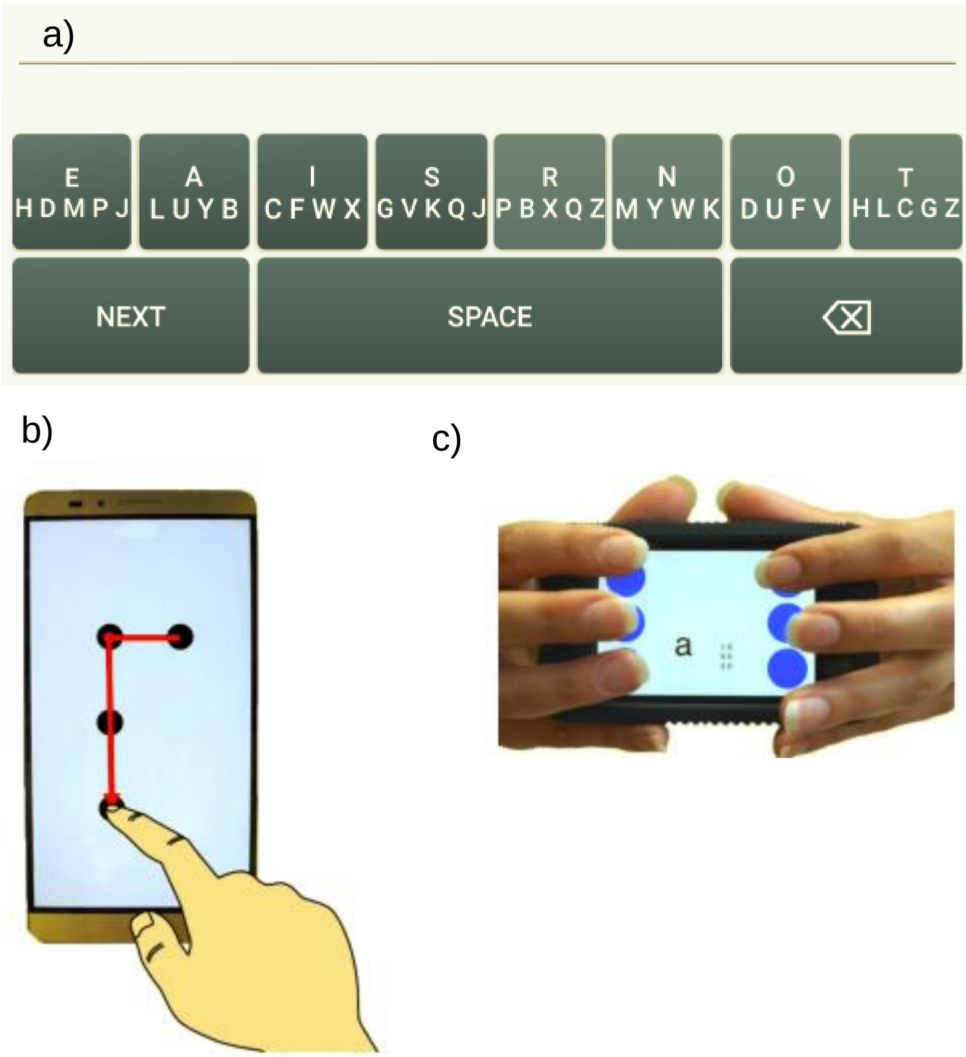
BrailleTouch is a Braille keyboard to be used in place of the regular QWERTY keyboard on touchscreen cell phones (Southern et al., 2012). The keyboard was designed based off of the Perkins Brailler, which is very similar to a type writer, however it consists of six keys. Southern et al. (2012) conducted an evaluation of the use of BrailleTouch and compared it to the use of a Perkins Brailler and a Braille keyboard on a tablet device. BrailleTouch was designed to be held with the screen of the device facing away from the user to allow six fingers to be able to simultaneously hit the screen, can be found in Figure 1c. The participant would hold the device in a landscape orientation allowing the pinkies to support the bottom of the phone, the pointer, middle, and third fingers to hit the keys, and the thumbs to add support or be free to relax. The results showed that expert Braille users could average 23.2 wpm while using BrailleTouch, and the highest reported speed was 32.1 wpm. The study found that people with experience in other Braille keyboards, such as the Perkins Brailler, could transfer their existing Braille typing skills to a touchscreen Braille keyboard with practice (Southern et al., 2012). Another study was conducted with the use of BrailleTouch in addition to a Braille correction system, called B# (Nicolau et al., 2014). B# was designed to make corrections at both the character-level entry and the word-level entry, and results have shown that correcting errors at the character-level has been proven effective. The use of spell checking softwares has been hypothesized to increase typing performance (Southern et al., 2012).

BrailleSketch is a gesture-based text input software that allows the users to input letters into a selected area by gesturing the Braille letter shape on the screen. BrailleSketch on a cell phone allows the user to touch anywhere on the screen, drag their finger in the pattern of the Braille letter, and with the release of their finger will input the intended letter into the device (example shown in Figure 1b). BrailleSketch is different from other Braille input software in the sense that it does not provide audio feedback after each letter but instead gives the audio feedback after the word is complete. This feature was designed with the intent to increase typing speed, without the focus on key correction with the addition of auto-correction.

Li, Fan, and Truong (2017) analyzed the use of BrailleSketch with 10 BLV Braille users. The study consisted of two parts, first the participants were given 15 minutes to type out as many phrases as they could and for the second part the participants were given three phrases to type out. The participants were given 10 minutes of training before beginning the study, they were then asked to complete these two parts five times, with a 5-minute break in between each session. The results for the first part gave an average of 5.37 wpm for the first session and 11.39 wpm for the final session. The results for the second part of the study were 6.56 wpm for the first session and 14.53 wpm for the final session. The findings also suggest that the typing speed did not begin to level out during the session, suggesting that the typing speed would continue to increase with further practice. The researchers also conducted a side experiment on a Braille expert, adding in the audio feedback after each letter rather than just at the end of the word. The final session typing speed of this participant was 8.37 wpm compared to the 11.39 wpm of the participants that conducted the experiment without the letter audio feedback (Li et al., 2017).

Figure 1

Digital Keyboard Examples



Note. a) Senorita is a simplified touchscreen QWERTY keyboard, b) BrailleSketch Interface, and c) BrailleTouch Interface

Feedback

Feedback is mainly used as a response to an action performed on a touchscreen device, letting the user know what action was carried out based on their input. Three forms of feedback are visual, auditory, and haptic feedback. In order to provide the appropriate feedback for the users, it is important to know capabilities in order to create and use feedback that is easily interpreted. Auditory cues in the form of feedback have been evaluated based on verbal feedback and sonification (Csapó et al., 2015; Ferati et al., 2011; Grussenmeyer & Folmer, 2017; Hakobyan et al., 2013; Oh et al., 2013, 2015; Vatavu, 2017).

Oh et al. (2013, 2015) proposed and evaluated the use of verbal feedback and gesture sonification feedback for the purpose of teaching touchscreen gestures. The two studies were set up similarly, but with additions added to the 2015 research. Both studies started with recruiting 12 sighted participants that tested different sound parameters such as pitch, volume, stereo, and timbre, to evaluate whether they could be used as a form of sound mapping. The sound parameters were used to convey screen coordinates, as well as different types of gesture characteristics: location, size, speed, direction, and shape. Both studies showed the combination of pitch and stereo having the best result for user understanding. The second phase of the 2013 study and the third phase of the 2015 study consisted of recruiting six BLV participants. These phases focused on gesture replication tasks based on verbal and gesture sonification feedback techniques. The performance and accuracy of the tasks being completed were pretty similar when comparing the verbal to the sonification gestures tasks, however subjective data showed preference in verbal feedback over sonification. The 2015 study had an additional phase within it, where its second phase was designed to evaluate gesture sonification feedback with single-stroke, multistroke, and multitouch gestures. The results showed multistroke gestures being harder to understand while sonification gestures were in use.

Haptic feedback can be used by BLV users as a tactile response to a non-tactile flat touchscreen, which can be used to sense and find target items. Vibration can be used as a notification, as a pulse to indicate an input, and as a form of mapping through vibrotactile intensity. Haptics are typically used with some form of audio to ensure the user understands what is happening on the screen. Previous research has investigated multimodal feedback, such as the use of both audio and haptic feedback, in efforts to provide the same level of information that is presented with visual cues and feedback (Tennison & Gorlewicz, 2019; Vatavu, 2017).

Tactile feedback can also include adhesive tactile dots or Braille labels placed on devices by the user to indicate target areas, and while not built into the device they still provide a tangible form of feedback that provides essential information to the user on their personal devices (Kane et al., 2008). However, other personal touchscreen devices owned by users that can be found in the household and used by others have little to no accessibility research to address the usability of the technologies, such as smart locks, smart thermostats, coffee makers, dish washing machines, washing and drying machines, as well as other household devices used by more than one member.

Public Devices

Not a lot of research has been done in evaluating the accessibility of touchscreen devices that are outside the home or with presenting solutions to the barriers that exist in the public domain for BLV users. A few studies that focused on the accessibility of mobile touchscreen devices had brief mentions of touchscreen devices in the public domain (Kane et al., 2008), and the social challenges faced while interacting with personal touchscreen devices in the public (Abdolrahmani et al., 2018; Kane et al., 2009). Abdolrahmani's (2018) study presented the use of VAPAs in public spaces, where some challenges discussed were concerns for privacy, the draw of attention, and the impact of ambient sounds on the accuracy of the VAPA.

Kane et al. (2009) conducted a study that interviewed participants about their experiences with their own mobile devices, and how they use or adapted to use them in the public domain. Their research presented three forms of barriers discussed by the participants: situational, fatigue/changing abilities, and device failure. Situational effects on use presented four types of difficulties in crowded spaces, lighting, while walking and interruptions. This included struggles while in vehicles or navigating through crowds, when the lighting in the room was not ideal, and while on the go due to reduction of motor control or situational awareness.

Guo, Kong, Rivera, Xu, and Bigham conducted a study in 2019, with the sole purpose of investigating interaction with touchscreen devices out in public spaces. Their research investigated the accessibility, or lack thereof, for touchscreen devices in public spaces, such as the screens on the back of passenger chairs on an airplane, coffee machines, and touchscreen self-checkout devices at a grocery store. A formative study consisting of semi-structured interviews was used to gather insight from BLV individuals centered on the challenges faced when interacting with dynamic touchscreen interfaces in public spaces, and design considerations for a system to provide better access. Afterwards, the researchers designed and developed a three-part system that they refer to as StateLens, which is a reverse engineering solution whose goal is to make exist-ing dynamic touchscreens accessible. The system uses point-of-view videos found online or taken by users to get the screen setup of the existing interfaces, and then creates an audio guide for intended actions for the interface. The last part of their user interaction setup is the 3D printed finger cap discussed in the Input Modalities section above, that allows the users to move their finger across the screen without activating any function in an effort to reduce slips (Guo et al., 2019).

Recommendations

Past researchers have presented recommendations for designing touchscreen devices to be more blind friendly. Branham and Roy (2019) presented recommendations directed towards commercial VAPA guideline authors, researchers, and developers of these systems. They reviewed VAPA guidelines that were published from Google, Amazon, Microsoft, Apple, and Alibaba. After their review, they suggested the creation of more inclusive actions and preferences, updating accessibility sections of the guidelines to not only address users with disabilities but also other situational conditions that can impact the user’s ability to interact with the system, and lastly, allowing the system to be customizable to the user’s preference.

Buzzi et al. (2017) created a list of recommendations based on their results of BLV participants performing gestures on a smartphone, and the subjective feedback about user preference and ease of execution. Their recommendations for choosing and designing gestures on smartphone devices included avoiding multi-touch gestures, using single-stroke gestures, using short gestures, setting up basic directions, and for more complex gestures using rounded angles (Buzzi et al., 2017).

The study conducted by Kane et al. (2008), mentioned previously, evaluated their Slide Rule and provided some system design recommendations, including risk-free exploration, gestural mappings that are intuitive to the user, and time allowance to get the current location or return home, and set-up for quick browsing and navigation. These design considerations were similar to those of Guo et al. (2019) for StateLens, emphasizing risk-free exploration, reducing cognitive load, and supporting the independence of the user.

Guidelines

While the recommendations above are suggestions of what can be done to make touchscreen devices more accessible to the BLV community, a comprehensive set of guidelines can be used as instructions to follow in efforts to complete the recommendations.

Palani, Fink, and Giudice (2020) and Tennison and Gorlewicz (2019), investigated the usability and acceptability of line profiles on touchscreens. Both studies evaluated the feasibility for following lines on touchscreens via either vibration or sound feedback. Tennison and Gorlewicz (2019), provided a list of guidelines for designing graphics for non-visual use that they believed to be similar to previous research recommendations. Their guidelines included the use of start and end points on lines, vibration-only and audio-only lines, bordered lines, alternative feedback signals, common tracing strategies, multitouch techniques, anchoring techniques, and screen orientations. While the set of guidelines created by Palani, Fink, and Giudice (2020) focused on maximizing accuracy and performance based on the results from experiments with simple line layout, their study created guidelines that addressed line width, separation, orientation, intersections, as well as the use of vibration feedback.

In 2017, Vatavu created a set of design guidelines based on their overview of past accessibility literature. They established 15 guidelines, addressing areas of general accessibility and usability, as well as the challenges faced by BLV mobile users. The guidelines can also be broken down into six groupings: design, detect, develop, deliver, allowance, and evaluation. The design guidelines include designing for new form factors, wearable devices, interactions for multiple devices, touch gestures, learning gestures, new features, and avoidance of usability obstacles. The detect guidelines include detection of context and unintended touch or inputs. Due to the limited available data on gesture recognition with BLV users, the creation of a guideline to develop new recognition techniques, or to adapt current techniques for BLV individuals was created. There are two guidelines in the deliver grouping that consist of providing working feedback for users regardless of their vision status, as well as during and after gestures are inputted into the system. The last two guidelines include allowing for customizable settings to match the user's needs and the evaluation of technologies through real-world scenarios (Vatavu, 2017).

Interview Study

Methodology

Participants

Interview participants were recruited by sending out the informational emails introducing the research project, purpose, setup, and compensation to a contact with the Association for the Blind and Visually Impaired (ABVI) and other organizations related to vision, as well as posting in the social media platform Reddit geared towards the BLV communities. The organizations and participants were also asked to forward the study information to others that may be interested and meet the criteria. The criteria being, they are 18 years of age or older and they identify as blind or low vision. A

Google form was included in the information about the study to allow potential participants to sign up for interviews, and this form also gathered basic demographic information and contact information (see Appendix B).

The informed consent information (see Appendix C) was sent to the participants through email before the interviews, and then introduced again at the beginning of the interview to open up time for any questions pertaining to the study. The participants were given the option to either provide verbal consent through the Zoom meeting while being recorded, or email consent by sending a reply of “I consent to include my data in the research study” to the email that contained the consent form. After interviews were completed, participants were emailed a $35 Amazon gift card as compensation for their time.

Participants for this study (Table 1) included 20 adults (*N* = 20), where 14 (70%) identified as male and six (30%) as female, 11 (55%) identified themselves as Black or African American, and the remaining nine (45%) as White or Caucasian. There was one (5%) participant between the ages of 18-24, 11 (55%) between 25-35 years old, two (10%) between 36-44 years old, four (20%) between 45-54 years old, and two (10%) participants between 55-70 years old. All had previous experience with touchscreen interfaces, and identify as blind (*n* = 2 (10%)) or having low vision (*n* = 18 (90%)). Two of the participants identified as legally blind, they were included within the low vision category, this was done because each participant indicated that they were not completely blind and had some level of vision.

Table 1

Interview Participant Demographic Information

ID	Gender Identity	Age	Race	Vision Status	Vision Description
P1	Man	45 - 54 years	Black/African American	Low Vision	I can still see but not so well
P2	Man	25 - 35 years	Black/African American	Low Vision	---
P3	Man	25 - 35 years	White/ Caucasian	Low Vision	Cannot see far
P4	Man	25 - 35 years	Black/African American	Low Vision	Can see with glasses
P5	Man	25 - 35 years	Black/African American	Low Vision	---
P6	Man	25 - 35 years	White/ Caucasian	Low Vision	Severe
P7	Man	25 - 35 years	Black/African American	Low Vision	Short Sighted
P8	Man	25 - 35 years	Black/African American	Low Vision	Blurry
P9	Man	25 - 35 years	Black/African American	Low Vision	Hard to see images, color blindness
P10	Man	36 - 44 years	White/ Caucasian	Low Vision	---
P11	Man	25 - 35 years	Black/African American	Low Vision	---
P12	Woman	25 - 35 years	Black/African American	Low Vision	---
P13	Man	45 - 54 years	White/ Caucasian	Legally Blind	---

P14	Man	25 - 35 years	Black/African American	Low Vision	---
P15	Woman	18 - 24 years	White/ Caucasian	Low Vision	can't see far
P16	Woman	55 - 70 year	Black/African American	Legally Blind	I have just enough vision to get into trouble, not out of it
P17	Woman	45 - 54 years	White/ Caucasian	Blind	No light perception. I'm just completely blind.
P18	Man	55 - 70 year	White/ Caucasian	Low Vision	no night vision or low light vision
P19	Woman	36 - 44 years	White/ Caucasian	Blind	Totally blind, can see light, dark, and colors
P20	Woman	45 - 54 years	White/ Caucasian	Low Vision	Retinitis pigmentosa

Procedure

Twenty one-on-one, semi-structured interviews were conducted with participants. Before each interview started, the researcher asked the participant if they had time beforehand to read through the informed consent form, asked if there were any questions before starting, explained the purpose of the interviews, and informed them that the interview would be recorded for transcribing and data analysis purposes.

Interviews consisted of a set of questions (found in Appendix D) that asked participants about their current practices with both personal and public touchscreen devices, with follow-up questions asked for clarification and elaboration. The questions were designed to answer RQ1 (What current features exist to assist individuals who are blind or have low vision in independent interactions with touchscreens?), RQ2 (What are the perceptions and experiences of individuals who are blind or have low vision in interactions with touchscreen interfaces?), RQ3 (What are the conditions and/or constraints that are preventing individuals who are blind or have low vision from having effective interactions with touchscreens?), and RQ4 (What improvements could be made to touchscreen interfaces that could improve interactions and experiences with individuals who are blind or have low vision?) by having the participants share types of features used, past and current experiences, challenges, approaches, and hope for the future with touchscreen devices. The semi-structure format of the interviews led to participants talking about what they would like to see in the future, even though it wasn't on the original list of questions designed for the interview. After discussing the same topic of future hopes with the first few participants the researcher started asking participants directly about what their hope to see in the future for touchscreen interactions. These types of questions closely mirror Blythe et al.'s (2002) technology biographies approach of gathering information on the past developments, current uses, and desired future developments based on concerns and problems discussed around the technology. This approach has been described as a holistic and explicit method that can be used by researchers in efforts of creating product suggestions, which ties in closely to the goals of this research. Interviews lasted between 12 minutes to 50 minutes (M = 23.46, SD = 11.52), depending on participant responses. The interviews were conducted and recorded with Zoom, transcribed with the Automatic Speech Recognition (ASR) software offered on the Otter website, and additional notes were taken throughout the session.

Data Analysis

Interview transcripts were reviewed, analyzed, and annotated by one researcher to discover potential patterns and the emergence of themes. The analysis consisted of listening to each individual audio recording and reading through the transcripts, while taking notes in a spreadsheet on the approaches and challenges discussed. After all interviews were analyzed the spreadsheet was used to compare the responses for commonalities and differences. Responses were often straight forward and required organization rather than interpretation, such as “font size was too small” or “used voice commands.” In some instances the responses involved summarizing participant statements through more detailed keywords/phrases and recording those in the spreadsheet to find the similarities between the participants. For example, if a participant mentioned getting help or having someone else interact with the screen for them the keyword “help” was put into the corresponding column. The spreadsheet was used to gather the frequencies of the same answers across the participants, this was done by putting the spreadsheet into R studio. Each question was evaluated individually to identify common responses, and all responses were then analyzed to identify overarching themes. The themes are discussed at the end of the results section. Cross tabulation tables are used to display the results of the entire interview participant group, as well as subgroups based on vision status, blind and low vision.

Results

Participants' views of touchscreens varied on whether they were their own personal touchscreen devices or those that are in the public domain. The findings show that the participants preferred interacting with their own devices because they are able to adjust them to their preferences, through various device settings on personal devices and by putting high markings and tape as tactile indicators on more appliance or machine-like devices, such as washing machines.

The results divided participants into groups based on their identified vision status: blind and low vision. While separate age groups were also evaluated, the sizes of the groups were too uneven for a proper comparison and therefore were not divided into groups for analysis.

It is important to note that detailed reporting of results presented in tables can be found in Appendices E-J. This is done to ensure that all readers, especially those who may use an assistive technology, such as a screen reader, would have full access to the results. The figures provide a visual representation of the information that is in the associated tables and appendices, and therefore are marked as decoration to limit repetitive information on screen readers.

Personal Touchscreens

When asked about what type of touchscreen devices they owned, participants were given examples such as smartphone, tablet, smartwatch, and coffee maker. The most common responses of personal touchscreens owned included smartphones, computer/laptop, and smartwatches. The least common type of touchscreen devices indicated by the participants were in-home appliances, such as washing machines and dryers, dishwashers, coffee makers, microwaves, printers, ovens, refrigerators, air fryers, and GPS devices in the car. Figure 2 shows the overall selection from all participants of each device, and Table 2 (Appendix E for text description) shows the breakdown between blind and low vision participants.

When talking about the appliances in the home, however, participants noted that the interaction was a bit more difficult than their personal mobile devices such as smartphones, tablets, laptops, and smartwatches. The difficulty stemmed from the fact that there were no additional customization features for the touchscreens on appliances, such as increasing the font size or including screen readers.

Figure 2

Personal Touchscreen Devices Owned by Interview Participants

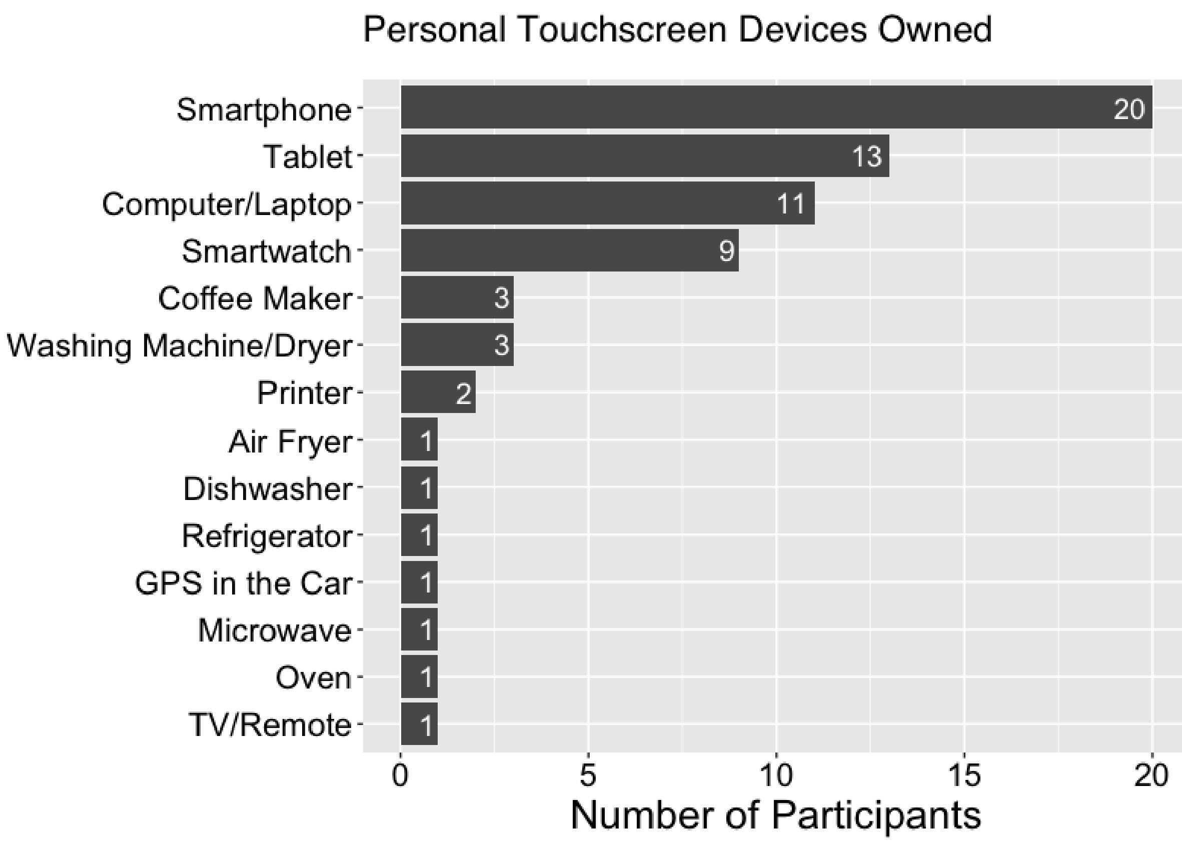


Table 2

Frequencies of Personal Devices Owned by Interview Participants by Vision Status

Personal Devices	Total (*N* = 20)		Blind (*n = 2)*		Low Vision (*n = 18)*	
	N	%	*n*	%	*n*	%
Smartphone	20	100	2	100	18	100
Tablet	13	65	0	0	13	72.22
Computer/Laptop	11	55	0	0	11	61.11
Smartwatch	9	45	2	100	7	38.89
Coffee Maker	3	15	0	0	3	16.67
Washing Machine/Dryer	3	15	0	0	3	16.67
Printer	2	10	0	0	2	11.11
Air Fryer	1	5	0	0	1	5.56
Dishwasher	1	5	0	0	1	5.56
Refrigerator	1	5	0	0	1	5.56
GPS in the Car	1	5	0	0	1	5.56
Microwave	1	5	0	0	1	5.56
Oven	1	5	0	0	1	5.56
TV/Remote	1	5	1	50	0	0

Note. For the raw text reporting of this table, see Appendix E

Mobile Touchscreen Devices. Most smartphones, tablets, laptops, and smartwatches have customization settings and accessibility features to enhance the user experience. Participants were asked about what type of features they set up on their personal devices to help them better interact with the device. The most common features (see Figure 3 and Table 3 (Appendix F for text description)) used between the participants was a screen reader, where most participants identified as using either VoiceOver, which is on iOS devices, or TalkBack, which is on Android devices. This was followed by voice commands such as Alexa, Siri, or Google Assistant, then screen magnifiers, text-to-speech, increasing the font size, increasing the icon size, adjusting the brightness of the screen, and high markings. Features that were only mentioned once by low vision participant were audio commands, adjusting screen contrast, voice messages, bolding the text, and refreshable Braille Display. Lastly, one of the blind participants indicated the use of Braille screen input.

Figure 3

Features Used by Interview Participants for their Personal Touchscreen Devices

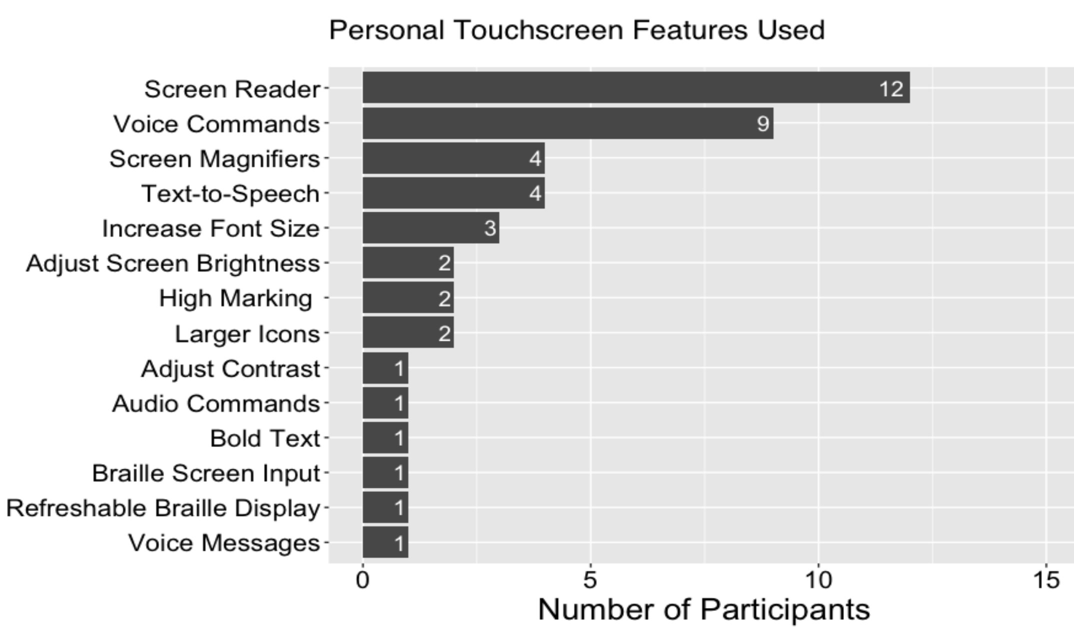


Table 3 *Frequencies of Personal Features Used by Interview Participants by Vision Status*

Features	Total (*N* = 20)		Blind (*n = 2)*		Low Vision (*n = 18)*	
	N	%	*n*	%	*n*	%
Screen Reader	12	60	2	100	10	55.56
Voice Commands	9	45	0	0	9	50
Screen Magnifiers	4	20	0	0	4	22.22
Text-to-Speech	4	20	1	50	3	16.67
Increase Font Size	3	15	0	0	3	16.67
Adjust Screen Brightness	2	10	0	0	2	11.11
High Marking	2	10	0	0	2	11.11
Larger Icons	2	10	0	0	2	11.11
Adjust Contrast	1	5	0	0	1	5.56
Audio Commands	1	5	0	0	1	5.56
Bold Text	1	5	0	0	1	5.56
Braille Screen Input	1	5	1	50	0	0
Refreshable Braille Display	1	5	0	0	1	5.56
Voice Messages	1	5	0	0	1	5.56

Note. For the raw text reporting of this table, see Appendix F

Applications that can be downloaded or installed on personal smart devices can be used to improve accessibility for easier interaction with the touchscreens and allow for an alternative format of information to be received. Applications used by the participants (see Table 4 (Appendix G for text description)) included those related to use of voice for commands, texting, and recordings, including: Alexa, Siri, Google Assistant, Dictation (text-to-speech), and Voice Record. Other applications discussed provide audio feedback to the users based on the information on the screen, such as Call Announcer and screen readers, as well as audio feedback based on the user's surroundings with the use of the camera including Speak, Look Around, Be My Eye, and Voice Dream Scanner and Meter. Another form of audio feedback for providing alternative means for visual content included libraries of audio clips and audiobooks, those include National Libraries Braille Reading, Audible, and Braille and Audio Reading Download (BARD). There were also applications that adjusted the set up of the whole phone, including dark mode, and Rejected Capacitive Touch, which adjusts the sensitivity of the screen. The last few applications were discussed by the participants as applications that made interaction with the outside world easier, including Google Maps, Google Translate, FitBit, along with scheduling, medical, and banking applications.

Table 4

Applications Used by Interview Participants with their Personal Touchscreen Devices by Vision Status

Applications	Total (*N* = 20)		Blind (*n* = 2)		Low Vision (*n* = 18)	
	N	%	*n*	%	*n*	%
Siri	5	25	1	50	4	22.22
Alexa	4	20	1	50	3	16.67
AIRA	3	15	2	100	1	5.56
Be My Eye	2	10	0	0	2	11.11
Google Maps	2	10	1	50	1	5.56
National Libraries Braille Reading Download Program	2	10	0	0	2	11.11

Screen Reader	2	10	0	0	2	11.11
Audible/Kindle	1	5	0	0	1	5.56
Banking application(s)	1	5	0	0	1	5.56
Call Announcer	1	5	0	0	1	5.56
Dark Mode	1	5	0	0	1	5.56
Dictation	1	5	0	0	1	5.56
FitBit	1	5	0	0	1	5.56
Google Assistant	1	5	1	50	0	0
Google Translate	1	5	0	0	1	5.56
Braille and Audio Reading Download (BARD)	1	5	0	0	1	5.56
Look Around	1	5	1	50	0	0
Magnifier	1	5	0	0	1	5.56
Medical application(s)	1	5	0	0	1	5.56
Rejected Capacitive Touch	1	5	0	0	1	5.56
Scheduling application(s)	1	5	0	0	1	5.56
Speak	1	5	0	0	1	5.56
Voice Dream Scanner and Meter	1	5	0	0	1	5.56
Voice Record	1	5	0	0	1	5.56

Note. For the raw text reporting of this table, see Appendix G

At Home Touchscreen Appliances. Touchscreen appliances in the home that were owned by participants who have low vision include such things as a coffee maker, laundry machines (washer/dryer), printers, ovens, refrigerators, dishwashers, microwaves, air fryers, and lastly GPS systems in the car. One participant who was blind mentioned owning a smart television that had a completely touchscreen remote. As shown in Figure 2 and Table 2 (Appendix E for text description), the three most commonly owned devices were the coffee maker, laundry machines, and at home printers, where each of the remaining devices were mentioned once. Participants with personal touchscreens that are appliances in the home (*N* = 6 (30%); Low Vision, *n* = 6 (33.33%)) mentioned that their approaches to interacting with them were either they used their eye glasses or a magnifier (*N* = 2 (10%); Low Vision, *n* = 2 (11.11%)), had a family member or friend help them out (*N* = 1 (5%); Low Vision, *n* = 1 (5.56%)), or put high markings or tape on them to provide them with tactical feedback (*N* = 2 (10%); Low Vision, *n* = 2 (11.11%)).

Public Touchscreens

The public domain is where the participants expressed the most frustrations and difficulties with their interactions with touchscreen devices. Two of the participants indicated that they have never used public touchscreens, both of which gave the explanation that the touchscreens in the public are not accessible. These two participants were also the only two participants to identify themselves as blind. However, one of the participants who identified as blind did describe an experience with self-checkout at grocery stores and restaurant kiosks. Although they were not the ones interacting with the screens, they had a support worker running errands with them. The remaining participants indicated at least one type of device that they have used or tried to use in the public setting. As shown in Figure 4 (breakdown shown in Table 5 (Appendix H for text description)), the most common device used was the ATM, followed by self-checkout machines in stores, kiosks in restaurants, computer/laptops in the office or library, coffee makers, smart TVs with touchscreen remotes, kiosks at the airport, tablets for customer or client use in the hospital, DMV, or social security office, touchpads, and voting machines. Digital maps at the mall, post office kiosks, printers, fingerprint security, and soda machines were mentioned by one participant who has low vision.

Figure 4

Public Touchscreen Devices Used by Interview Participants

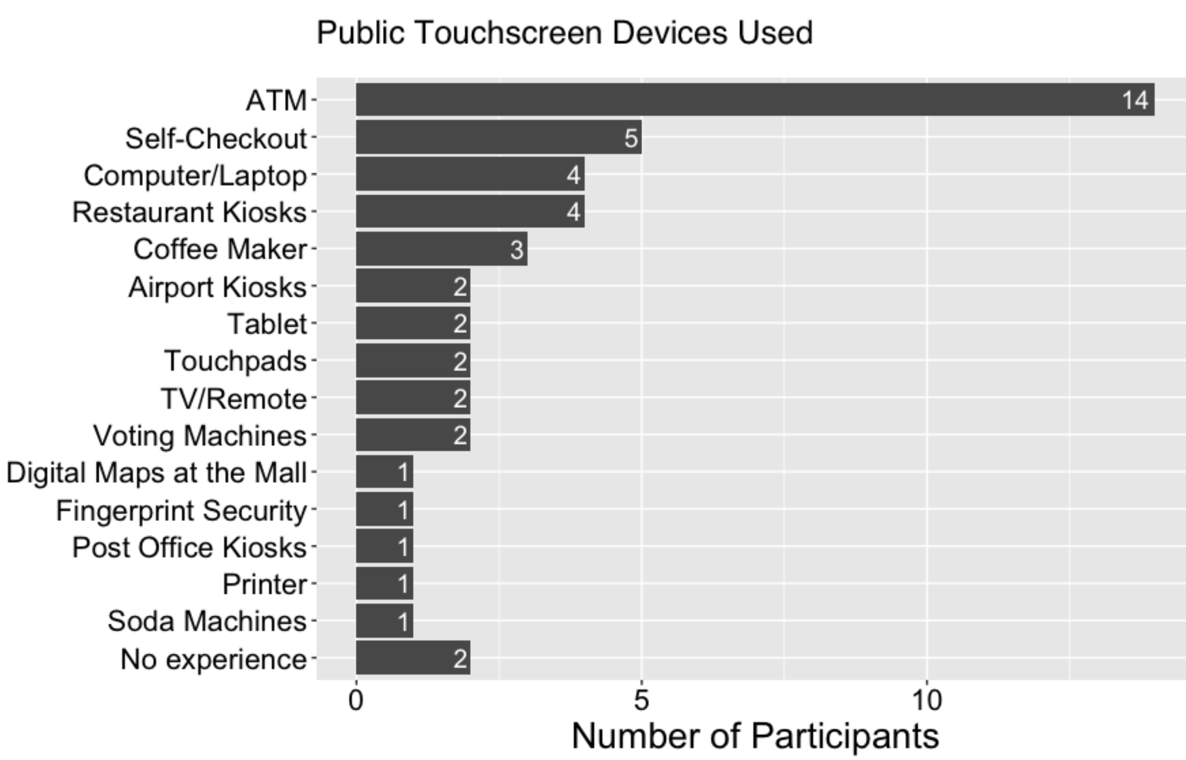


Table 5

Frequencies of Public Touchscreen Devices Used by Interview Participants by Vision Status

Public Devices	Total (*N* = 20)		Blind (*n = 2)*		Low Vision (*n = 18)*	
	N	%	*n*	%	*n*	%
ATM Machines	14	70	0	0	14	77.78
Self-Checkout	5	25	1	50	4	22.22
Computer/Laptop	4	20	0	0	4	22.22
Restaurant Kiosks	4	20	1	50	3	16.67
Coffee Maker	3	15	0	0	3	16.67
Airport Kiosks	2	10	0	0	2	11.11
Tablet	2	10	0	0	2	11.11
Touchpads	2	10	0	0	2	11.11
TV/Remote	2	10	0	0	2	11.11
Voting Machines	2	10	0	0	2	11.11
Digital Maps at the Mall	1	5	0	0	1	5.56
Fingerprint Security	1	5	0	0	1	5.56
Post Office Kiosks	1	5	0	0	1	5.56
Printer	1	5	0	0	1	5.56
Soda Machines	1	5	0	0	1	5.56
No experience with public touchscreens	2	10	2	100	0	0

Note. For the raw text reporting of this table, see Appendix H

Features. Participants were asked about what type of features they have used with public devices to help them better interact with the device. Five participants indicated that they have never used an additional feature, two of which include those who have never used public devices before, and the remaining three explained that they did not use any accessibility features because they have never seen them available. One participant with low vision noted that it depended on what type of device is being used and whether or not the features could be accessed. Features that have been identified and used by participants who identified as low vision include, audio commands, text-to-speech, increased font size, voice commands, AIRA, adjusted brightness, larger icons, and magnifiers. Figure 5 below, shows the number of participants that mentioned each of the features above, Table 6 (Appendix I for text description) shows the number and percentages of by vision status.

While the participants have used such features in the past, an important note is that the participants stressed that the features in the public are very hard to find, and it is difficult to know which will have those features. An example from the interviews includes the audio commands on the ATM machines, where in order to access the feature a pair of headphones need to be plugged into the machine. However, when asked about using this feature some participants (*N* = 6 (30%); Blind, *n* = 2 (100%); Low Vision, *n* = 4 (22.22%)) said that they did not know if that is available on the machines they use or that they were unaware of the feature all together. One participant (*N* = 1 (5%); Blind, *n* = 1 (50%)) stated that “you wouldn't really have a way to know if the kiosks were accessible because, you know, generally they're not and you would just assume probably, they weren't listed at some way of knowing any differently to how to activate those kiosks and things. But yeah, generally, from any situation I've ever run into they're not accessible."

Figure 5

Features Used by Interview Participants while using Public Touchscreen Devices

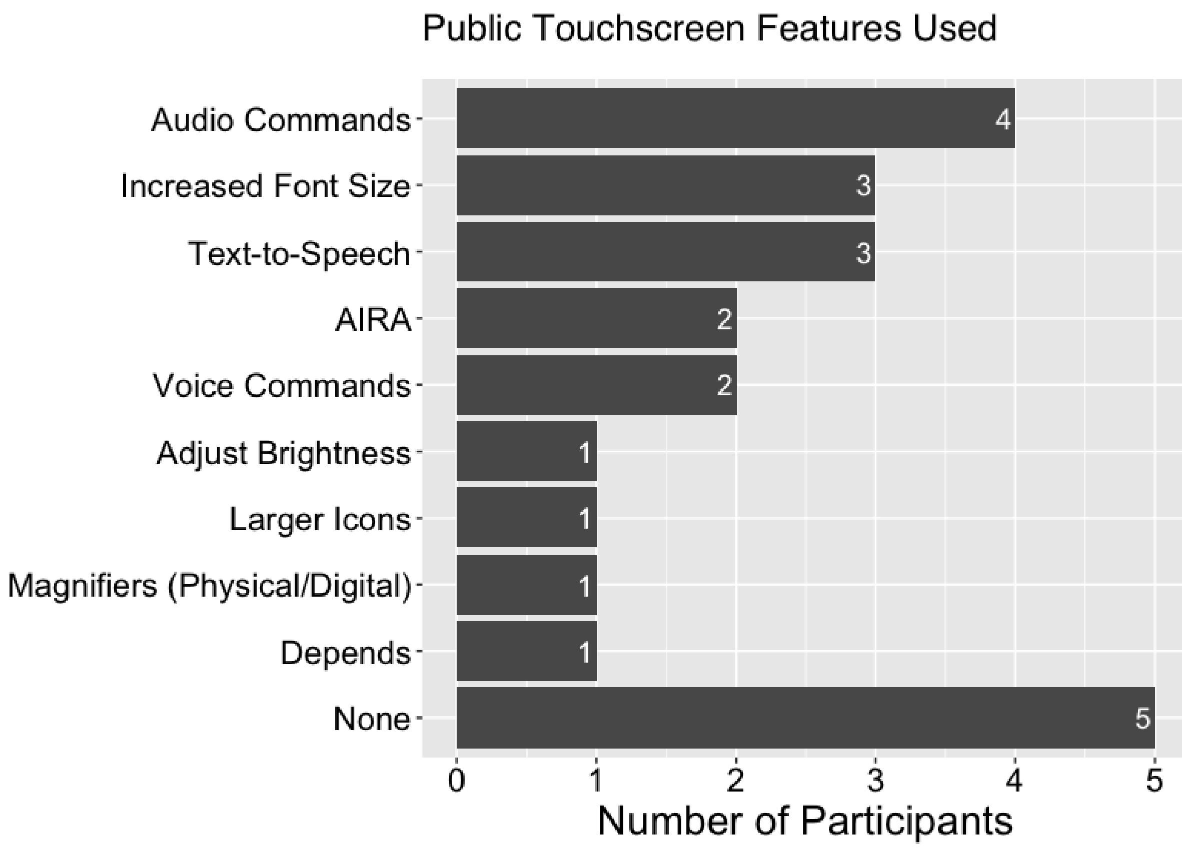


Table 6

Frequencies of Features Used by Interview Participants with Public Touchscreen Devices by Vision Status

Public Features	Total (N = 20)		Blind (n = 2)		Low Vision (n = 18)	
	N	%	n	%	n	%
Audio Commands	4	20	0	0	4	22.22
Increased Font Size	3	15	0	0	3	16.67
Text-to-Speech	3	15	0	0	3	16.67
AIRA	2	10	0	0	2	11.11
Voice Commands	2	10	0	0	2	11.11
Adjust Brightness	1	5	0	0	1	5.56
Larger Icons	1	5	0	0	1	5.56
Magnifiers (Physical/Digital)	1	5	0	0	1	5.56
Depends	1	5	0	0	1	5.56
None	5	25	2	100	3	16.67

Note. For the raw text reporting of this table, see Appendix I

While most features are built into the device, one feature used by two participants with low vision was AIRA, a smartphone application that connects to a trained agent that provides visual interpretation of the user's surroundings which includes reading and navigating. The application connects the user to a visual interpreter in real time, the user then points the device in the direction in which they require visual interpreting. The interpretation can be about anything including describing the navigation of their surroundings, any text or writings, and visual descriptions of items (Aira Tech Corp, n.d.). This application can then be used to interact with touchscreen devices in the public, by pointing the camera of the phone towards the devices and explaining to the visual interpreter your goal of the interaction for nativational instructions.

Approaches. Participants were also asked about their approaches while interacting with public touchscreen devices (see Figure 6 and Table 7 (Appendix J for text description)). Four participants, two who are blind and two with low vision indicated that their approach is avoidance. In many cases like the grocery store or the airport, the solution to avoiding frustration is to use the person or agent that does the same job, when available. This solution was similar to the most common approach used by the participants, which was giving up their sense of independence and asking for help or bringing an assistant or family member to help with the interaction. Another approach participants took was learning the layout of the screen for technologies that they came across often, but the issue with this approach that they mentioned is when devices are updated the layout sometimes shifts and they have to relearn the layout. Nine participants (N = 9 (45%); Low Vision, n = 9 (50%)) indicated that they will look closer at the screen and/or bring physical objects with them that make the interaction easier with their conditions, such as a magnifying glass, their eye glasses, and/or a flashlight. Another approach included using their smartphones to either utilize AIRA (an application that provides visual interpretation), or to take a picture with their camera and then zoom in as a form of magnification. The rest of the approaches mentioned by participants focused on the use of features when available, including audio commands, increased brightness, larger icons, and increased font size.

Figure 6

Approaches Used by Interview Participants while Interacting with Public Touchscreen Devices

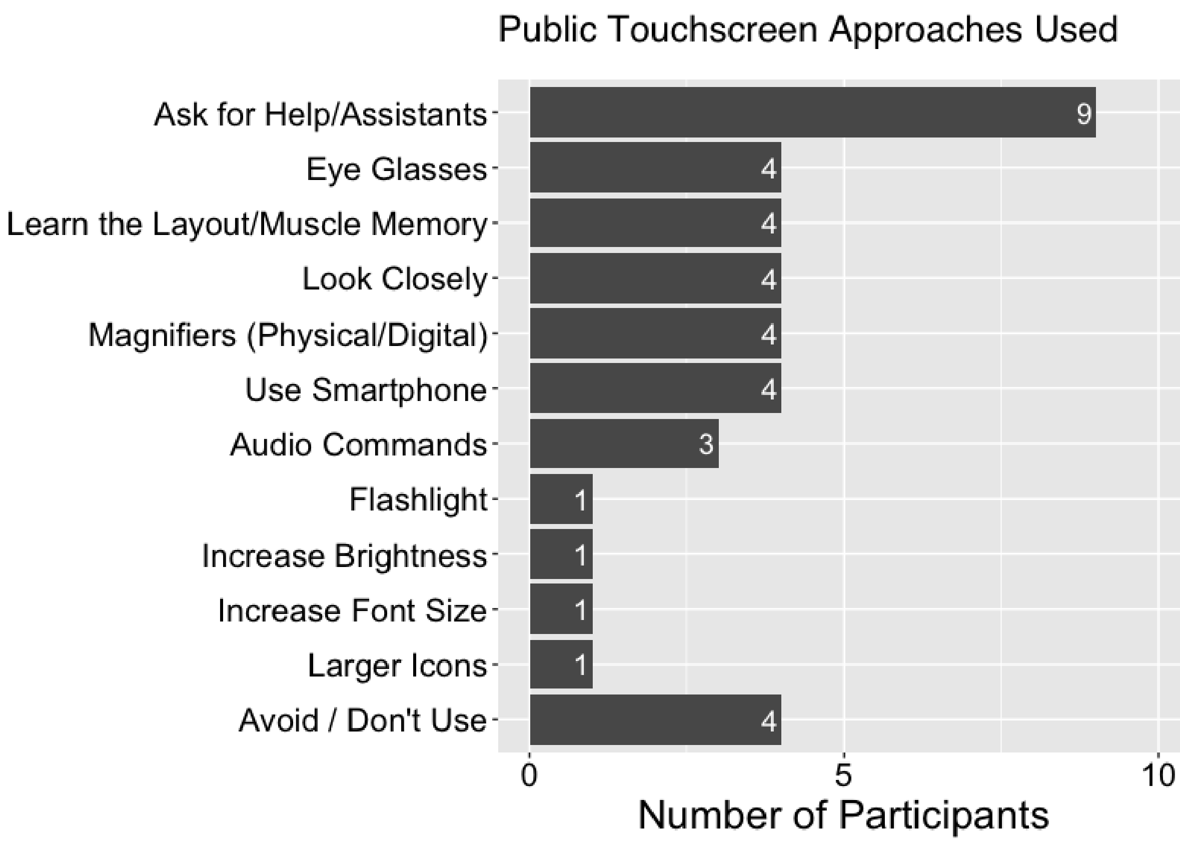


Table 7

Frequencies of Approaches Used by Interview Participants with Public Touchscreen Devices by Vision Status

Personal Approaches	Total (*N* = 20)		Blind *(n = 2)*		Low Vision *(n = 18)*	
	N	%	*n*	%	*n*	%
Ask for Help/Assistants	9	45	1	50	8	44.44
Eye Glasses	4	20	0	0	4	22.22
Learn the Layout/Muscle Memory	4	20	0	0	4	22.22
Look Closely	4	20	0	0	4	22.22
Magnifiers (Physical/Digital)	4	20	0	0	4	22.22
Use Smartphone	4	20	0	0	4	22.22
Audio Commands	3	15	0	0	3	16.67
Flashlight	1	5	0	0	1	5.56
Increase Brightness	1	5	0	0	1	5.56
Increase Font Size	1	5	0	0	1	5.56
Larger Icons	1	5	0	0	1	5.56
Avoid/Don’t Use	4	20	2	100	2	11.11

Note. For the raw text reporting of this table, see Appendix J

Accessibility. All 20 participants said “yes” when asked if they would use public touchscreen devices more in the future if they were more accessible. Two participants with low vision (N = 2 (10%); Low Vision, n = 2 (11.11%)) commented that they love touchscreen devices and would want to use them more often.

Touchscreens in General

The participants were probed about whether or not they believed the available accessibility for touchscreen devices worked for what they used them for or if they were lacking in some areas. While eleven participants (*N* = 11 (55%); Blind, *n* = 2 (100%); Low Vision, *n* = 9 (50%)) believed that they were lacking in some way or another, six (*N* = 6 (30%); Low Vision, *n* = 6 (33.33%)) of them said that they worked for what they used them for. However, three expanded on their answer, stating that they only use them for the basic things (*n* = 1), know that they need improvements for other users (*n* = 1), or that they work, but are not great (*n* = 1). The remaining three participants, who have low vision, said that it depends on the device and what is being attempted.

Experiences and Solutions. Participants were asked to recall an experience that they had with any type of touchscreen interface that was difficult, and to recall an experience that they had with any type of touchscreen interface that was easy.

Fifteen participants (*N* = 15 (75%); Blind, *n* = 2 (100%); Low Vision, *n* = 13 (72.22%)) recalled an interaction that was difficult for them, with a variety of settings and devices described within these experiences. Six participants (*N* = 6 (30%); Blind, *n* = 1 (50%); Low Vision, *n* = 5 (27.78%)) talked about experiences when they tried using a friend's phone or when they were transitioning to a new phone. Below is an experience shared by one of the participants with low vision (*N* = 1 (5%); Low Vision, *n* = 1 (5.56%)), when trying to interact with their friends phone:

> [My friend] gave me [their smartphone] to me, so I was unable to access it because the phone is lacking some features that I do use on my mobile phone, there was no voice recording it was not there, voice command or text to speech all these other features I know…So that was the first account. I come across I've been expressing having difficulty in going through a smartphone for the first time.

Six participants who identified as low vision (*N* = 6 (30%); Low Vision, *n* = 6 (33.33%)) talked about their experiences interacting with touchscreens in the public including ATMs (Low Vision, *n* = 1 (5.56%)), grocery store (Low Vision, *n* = 1 (5.56%)), airport kiosk (Low Vision, *n* = 1 (5.56%)), post office kiosk (Low Vision, *n* = 1 (5.56%)), and in general (Low Vision, *n* = 2 (11.11%)). One participant (Low Vision, *n* = 1 (5.56%)) talked about the sensitivity of devices, while two participants (Low Vision, *n* = 2 (11.11%)) discussed the difficulty of different screen sizes and the font being too small, as well as one participant (Low Vision, *n* = 1 (5.56%)) discussed the action of filling out and submitting forms online. One participant (Blind, *n* = 1 (50%)) who was blind indicated that interaction can be difficult when they use devices with different operating systems than they are used to, in this case they prefered Apple products or Android and Windows.

Seventeen participants (*N* = 17 (85%); Blind, *n* = 1 (50%); Low Vision, *n* = 16 (88.89%)) recalled experiences of interactions with touchscreens that they found easy. Two participants with low vision (11.11%) recalled experiences with technologies in the public. The first being with a kiosk at McDonald’s where the participant said that the large display and availability to change some aspects of the interface (e.g, size) in the restaurant made the interaction in public easier than other types of kiosks. The second participant mentioned when the ATMs have audio commands the interaction tends to go pretty smooth for them. The remaining fifteen participants (N = 15 (75%); Blind, n = 1 (50%); Low Vision, n = 14 (77.78%)) all recalled interactions with their personal devices that were easy because their preferred features were being used.

Hope for the Future. Participants' hope for improvement in the future focused on the technologies that are placed in the public domain, expressing the desire for available customization features and settings. Figure 7 and Table 8 (Appendix K for text descriptions) show the responses given along with the number of participants that mentioned the same hope through their interviews. The most common feature that participants hoped to see in the future for public devices was the ability to use voice commands, followed by increased font size, screen readers, audio commands, magnifiers, larger icons, and to adjust brightness of the screen. The next set of hopes showed up twice during the interviews, which were designing for all, physical keypads, simple mode (e.g, reduce busy screens to only display main text by getting rid of images), adjust contrast, consideration of the lighting where the device is positioned, connection to personal devices, and bold text. The last remaining ideas for future touchscreen devices in the public domain were mentioned once throughout the interviews by participants with low vision and included larger screens, sturdier devices, tactile feedback, and use of gestures.

Figure 7

Interview Participants' Future Hopes for Touchscreen Devices

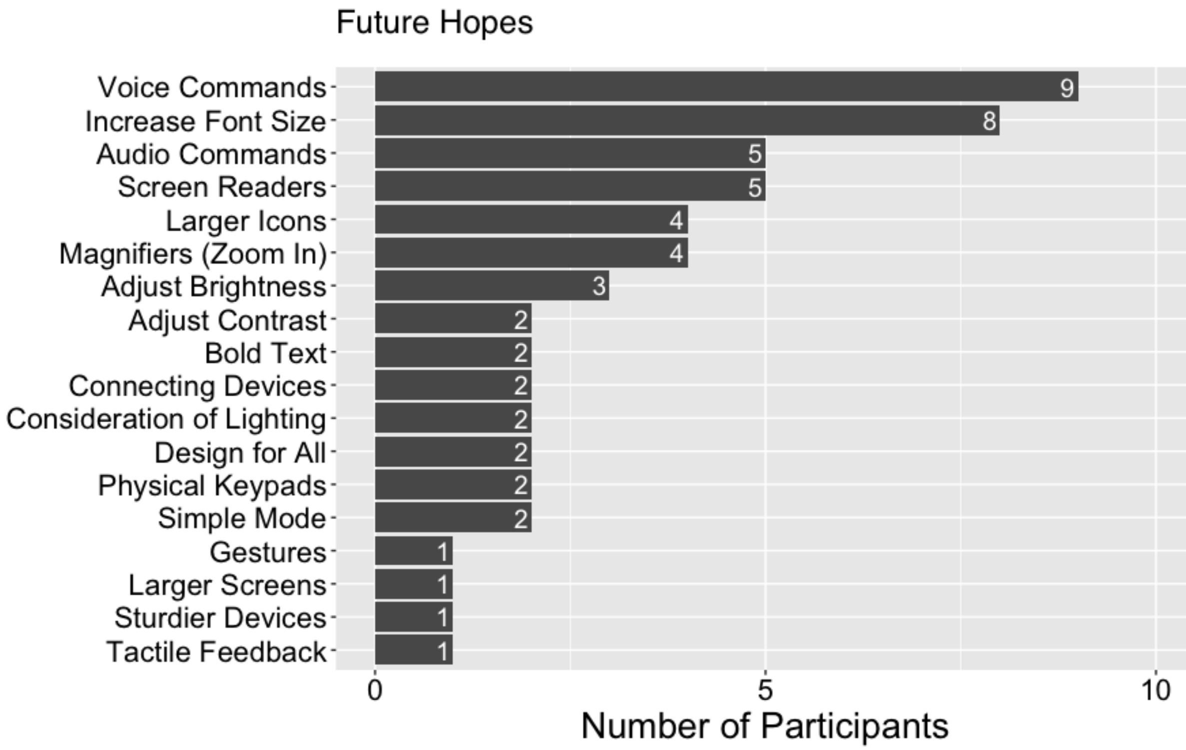


Table 8

Frequencies of Interview Participants' Future Hopes for Touchscreen Devices by Vision Status

Future Hopes	Total (*N* = 20)		Blind (*n = 2*)		Low Vision (*n = 18*)	
	N	%	*n*	%	*n*	%
Voice Commands	9	45	1	50	8	44.44
Increase Font Size	8	40	0	0	8	44.44
Audio Commands	5	25	0	0	5	27.78
Screen Readers	5	25	2	100	3	16.67
Larger Icons	4	20	0	0	4	22.22
Magnifiers (Zoom In)	4	20	0	0	4	22.22
Adjust Brightness	3	15	0	0	3	16.67
Adjust Contrast	2	10	0	0	2	11.11
Bold Text	2	10	0	0	2	11.11
Connecting Devices	2	10	1	50	1	5.56
Consideration of Lighting	2	10	0	0	2	11.11
Design for All	2	10	1	50	1	5.56
Physical Keypads	2	10	1	50	1	5.56
Simple Mode	2	10	0	0	2	11.11
Gestures	1	5	0	0	1	5.56
Larger Screens	1	5	0	0	1	5.56
Sturdier Devices	1	5	0	0	1	5.56
Tactile Feedback	1	5	0	0	1	5.56

Note. For the raw text reporting of this table, see Appendix K

Universal Design. When talking about the current accessibility and hopes for the future, four participants (*N* = 4 (10%); Blind, *n* = 2 (100%); Low Vision, *n* = 2 (11.11%)) mentioned standardizing customization features for personal touchscreen appliances and public devices, that not only aid people who are blind or who have low vision, but so that people with diverse abilities can also interact smoothly with the technologies. In addition, with standardizing customization or accessibility features, users would be able to know whether or not there are features they can use to improve their interactions. Two participants with low vision (*N* = 2 (10%); Low Vision, *n* = 2 (11.11%)) discussed the concept of universal design specifically mentioning older adults, and the idea that as people are getting older, more accommodations would be beneficial to ensure continuous access to the devices they have used in the past and want to continue to use in the future. A concern that arose during the interviews by the only two participants who identified as blind (*N* = 2 (10%); Blind, *n* = 2 (100%)) was how users would access the customization features if available, and how these features could be set up so that any user could activate them. The first participant mentioned this concern when discussing what was lacking with touchscreen devices:

> That was a menu in an Applebee's that just happened to have talkback loaded on it and that's the other thing is you wouldn't really have a way to know if the kiosks were accessible because, you know, generally they're not and you would just assume probably they weren't listed at some way of knowing any differently to how to activate those kiosks and things.

The second participant described their approach for easier excess when talking about future hopes for touchscreen devices:

> Well, definitely public accessibility at all. Because there's none. They could at least make some kind of a voice assistant. Or, well use some kind of operating system like Android or iOS, make sure there's a screen reader setting that's easy to access. Like, I don't know, tap the left hand corner three times to make it talk, etc.

Discussion

While the results section divides the data by vision status, the size difference between the groups makes it difficult to compare the results. However, during the interviews some differences between the groups were noticed, including the type of features being used and approaches taken to interact with the touchscreen devices. The participants who identified as blind utilized fewer features and their accessibility with the devices were more heavily dependent on voice commands, audio commands, and screen readers. Participants with low vision had more accessibility features available to them that made interacting with the devices easier on them, such as adjusting the screen brightness, increasing the font or icon sizes, and magnifiers. This also shows through in the future hopes for the participants.

Participants felt most comfortable with their personal devices, which was due to the ability to customize one's own device to improve accessibility. Participants described adjusting accessibility settings, as well as adding tape, Braille labels, or high markings to their appliance touchscreens. Devices in the public are set up by the businesses or manufacturers of the device with controlled views and limited functionality allowed to the users. For both personal and public devices, it was common amongst the participants to ask for help when they were unable to access a feature or function, and to have others with them who could help them in public situations. Discussion of touchscreen device inaccessibility throughout the interviews focused on mostly devices in the public domain and appliance type devices in the home. The barriers and challenges that arose centered around the inability to customize settings on such devices. Participants' hopes for the future focused on improvements on public devices and appliance type devices in the home. Also, they expressed the desire for their already existing accessibility features that they use on their smart devices to be available in the public arena, such as increasing the font size, adjusting the screens brightness, and the ability to use voice commands.

The accessibility features in the public are starting to take shape, such as larger screens at the McDonald's kiosks and audio commands through the headphone jack on ATMs. However, accessible features in the public are not available all the time, even with the same type of machines. One example is the ATM. Some ATMs have a headphone jack that allows the user to listen to commands and interact with the physical buttons on the machine instead of the touchscreen. Although the headphone jack positioning is often found in different places on different ATM machines, this makes it difficult for BLV individuals to find the headphone jack and in turn they may not know the machine has that option available. Other ATMs, even the ATMs from the same banks, may not have the headphone jack.

One of the applications that was discussed in both the approaches section and application section that was used for interacting with public devices was AIRA. AIRA provides visual interpretation to the users and can be used for verbal instruction while interacting with touchscreens in the public. However it also presents privacy risks for the user such as disclosing private information with the interpreting agent that is required to complete desired tasks, and use in the public presents an opportunity for bystanders in the area to hear private information being discussed with the agent. The privacy risks highlights the need for multiple accessibility features for different types of touchscreen interactions.

Universal design and standardization were also introduced during the interviews, by participants who expressed they want the touchscreen devices to not only be accessible to them but to anyone who would benefit from using them, and when discussing how to access features in the public if they existed. The definition for universal design has evolved over the years after its conception, many of which contained vague terminology. Steinfeld, Maisel, and Levine (2012) created their own definition, after evaluating past definitions and it is as follows:

> Universal design is a process that enables and empowers a diverse population by improving human performance, health and wellness, and social participation. (Steinfeld et al., 2012, p. 29)

Universal design focuses on designing interfaces that are accessible for anyone who may interact with them including those with disabilities, which can include accessibility features on touchscreen devices. Though the focus of this study was with people who are BLV, accessibility features could help other groups of individuals, for example older adults as mentioned by the participants in this study. While discussing the current accessibility of touchscreen devices, two participants with low vision commented on how improving the devices would not just help the blind and low vision community, but help others, specifically mentioning the older adult population due to its size. On the other hand, standardization is the process of conforming, and in this case it would be designing accessibility features in the same manner for all touchscreen devices, in both activation and layout.

The codes from the interviews resulted in the emerging themes of loss of independence/asking for help (*N* = 14 (70%); Blind, *n* = 2 (100%); Low Vision, *n* = 12 (66.67%)), avoidance (of inaccessible devices) (*N* = 5 (25%); Blind, *n* = 2 (100%); Low Vision, *n* = 3 (16.67%)), need and desire for improvements (*N* = 20 (100%)), uncertainty of available resources and features (*N* = 5 (25%); Blind, *n* = 2 (100%); Low Vision, *n* = 3 (16.67%)), and universal design/standardizing (*N* = 5 (25%); Blind, *n* = 2 (100%); Low Vision, *n* = 3 (16.67%)).

Survey Study

Methodology

Participants

Participants for this study included 106 adults who identify as blind or having low vision (*N* = 106), of which 32 (30.19%) identified as female, 73 (68.87%) as male, and one (0.94%) as non-conforming. There were 23 (21.70%) participants that identified as blind, 83 (78.30%) that identified as low vision. There were 39 (36.79%) participants between the ages of 18-24, 43 (40.57%) between 25-34 years old, 17 (16.04%) between 35-44 years old, five (4.72%) between 45-54 years old, and two (1.89%) between 55-64 years old. Participants who signed up for and completed the interview were recruited for the survey through an email containing a Google form. The email informed those on the receiving end about the survey including type of questions asked, estimated time of completion, and compensation. They were also informed that they could forward the study information to others that may be interested and meet the criteria, and this message was also positioned at the end of the survey with a link to share. The informed consent (see Appendix L) was placed at the beginning of the survey, participants were informed that by continuing on with the survey they were giving their consent for their data to be used in this study. A $5 gift card was sent to the first 100 qualifying participants that completed the survey and provided an email address. The remaining participants were put in a raffle to win a $5 gift card, which was awarded after the survey was closed.

Instrument Design

The questions and available answers to select in the survey were created based on the results of the interview phase, to more fully answer RQ1 (What current features exist to assist individuals who are blind or have low vision in independent interactions with touchscreens?), RQ2 (What are the perceptions and experiences of individuals who are blind or have low vision in interactions with touchscreen interfaces?), and RQ3 (What are the conditions and/or constraints that are preventing individuals who are blind or have low vision from having effective interactions with touchscreens?). This was done to get a larger sample size of the BLV population, and evaluate whether the patterns and themes that emerged during the interviews persisted with a larger population. The verification of the patterns and themes were used to answer RQ4 (What improvements could be made to touchscreen interfaces that could improve interactions and experiences with individuals who are blind or have low vision?) and establish a set of design guidelines that would address the barriers and challenges that arose during both the interviews and from the survey.

The survey for this study was designed and published in Qualtrics. The default design of Qualtrics surveys was modified to be more accessible to the target population, which included increasing the font size, adjusting the contrast of the page, and creating bigger target zones for the participant to select their response.

The survey included four sections: a brief screening, personal touchscreen devices, public touchscreen devices, and demographics. The survey questions can be found in Appendix M.

The screening section consisted of two questions, the first asking about their vision status (blind, low vision, sighted, or other) and the second being optional to describe their vision status in words. Any participants that selected “sighted” were sent to the end of the survey, with a message that stated they did not match the qualification requirements of the survey.

The personal touchscreen section asked the participant about what current personal touchscreen devices they owned and used, approaches and features they used for easier interaction, their satisfaction on the accessibility of their devices, features they hope to see in the future, and an open text box for any additional information. If a participant indicated that they did not own any touchscreen devices, they skipped questions about their experiences, and were asked for a reasoning for which they did not own or use any touchscreen devices.

The public touchscreen section had a similar set of questions compared to the personal touchscreen section. The participant was asked about touchscreen devices they have used in places in the past, their approaches and features they used for easier interaction, their satisfaction on the accessibility of public devices, whether they would be more likely to use public touchscreens if they were more accessible, features they hope to see in the future, preference in presented options to access the accessibility features of a public touchscreen device (e.g., 3 taps in the top right corner of the screen), and an open text box for any additional information or comments. If the participant indicated that they did not have any experience with public touchscreen devices, they skipped the questions related to experiences with public devices, and were asked for a reasoning behind not having interacted with any public touchscreen devices in the past.

The demographics section included questions regarding age, gender, race, level of education, and employment status. The participants were also asked if they would like to be contacted for further studies, and for their email address. The email address was optional, but for a participants that wanted to be included in the compensation for the study, the email was needed in order to send compensation.

During the interview, the participants were asked about both the features they use and the approaches they take, however it became clear that the approaches used included utilizing the features, which led to the survey study only asking about common approaches discussed in the interview, because this included the features.

The same questions were presented in the personal device section and public touchscreens with the addition of two questions in the public section. The additional questions addressed whether participants would be more likely to use public touchscreens if they were more accessible and if they had a preference on how to access accessibility features with public touchscreen devices. The shared questions between the sections were designed to get an understanding of what current devices, features, and approaches are being used with such technologies, as well as their opinions on whether or not the technologies are accessible along with their hopes for the future. This was developed to get a sense on how the participants envisioned advancements in both domains and what they were hoping to see. At the end of both the personal device section and the section on devices in the public domain, participants were presented with an optional textbox to add in any other thoughts or comments about their experiences with touchscreens devices.

The additional question in the public section that related to the likelihood of using public touchscreens if they were more accessible, was also asked during the interview session. This question was designed to get a sense of whether or not BLV individuals would use public touchscreen devices if they had the means. The second additional question in the public section was created based on the interview responses showing the need for a method to know whether there are and how to access the accessibility features on public devices. A common theme that arose during the interview phase was BLV individuals not knowing whether or not a device in the public had accessibility features that they could use or not. In order to address this, the researcher created a new question in the survey to gather information on whether or not BLV individuals would want some sort of standardized input to activate accessibility features. The selection answers for this question were created based on ideas from participants in the interview study, and the purpose of the question was to understand what types of approaches would be viable and acceptable for activating accessibility features in public touchscreen devices, and if there were any other new ideas for approaches.

The demographics section was created to get an understanding of the population's diversity, and to create an opportunity to see if any commonalities and differences existed in the data between different groups.

Procedure

For the survey, the informed consent information (see Appendix L) was presented before the survey began, and provided the participants with a brief description of the study focusing on touchscreen interactions. Participants were informed that the study was designed to explore their opinions of, perceptions of, and current practices while interacting with touchscreens. The participants were made aware that if they continued onto taking the survey, that would mean they have consented to participate in the survey. At the end of the survey participants were thanked for their time and provided a survey link to share with others.

Data Analysis

The responses from the survey were cleaned up to remove unviable responses, then the remaining valid responses were analyzed. Valid responses consisted of participants that identified as blind or low vision, and were over the age of 18. Survey responses with duplicate IP addresses were vetted, those with start and end times one right after another were deleted.

Common themes that emerged from the interview were presented through the survey and evaluated against the larger sample of the survey. The data from the survey was handled similarly to the data collected in the interview study, frequencies of the same answers were compiled and viewed for commonalities across the participants. The data tables are set up as cross tabulations that display the results of the entire survey participant group, as well as subgroups based on age and vision status, blind and low vision. In addition, a Chi-Square Test of Independence was performed on Tables 9-23, however all tables had more than 20% of expected values greater than 5. This is a violation of an assumption of the Chi-Square Test of Independence, and therefore was not reported within the results.

Results

On average, it took participants 8.5 minutes to complete the survey. The time completion ranged from 1.25 to 45.40 minutes.

It is important to note that the detailed reporting of results presented in tables can be found in Appendices N-AB. This is done to ensure that all readers, especially those who may use an assistive technology, such as a screen reader, would have full access to the results. The figures provide a visual representation of the information that is in the associated tables and appendices, and therefore are considered decoration to limit repetitive information on screen readers.

Personal Touchscreens

The three most commonly owned touchscreen devices indicated in the survey were respectively, smartphones, tablets, and smartwatches. These were followed by microwaves, coffee makers, dishwashers, laundry machines, and lastly, “other”. The two participants with low vision who selected “other” listed smart television and oven as the additional devices with touchscreens they use. The overall selection from all participants of each device can be seen in Figure 8, and the breakdown between blind and low vision can be seen in Table 9 (Appendix N for text descriptions). Another option available for the question about which touchscreens the participants owned was the option of not owning any touchscreen devices, and those who selected this option were prompted with another question that asked for the reasoning. The available answer options included “The devices are not accessible”, “I use alternative devices with physical buttons”, “No reasoning”, and “Other”. All chose “Other” as their reasoning, three of whom explained that they always ask for help or assistance when using those devices, while the other two stated that they never had experience with any type of touchscreen device.

Figure 8

Personal Touchscreen Devices owned by Survey Participants

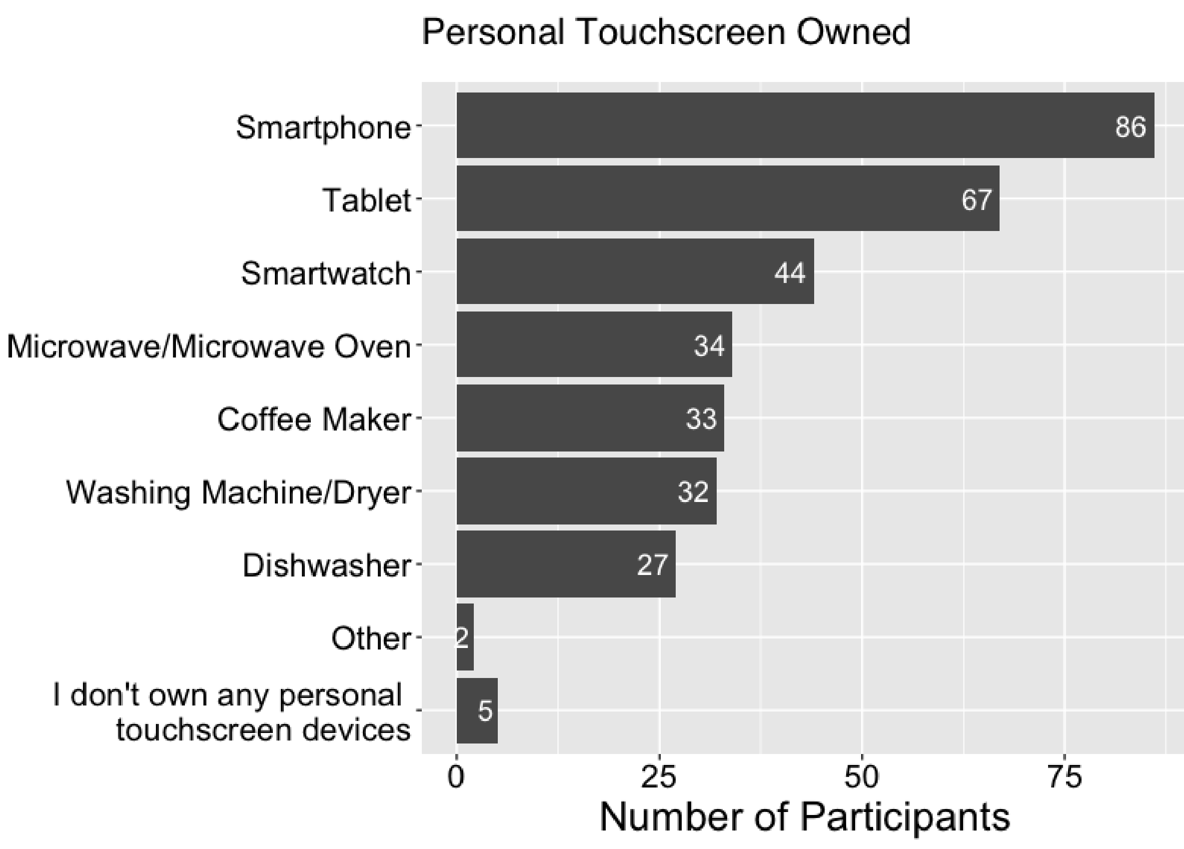


Table 9

Frequencies of Personal Devices Owned by Survey Participants by Vision Status

Personal Devices	Total (*N* = 106)		Blind (*n = 23)*		Low Vision (*n = 83)*	
	N	%	*n*	%	*n*	%
Smartphone	86	81.13	12	52.17	74	89.16
Tablet	67	63.21	11	47.83	56	67.47
Smartwatch	44	41.51	2	8.70	42	50.60
Microwave/Microwave Oven	34	32.08	3	13.04	31	37.35
Coffee Maker	33	31.13	7	30.43	26	31.33
Washing Machine/Dryer	32	30.19	1	4.35	31	37.35
Dishwasher	27	25.47	3	13.04	24	28.92
Other	2	1.89	0	0	2	2.41
Do not own personal touchscreen devices	5	4.72	5	21.74	0	0

Note. For the raw text reporting of this table, see Appendix N

The only noticeable difference between the age groups was of the youngest range (18-24), whose reportings of devices owned were fewer than all of the other age groups. Also, the five participants that did not own any type of touchscreen device were all in the 18-24 age range. These differences can be seen in Table 10 (Appendix O for text descriptions).

Table 10

Frequencies of Personal Devices Owned by Survey Participants by Age

Personal Devices	18-24 (*n* = 39)		25-34 (*n* = 43)		35-44 (*n* = 17)		45-54 (*n* = 5)		55-64 (*n* = 2)	
	n	%	*n*	%	*n*	%	*n*	%	*n*	%
Smartphone	23	58.97	40	93.02	17	100.00	4	80.00	2	100.00
Tablet	19	48.72	31	72.09	12	70.59	3	60.00	2	100.00
Smartwatch	8	20.51	21	48.84	12	70.59	3	60.00	0	0.00
Microwave/ Microwave Oven	5	12.82	15	34.88	9	52.94	3	60.00	2	100.00
Coffee Maker	9	23.08	14	32.56	6	35.29	3	60.00	1	50.00
Washing Machine/Dryer	7	17.95	14	32.56	6	35.29	3	60.00	2	100.00
Dishwasher	3	7.69	14	32.56	7	41.18	2	40.00	1	50.00
Other	0	0.00	0	0.00	0	0.00	1	20.00	1	50.00
Do not own personal touchscreen devices	5	12.82	0	0.00	0	0.00	0	0.00	0	0.00

Note. For the raw text reporting of this table, see Appendix O

Approaches. Survey participants were presented with six approaches for an easier interaction with personal touchscreen devices that were gathered from the interviews, and asked which of those they utilize: "Asked someone for help", "Audio Commands (audio instructions given)", "Voice Commands", "Learned the layout", "Magnifying glass", and "Flashlight". Selections are shown in Figure 9, and breakdown in Table 11 (Appendix P for text descriptions). Of the six approaches, the most common approach taken by survey participants was asking for help, followed by voice commands, audio commands, magnifying glass, learning the layout, and using a flashlight. Three participants, all of which identified as blind, selected “Other”, and of the three, one specified their use of high contrast text and smart glasses for their approach to making touchscreens more accessible.

Figure 9

Approaches Used by Survey Participants with Personal Touchscreen Devices

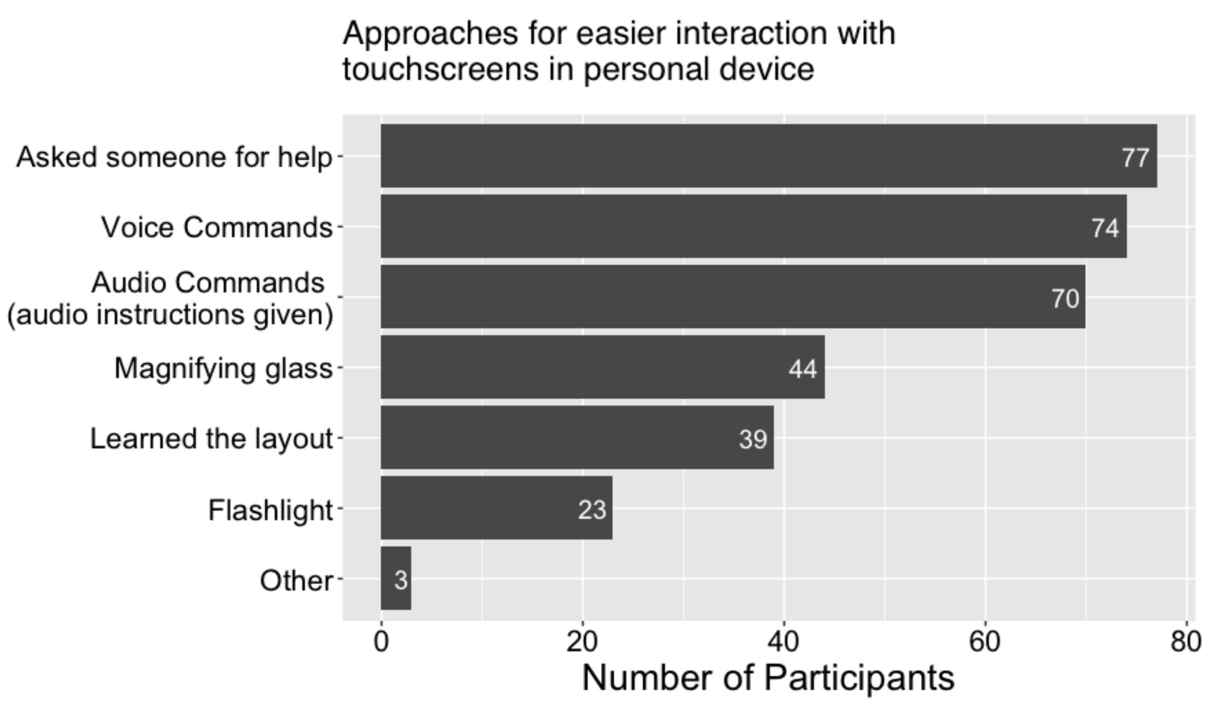


Table 11

Frequencies of Approaches Used by Survey Participants with Personal Touchscreen Devices by Vision Status

Personal Approaches	Total (*N* = 106)		Blind *(n = 23)*		Low Vision *(n = 83)*	
	N	%	*n*	%	*n*	%
Ask someone for help	77	72.64	20	86.96	57	68.67
Voice Commands	74	69.81	13	56.52	61	73.49
Audio Commands (audio instructions given)	70	66.04	10	43.48	60	72.29
Magnifying glass	44	41.51	3	13.04	41	49.40
Learned the layout	39	36.79	5	21.74	34	40.96
Flashlight	23	21.70	1	4.35	22	26.51
Other	3	2.83	3	13.04	0	0

Note. For the raw text reporting of this table, see Appendix P

The approaches for personal devices used were similar across the age groups. However, the 18-24 age group had lower frequency ratings across the available options, except for the most common approach selected, asking for help (shown in Table 12 (Appendix Q for text description)). This pattern was similar to what was presented in the previous data table about personal touchscreen devices owned by the participants.

Table 12

Frequencies of Approaches Used by Survey Participants with Personal Touchscreen Devices by Age

Personal Approaches	18-24 (*n* = 39)		25-34 (*n* = 43)		35-44 (*n* = 17)		45-54 (*n* = 5)		55-64 (*n* = 2)	
	n	%	*n*	%	*n*	%	*n*	%	*n*	%
Ask someone for help	28	71.79	30	69.77	13	76.47	4	80.00	2	100.00
Voice Commands	20	51.28	33	76.74	15	88.24	4	80.00	2	100.00
Audio Commands	19	48.72	31	72.09	14	82.35	4	80.00	2	100.00
Magnifying glass	8	20.51	21	48.84	13	76.47	1	20.00	1	50.00
Learned the layout	3	7.69	22	51.16	9	52.94	3	60.00	2	100.00
Flashlight	3	7.69	11	25.58	5	29.41	3	60.00	1	50.00
Other	0	0.00	2	4.65	0	0.00	0	0.00	1	50.00

Note. For the raw text reporting of this table, see Appendix Q

Accessibility. When asked whether they thought that the accessibility of personal touchscreen devices was sufficient for them, participants were given four options: “They work for what I use them for”, “They are lacking in some areas”, “It depends”, and “I don’t know”. Each option also had available text space to explain their selection. This question was only visible to those participants who selected a type of touchscreen device that they owned (*N* = 101 (95.28%); Blind, *n* = 18 (78.26%); Low Vision, *n* = 83 (100%)). The overall selection results can be seen in Figure 10, and the breakdown between low vision and blind can be seen in Table 13 (Appendix R for text description). Most of the participants chose the option stating that they worked for them, followed by those who thought they were lacking, and a few participants indicated that accessibility was dependent on situations. Many participants expanded on their selections to describe their experiences further. Some examples of extra details from those who selected that they work for them included explaining that the devices work some of the time (*N* = 2 (1.89%); Low Vision, *n* = 2 (2.41%)), they work for specific devices while others are lacking accessible features (*N* = 1 (0.94%); Blind, *n* = 1 (4.35%)), the ease of interacting with the devices is because of the customizations they have been able to implement on their devices (*N* = 4 (3.77%); Blind, *n* = 2 (8.70%); Low Vision, *n* = 2 (2.41%)), and that the ability to do their daily tasks was sufficient (*N* = 3 (2.83%); Low Vision, *n* = 3 (3.61%)).

For the participants that expanded on the lacking in some areas selection, all of them had different explanations, where one participant with low vision (*N* = 1 (0.94%); Low Vision, *n* = 1 (1.20%)) mentioned that they were missing important information, another participant with low vision (*N* = 1 (0.94%); Low Vision, *n* = 1 (1.20%)) said that voice commands do not understand what they are saying, and someone else who has low vision (*N* = 1 (0.94%); Low Vision, *n* = 1 (1.20%)) said that the systems need to be more standardized with higher contrast and larger print. One participant who identified as blind (*N* = 1 (0.94%); Blind, *n* = 1 (4.35%)) said, “The mobile side (Mobile, tablet, even laptop) isn't in the bad shape these days. But other consumer products (washing machine, micro-oven, musical keyboard, etc), is kind of unusable state.”, and others responses mentioned issues with the font being too small (*N* = 1 (0.94%); Low Vision, *n* = 1 (1.20%)) or the content being unable to be read aloud (*N* = 1 (0.94%); Low Vision, *n* = 1 (1.20%)). Only one of the participants (*N* = 1 (0.94%); Low Vision, *n* = 1 (1.20%)) that selected “It depends” provided their reasoning as, “Some apps provide more audio descriptions than others. Many iOS apps have more description of how to navigate and the screen layout is straight forward. Other third party apps don't provide as much audio description within the app.”

Figure 10

Survey Participants' Thoughts About the Accessibility of Personal Touchscreen Devices

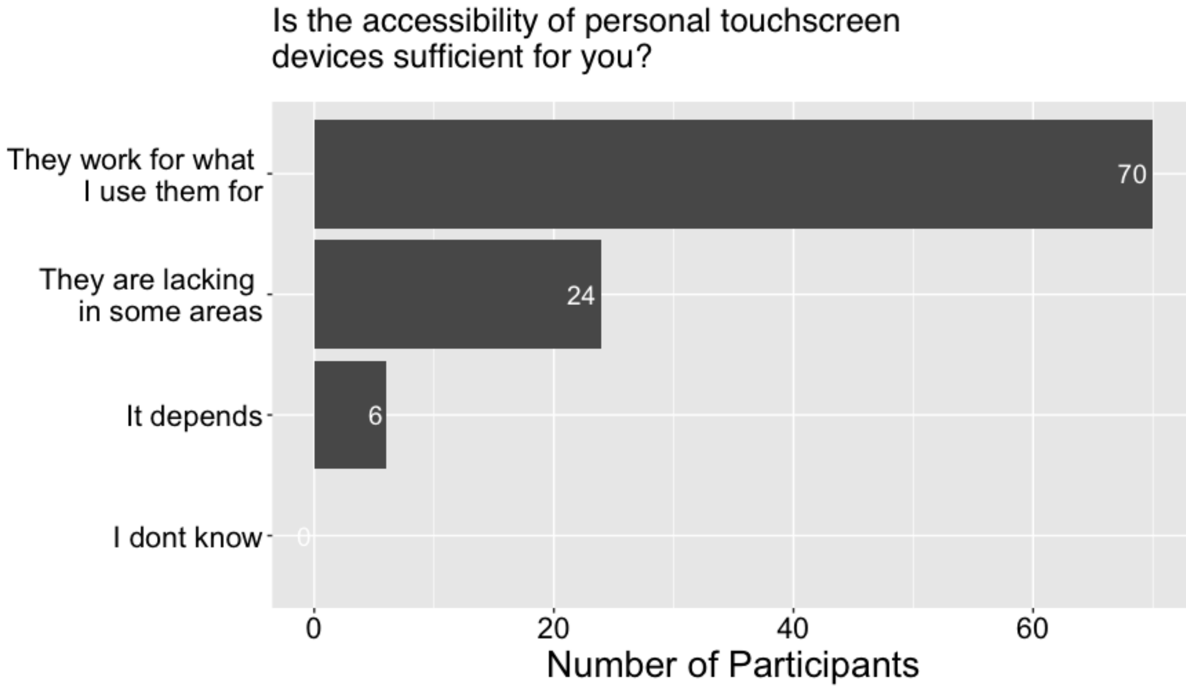


Table 13

Frequencies of Survey Participants' Thoughts About the Accessibility of Personal Touchscreen Devices by Vision Status

Personal Device Accessibility	Total (*N* = 106)		Blind *(n = 23)*		Low Vision *(n = 83)*	
	N	%	*n*	%	*n*	%
They work for what I use them for	70	66.04	15	65.22	55	66.27
They are lacking in some areas	24	22.64	2	8.70	22	26.51
It depends	6	5.66	1	4.35	5	6.02
I don't know	0	0	0	0	0	0

Note. For the raw text reporting of this table, see Appendix R

The responses divided by age groups showed differences of thoughts around this topic of available accessibility of personal devices, where the majority of each group except the oldest group (55-64) selected the choice of the technology working for them. The older group had more participants select that the accessibility was lacking or that it was dependent on the situation compared to the youngest age group. This pattern can be shown in Table 14 (Appendix S for text description).

Table 14

Frequencies of Survey Participants' Thoughts About the Accessibility of Personal Touchscreen Devices by Age

Personal Device Accessibility	18-24 *(n = 39)*		25-34 *(n = 43)*		35-44 *(n = 17)*		45-54 *(n = 5)*		55-64 *(n = 2)*	
	n	%	*n*	%	*n*	%	*n*	%	*n*	%
They work for what I use them for	27	69.23	30	69.77	9	52.94	4	80.00	0	0.00
They are lacking in some areas	5	12.82	11	25.58	7	41.18	0	0.00	1	50.00
It depends	2	5.13	2	4.65	0	0.00	1	20.00	1	50.00
I don’t know	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00

Note. For the raw text reporting of this table, see Appendix S

Open-Ended Thoughts and Solutions. At the end of the personal device section many participants (*N* = 21 (19.81%); Blind, *n* = 6 (26.09%); Low Vision, *n* = 15 (18.07%)) left comments in the optional textbox. The responses left in the personal section consisted of participants talking about improvements that should be made, where two concepts that were common among the responses are voice assistant applications needing updates to have better voice recognition (*N* = 3 (2.83%); Blind, *n* = 1 (4.35%); Low Vision, *n* = 2 (2.41%)) and how useful touchscreen devices are despite them being difficult at times (*N* = 4 (3.77%); Blind, *n* = 1 (4.35%); Low Vision, *n* = 3 (3.61%)). Below are two quotes that put the situation into perspective:

> "Using touchscreen device can be really stressful due to the fact that I will spend more time trying to operate it. But it has been helpful really."

and

> "They have personally helped me with my daily tasks though everything has it's good and bad side they have helped 90%"

Public Touchscreens

The results showed that the ATMs were the most common touchscreen device used in the public for the BLV participants. This was followed by ordering machines like touchscreens in restaurants, kiosks (such as those found in airports, bus stations, and the post office), digital maps and other. Three participants (2.83%) selected the "other" option, each one giving an example of what other devices they have used, which included smart locks (Low Vision, *n* = 1), debit card payment machines in a shop (Blind, *n* = 1), and terminals in grocery stores and pharmacies (Low Vision, *n* = 1). Ten participants indicated that they have never used a public touchscreen device. Figure 11 and Table 15 (Appendix T for text description) display the overall selection results, and the breakdown between low vision and blind participants.

Figure 11

Public Touchscreen Devices Used by Survey Participants

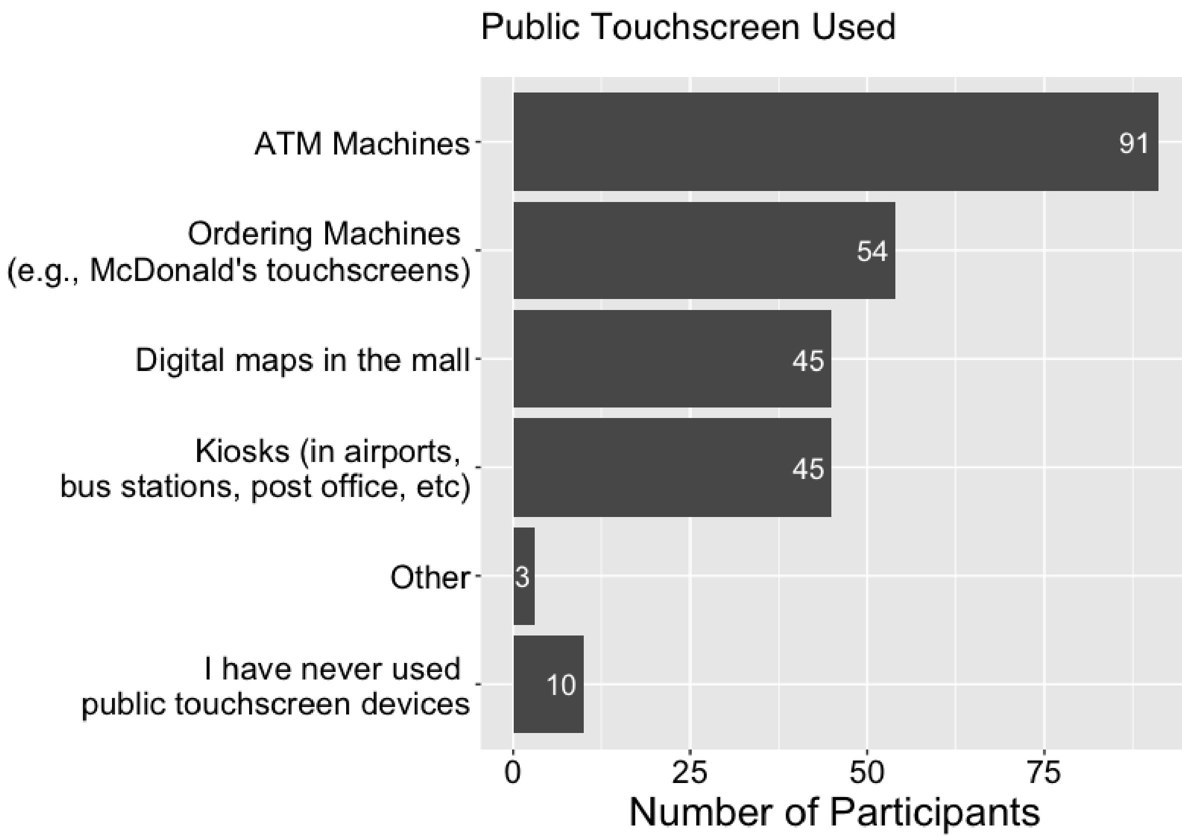


Table 15

Frequencies of Public Touchscreen Devices Used by Survey Participants by Vision Status

Public Devices	Total (*N* = 106)		Blind *(n = 23)*		Low Vision *(n = 83)*	
	N	%	*n*	%	*n*	%
ATM Machines	91	85.85	16	69.57	75	90.36
Ordering Machines	54	50.94	7	30.43	47	56.63
Digital Maps in the Mall	45	42.45	10	43.48	35	42.17
Kiosks	45	42.45	3	13.04	42	50.60
Other	3	2.83	1	4.35	2	2.41
Never Used	10	9.43	6	26.09	4	4.82

Note. For the raw text reporting of this table, see Appendix T

The ten participants that did not have experience with public touchscreen devices were asked a follow up question for their reasoning, and given the following multi-select choices "The devices are not accessible", "Take more time than alternatives that involve human services", "Haven't come across any touchscreen devices to use", "No reasoning", and "Other". The overall selection results can be seen in Figure 12, and the breakdown between low vision and blind can be seen in Table 16 (Appendix U for text description). The top reasoning was they just have not come across any touchscreen devices to use, followed by the devices being inaccessible, alternative means being easier, no reasoning, and other, which the participant explained “I haven't access any before”.

Figure 12

Survey Participants' Reasoning for Not Having Past Experience with Public Touchscreen Devices

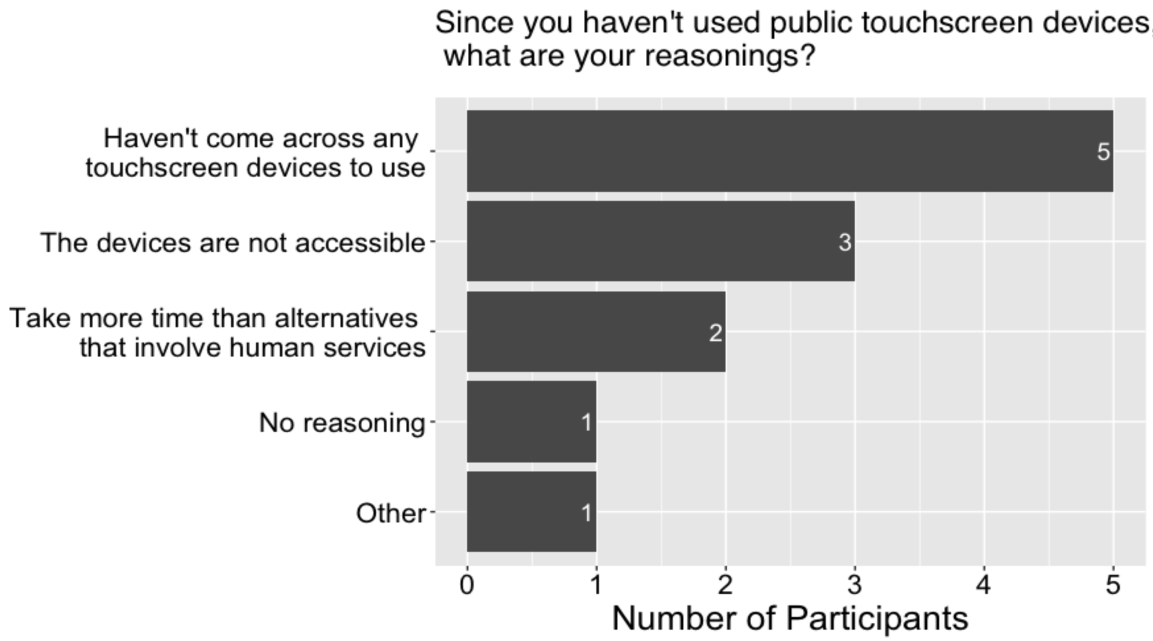


Table 16

Frequencies of Survey Participants' Reasonings for Not Having Past Experiences with Public Touchscreen Devices by Vision Status

Reasonings	Total (*N* = 106)		Blind (*n = 23)*		Low Vision (*n = 83)*	
	N	%	*n*	%	*n*	%
Haven't come across any touchscreen devices to use	5	4.72	5	21.74	0	0
The devices are not accessible	3	2.83	0	0	3	3.61
Take more time than alternatives that involve human services	2	1.89	0	0	2	2.41
No reasoning	1	0.94	1	4.35	0	0
Other	1	0.94	1	4.35	0	0

Note. For the raw text reporting of this table, see Appendix U

The difference between the age groups from the personal device section follows the same pattern present here with the public devices used. The youngest range (18-24) had the most participants that did not have experience with public touchscreens and their group percentages of the other types of devices used, beside ATMs, were less than each of the other age groups. These differences can be seen in Table 17 (Appendix V for text description).

Table 17

Frequencies of Public Touchscreen Devices Used by Survey Participants by Age

Public Devices	18-24 *(n = 39)*		25-34 *(n = 43)*		35-44 *(n = 17)*		45-54 *(n = 5)*		55-64 *(n = 2)*	
	n	%	*n*	%	*n*	%	*n*	%	*n*	%
ATM Machines	29	74.36	40	93.02	15	88.24	5	100.00	2	100.00
Ordering Machines	10	25.64	28	65.12	12	70.59	3	60.00	1	50.00
Digital Maps in the Mall	12	30.77	18	41.86	11	64.71	3	60.00	1	50.00
Kiosks	12	30.77	21	48.84	9	52.94	2	40.00	1	50.00
Other	0	0.00	0	0.00	1	5.88	1	20.00	1	50.00
Never Used	9	23.08	1	2.33	0	0.00	0	0.00	0	0.00

Note. For the raw text reporting of this table, see Appendix V

Approaches. Participants (*N* = 96 (90.57%); Blind, *n* = 17 (73.91%); Low Vision, *n* = 79 (95.18%)) were asked about their approaches for easier interaction with public touchscreen devices. The same six approaches from the personal section were presented to the participants, with the addition of “Avoided having to use such devices”. The order of most common approach to least selected by the participants, for personal and public devices was very similar with the exception of audio commands being a more common approach than voice commands in the public. The avoidance approach was the least common approach right after the use of a flashlight. This puts the order of approaches utilized to asking for help, audio commands, voice commands, magnifying glass, learning the layout, using flashlight, and avoid. One participant with low vision did select the “other” option for this question in which they explained that they sometimes use additional technologies such as their smartphone and/or smart glasses to better interact with public devices. The overall selection results can be seen in Figure 13, and the breakdown between low vision and blind can be seen in Table 18 (Appendix W for text description).

Figure 13

Approaches Used by Survey Participants with Public Touchscreen Devices

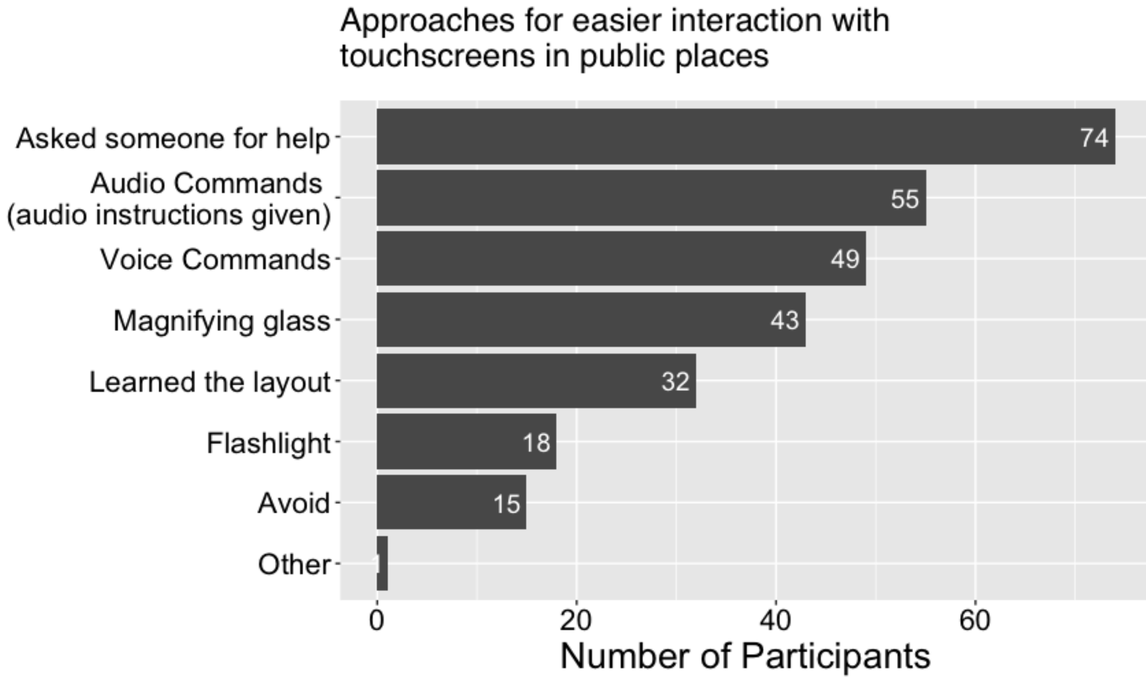


Table 18

Frequencies of Approaches Used by Survey Participants with Public Touchscreen Devices by Vision Status

Public Approaches	Total (*N* = 106)		Blind *(n = 23)*		Low Vision *(n = 83)*	
	N	%	*n*	%	*n*	%
Ask someone for help	74	69.81	17	73.91	57	68.67
Audio Commands	55	51.89	9	39.13	46	55.42
Voice Commands	49	46.23	9	39.13	40	48.19
Magnifying Glass	43	40.56	3	13.04	40	48.19
Learned the Layout	32	30.19	2	8.70	30	36.14
Flashlight	18	16.98	1	4.35	17	20.48
Avoid	15	14.15	2	8.70	13	15.66
Other	1	0.94	0	0	1	1.20

Note. For the raw text reporting of this table, see Appendix W

The approaches for public devices used were similar across the age groups with the same pattern of age group 18-24 having lower frequency rating across the options. There were participants that selected the approach of avoidance in each of the age groups except the oldest. The 25-34 year old group had the most participants that indicated they avoided public devices, while the 45-54 age group had the highest percentage (shown in Table 19 (Appendix X for text description)).

Table 19

Frequencies of Approaches Used by Survey Participants with Public Touchscreen Devices by Age

Public Approaches	18-24 (*n = 39)*		25-34 (*n = 43)*		35-44 (*n = 17)*		45-54 (*n = 5)*		55-64 (*n = 2)*	
	n	%	*n*	%	*n*	%	*n*	%	*n*	%
Ask someone for help	23	58.97	33	76.74	12	70.59	4	80.00	2	100.00
Audio Commands	16	41.03	25	58.14	10	58.82	3	60.00	1	50.00
Voice Commands	14	35.90	20	46.51	10	58.82	4	80.00	1	50.00
Magnifying Glass	9	23.08	21	48.84	10	58.82	2	40.00	1	50.00
Learned the Layout	4	10.26	20	46.51	5	29.41	2	40.00	1	50.00
Flashlight	2	5.13	10	23.26	3	17.65	2	40.00	1	50.00
Avoid	1	2.56	8	18.60	4	23.53	2	40.00	0	0.00
Other	0	0.00	0	0.00	0	0.00	0	0.00	1	50.00

Note. For the raw text reporting of this table, see Appendix X

Accessibility. When asked whether they thought that the accessibility of public touchscreen devices was sufficient for them, participants were provided with the same four options as before: “They work for what I use them for”, “They are lacking in some areas”, “It depends”, and “I don’t know”. This question was only visible to those who indicated that they have had prior experience with public touchscreens (*N* = 96 (90.57%); Blind, *n* = 17 (73.91%); Low Vision, *n* = 79 (95.18%)). The overall selection results can be seen in Figure 14, and the breakdown between low vision and blind participants can be seen in Table 20 (Appendix Y for text description). The order of highest selection followed the same pattern from the personal devices with most selecting the option stating that they worked for them, followed by those who thought they were lacking, and “it depends”.

Figure 14

Survey Participants' Thoughts About the Accessibility of Public Touchscreen Devices

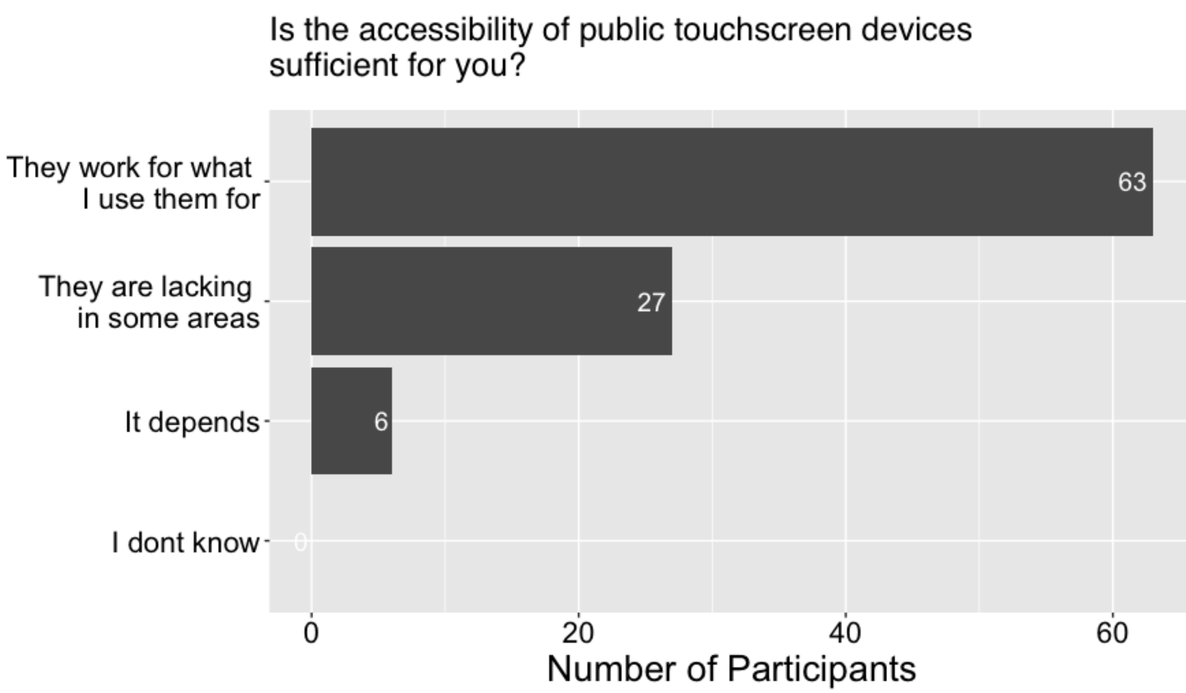


Table 20

Frequencies of Survey Participants' Thoughts About the Accessibility of Public Touchscreen Devices by Vision Status

Public Device Accessibility	Total (*N* = 106)		Blind *(n = 23)*		Low Vision *(n = 83)*	
	N	%	*n*	%	*n*	%
They work for what I use them for	63	59.43	13	56.52	50	60.24
They are lacking in some areas	27	25.47	2	8.70	25	30.12
It depends	6	5.66	2	8.70	4	4.82
I don’t know	0	0	0	0	0	0

Note. For the raw text reporting of this table, see Appendix Y

Each selection had a few participants that expanded upon their answers, including 21 participants (*N* = 21 (19.81%); Blind, *n* = 5 (21.74%); Low Vision, *n* = 16 (19.28%)) that selected it works, seven that selected they are lacking (*N* = 7 (6.60%); Low Vision, *n* = 7 (8.43%)), and three participants (*N* = 3 (2.83%); Blind, *n* = 1 (4.35%); Low Vision, (*n* = 2 (2.41%)) that selected it depends. Those that expanded off of their selection that they work for them, focused on the devices making tasks easier for them (*N* = 5 (4.72%); Blind, *n* = 2 (8.70%); Low Vision, *n* = 3 (3.61%)), commented on how they liked certain touchscreen devices (*N* = 3 (2.83%); Low Vision, *n* = 3 (3.61%)), and two participants (*N* = 2 (1.89%); Low Vision, *n* = 2 (2.41%)) mentioned that if they were to get stuck they could just ask for help.

Seven participants with low vision (*N* = 7 (6.60%); Low Vision, *n* = 7 (8.43%)) expanded on their selection of “the devices are lacking” in some areas, two of whom commenting on the font sizes being too small, another two discussing the devices lacking in some parts including audio communication and tactile markings, one focusing on the lack of features (“need to be brighter, higher contrast, clearer functions”), another saying that sometimes the machines do not understand their commands, and the last comment pointing out that in many places they are not available to use.

Three participants, one who was blind and the other two having low vision (N = 3 (2.83%); Blind, n = 1 (4.35%); Low Vision, n = 2 (2.41%)) explained their reasoning for selecting “It depends”. The first participant with low vision stated it was dependent on where they were, the second with low vision said it varied between different types of devices, and the last one who was blind said that most of the time sighted help is needed to complete the tasks on the device.

The additional question that was asked in the public device section but not in the personal device section was asking if participants would use public touchscreen devices if they were more accessible. Most of the participants said “Yes” (N = 92 (86.79%); Blind, n = 21 (91.30%); Low Vision, n = 71 (85.54%)), 36 of whom (N = 37 (34.91%); Blind, n = 11 (47.83%); Low Vision, n = 26 (31.33%)) provided explanations for their selection by stating that they would love be able to interact with touchscreens in the public (N = 5 (4.72%); Blind, n = 2 (8.70%); Low Vision, n = 3 (3.61%)), to be able to easily access the information they sought (N = 20 (18.87%); Blind, n = 7 (30.43%); Low Vision, n = 13 (15.66%)), have a sense of independence (N = 2 (1.89%); Low Vision, n = 2 (2.41%)), if they need to they could still ask for help (N = 3 (2.83%); Blind, n = 1 (4.35%); Low Vision, n = 2 (2.41%)), to be able to use accessible features with public devices (N = 5 (4.72%); Low Vision, n = 5 (6.02%)), and avoid social stigma by using the same technologies as their sighted counterparts (N = 2 (1.89%); Blind, n = 1

(4.35%); Low Vision, *n* = 1 (1.20%)). One participant with low vision of the 13 participants (*N* = 13 (12.26%); Blind, *n* = 11 (47.83%); Low Vision, *n* = 2 (2.41%)) that selected “Maybe” explained “I may use them if I have no other option”. The one participant who identified as low vision that said “No” to the question left a simple explanation of “Not at all”.

The responses analyzed by the age groups showed similar thoughts about the available accessibility of public devices, similarly to the personal devices sections results where the majority of each group except the oldest group (55-64) selected the choice of the technology working for them. The age groups 25-34 and 55-64 had more participants select that the accessibility was lacking, while the other groups had similar response rates. This pattern can be seen in Table 21 (Appendix Z for text description).

Table 21

Frequencies of Survey Participants' Thoughts About the Accessibility of Public Touchscreen Devices by Age

Public Device Accessibility	18-24 *(n = 39)*		25-34 *(n = 43)*		35-44 *(n = 17)*		45-54 *(n = 5)*		55-64 *(n = 2)*	
	n	%	*n*	%	*n*	%	*n*	%	*n*	%
They work for what I use them for	24	61.54	27	62.79	9	52.94	3	60.00	0	0.00
They are lacking in some areas	5	12.82	12	27.91	7	41.18	1	20.00	2	100.00
It depends	1	2.56	3	6.98	1	5.88	1	20.00	0	0.00
I don’t know	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00

Note. For the raw text reporting of this table, see Appendix Z

Open-Ended Thoughts and Solutions. At the end of the public device section many participants (*N* = 14 (13.21%); Blind, *n* = 5 (21.74%); Low Vision, *n* = 9 (10.84%)) left comments in the optional textbox. Some of the responses talked about making public devices accessible to people with other disabilities and everyone in general (*N* = 4 (3.77%); Blind, *n* = 2 (8.70%); Low Vision, *n* = 2 (2.41%)). A few of the comments were directed toward improvements in the systems (*N* = 7 (6.60%); Blind, *n* = 3 (13.04%); Low Vision, *n* = 4 (4.82%)), including better voice commands (*N* = 4 (3.77%); Blind, *n* = 2 (8.70%); Low Vision, *n* = 2 (2.41%)), bigger buttons (*N* = 1 (0.94%); Low Vision, *n* = 1 (1.20%)), higher contrast (*N* = 1 (1.20%); Low Vision, *n* = 1 (1.20%)), brighter screens (*N* = 1 (0.94%); Low Vision, *n* = 1 (1.20%)), and having a simple mode (*N* = 1 (0.94%); Low Vision, *n* = 1 (1.20%)). One participant who identified as blind (*N* = 1 (0.94%); Blind, *n* = 1 (4.35%)) simply put, “Public touchscreen is the future”. Another participant who has low vision expressed their excitement for future developments, “I definitely would interact with public touch screen devices for independence and convenience. I look forward to the opportunity to use these devices like my sighted individuals.” The last comment made by a participant with low vision expanded on the concepts presented in the survey, where they said, “I forgot to include the touchscreens at stores, the self-checkout options that are becoming the norm. They need all of the items discussed in this survey - higher contrast, brighter, simple mode, etc. I am hoping that over the next 5-15 years, smart glasses will become as widely used as smartphones today, and they will customize and enhance the view for all users dependent on their needs.”

Touchscreens in General

Hope for the Future. The participants in the survey were asked about their future hopes in both personal devices and public devices. The participants were presented with a multi-select question that asked what type of features they hope to see in the future for either their personal or public touchscreen devices. They were then provided with thirteen options to select from: "Voice command", "Read aloud", "Audio commands", "The ability to zoom in", "The ability to increase font size", "An option for bigger icons", "Physical buttons", "Brightness adjustment", "High contrast", "Simple mode", "Tactile feedback", "Gestures", "Other". The overall selection results can be seen in Figure 15, and the breakdown between low vision and blind can be seen in Table 22 (Appendix AA for text description).

The order of which features were most sought for were slightly different between personal and public devices, but the most common selection for both sections was voice commands (Personal, n = 73 (68.87%); Public, n = 81 (76.42%)). For personal devices after voice commands followed: read aloud, ability to zoom, audio commands, increase font, physical buttons, bigger icons, adjust brightness, high contrast, tactile feedback, gestures, simple mode, and other, which was identified as a Braille display.

For the public devices after voice commands followed: audio commands, read aloud, ability to zoom, increase font, bigger icons, high contrast, physical buttons, adjust brightness, gestures, tactile feedback, simple mode, and other. The other option was specified by the participant as “description of images when present.”

Figure 15

Comparison of Survey Participants' Future Hopes in Personal and Public Touchscreen Devices

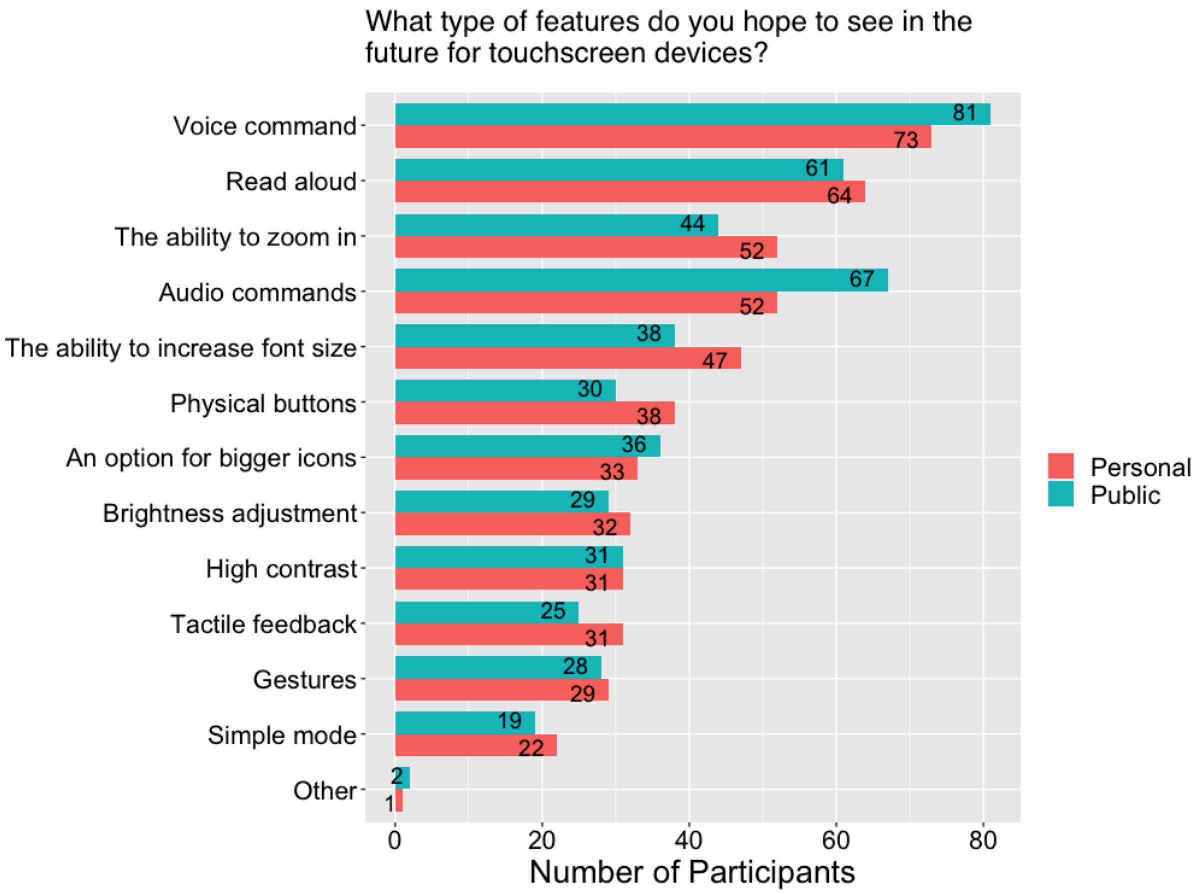


Table 22

Frequencies of Survey Participants' Future Hopes in Personal and Public Touchscreen Devices by Vision Status

	Personal						Public					
Features Hoped For	Total (*N* = 106)		Blind (*n* = 23)		Low Vision (*n* = 83)		Total (*N* = 106)		Blind (*n* = 23)		Low Vision (*n* = 83)	
	N	%	*n*	%	*n*	%	*N*	%	*n*	%	*n*	%
Voice commands	73	68.87	20	86.96	53	63.86	81	76.42	20	86.96	61	73.49
Read aloud	64	60.38	14	60.87	50	60.24	61	57.55	15	65.22	46	55.42
Audio commands	52	49.06	10	43.48	42	50.60	67	63.21	18	78.26	49	59.04
The ability to zoom in	52	49.06	5	21.74	47	56.63	44	41.51	5	21.74	39	46.99
The ability to increase font size	47	44.34	5	21.74	42	50.60	38	35.85	3	13.04	35	42.17
An option for bigger icons	33	31.13	3	13.04	30	36.14	36	33.96	2	8.70	34	40.96
Physical buttons	38	35.85	8	34.78	30	36.14	30	28.30	6	26.09	24	28.92
High contrast	31	29.25	3	13.04	28	33.73	31	29.25	3	13.04	28	33.73
Adjust Brightness	32	30.19	2	8.70	30	36.14	29	27.36	2	8.70	27	32.53
Gestures	29	27.36	6	26.09	23	27.71	28	26.41	3	13.04	25	30.12
Tactile feedback	31	29.25	3	13.04	28	33.73	25	23.58	3	13.04	22	26.51
Simple mode	22	20.75	1	4.35	21	25.30	19	17.92	2	8.70	17	20.48
Other	1	0.94	0	0	1	1.20	2	1.89	0	0	2	2.41

Note. For the raw text reporting of this table, see Appendix AA

Universal Design. The participants were asked about their preference in getting access to the accessibility features of a public touchscreen device. The participants were provided with four options: "A universal tap sequence (e.g., 3 taps in the top right corner of the screen)", "Phone application that can save your preferences and connect to the touchscreen device", "I don't like any of the available option", and "Other". The participants were asked which of the presented options they would prefer to use to access the accessibility features of a public touchscreen device, and were able to select multiple responses. Eighty-one participants selected the phone application option, sixty-three chose the universal tap option, and six selected they did not like either of the options. The overall selection results can be seen in Figure 16, and seen in Table 23 (Appendix AB for text description) is the breakdown between low vision and blind.

Figure 16

Survey Participants' Preference for Accessing Accessibility Features with Public Touchscreen Devices

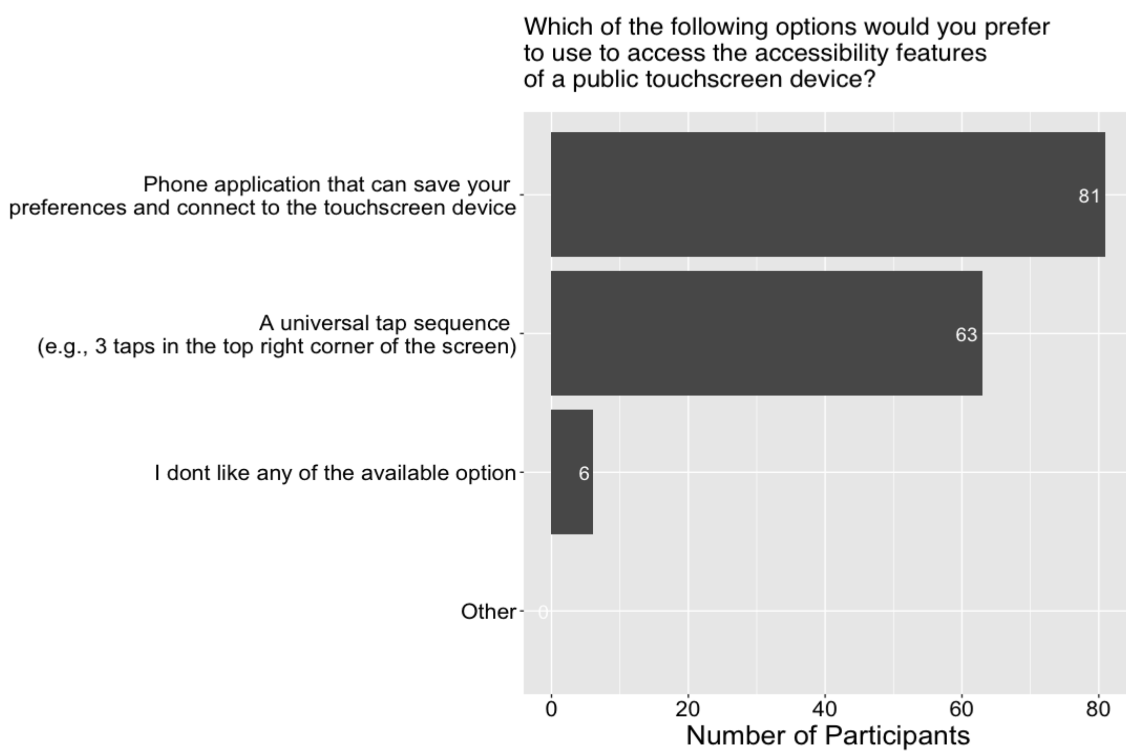


Table 23

Frequencies of Survey Participants' Preferences for Accessing Accessibility Features in Public Devices by Vision Status

Preferences	Total (*N* = 106)		Blind *(n = 23)*		Low Vision *(n = 83)*	
	N	%	*n*	%	*n*	%
Phone application that can save your preferences and connect to the touchscreen device	81	76.42	18	78.26	63	75.90
A universal tap sequence (e.g., 3 taps in the top right corner of the screen)	63	59.43	9	39.13	54	65.06
I don't like any of the available option	6	5.66	0	0	6	7.23
Other	0	0	0	0	0	0

Note. For the raw text reporting of this table, see Appendix AB

Discussion

The results were again presented by vision status, and the survey study had a larger sample of both participants who are blind and have low vision. Similarly to the interviews there were some differences between the participants who were blind and participants with low vision, including the type of approaches taken to interact with the touchscreen devices and features hoped for in the future. The participants who identified as blind selected fewer approaches with the majority selecting asking for help, voice commands, and audio commands. The same top three approaches appeared with the participants with low vision, in addition the other approaches (e.g., magnifying glass, learned the layout, and flashlight) available had a higher percentage of selection. The future hopes for the participants showed again a higher percentage of blind participants wanting voice commands compared the low vision participant, however the remaining of the features were relatively similar.

The results were also divided by age groups. The findings showed that the youngest age group of participants between the ages of 18-24 owned fewer touchscreen devices, had fewer experiences with public touchscreens, and tried fewer approaches to interact with touchscreens. Even with these lower ratings, this age group still had a high rating related to the thoughts on accessibility of touchscreen devices being sufficient for them. While the older age groups showed to try out different technologies and approaches, and showed higher ratings towards the technology lacking in accessibility.

The survey study was designed based on the responses and information presented during the interview phase. The changes consisted of asking the participants the same questions about their personal touchscreen devices versus the public devices they have used, asking about their future hopes, and asking about standardization of accessing accessible features. The findings from the survey data were similar to those of the interviews, and are described in detail below.

Questions with the same setup and similar response selection for personal and public devices included those about the approaches taken, future hopes, and sufficient accessibility. The chosen approaches were almost exactly the same in terms of frequency between the two categories with the exception of voice commands and audio commands, where personal approaches had voice commands above audio commands, and public approaches had audio commands above voice commands. The top choice for both categories was asking someone for help, followed by voice and audio commands, and then magnifying glass, learning the layout, and using a flashlight.

For future hopes a similar pattern existed, as the features selected for both personal and public devices were almost exactly the same from most common to least common selected choices. The exception here was audio commands rating fourth for personal devices and second for public devices. The second rating for personal devices was read aloud and the fourth for public was the ability to zoom.

The responses were very similar in terms of how participants felt about the available accessibility for both personal and public devices. Fewer participants believed that public touchscreen devices worked for what they needed them to do than those who believed that they were lacking in some areas. The general findings show that participants were comfortable using their personal devices for their daily tasks and making tasks easier for them, but would like to see specific improvements for public touchscreen accessibility.

During the survey, participants were given a list of options to choose from in response to the questions presented. The personal devices owned by the participants mainly included mobile touchscreen devices that allowed the users to customize the device to their preferences. Some other types of personal touchscreen devices that were discussed in the interview phase were appliance-like touchscreens (e.g., microwave), however many people may not have considered it when asking an open-ended question about devices they own. The results showed that BLV individuals do own various forms of touchscreens in the home. The types of touchscreens owned by BLV individuals are important to consider in terms of accessibility, and whether the users are satisfied with their setup. This information was shown through the results about whether the participants thought that the accessibility of personal touchscreen devices was sufficient for them, participants that indicated that they were lacking focus on devices that did not have accessibility settings and were described as unusable.

While the participants’ hope for improvement in the future focused on the technologies that are placed in the public domain during the interview phase, in the survey phase the participants were asked about their hopes in the context of both personal and public devices. This was in the form of accessible features they would like to see in the future, the most common for both personal and public devices were voice commands and read aloud. Another hope for the future that was addressed in the open spaces in the survey were the improvements of existing features, such as voice commands having better voice recognition. Those open text fields for participants' thoughts also presented some of the barriers and challenges including the voice recognition issue, not knowing of any features in public areas, and the desire to use touchscreens that are not accessible to them. These forms of accessibility features and hopes for the future were used in the consideration of the creation of the guidelines to address the needs and challenges of BLV individuals.

The preference of accessibility access question was created based on the interview phase responses. The results from the survey showed that participants were open to the ideas of accessing or setting up the accessibility features through a smart application or a universal tap sequence. The idea behind this concept would be to set up all touchscreen devices, personal devices, personal appliances, and public devices with a standardized method of accessing the accessibility settings.

Overall Discussion

The purpose of the survey was to evaluate whether the findings from the interview stage held true with a larger population sample. Throughout both the interview and the survey the types of devices owned, and the types of public devices used followed a similar pattern of most common to least common of the participants. Mobile touchscreen devices including smartphones, tablets, laptops, and smartwatches, were the most common types of personal devices owned. The most common public touchscreens used were ATMs and different forms of kiosks.

To address the first research question (RQ1), "What current features exist to assist individuals who are blind or have low vision in independent interactions with touchscreens?", participants were asked about types of features that they used in the interview study, as well as the approaches they use to interact with such devices in both the interview and survey studies. The approaches used by participants to interact with these devices were also similar between the interviews and the survey, but the interview phase only asked the participants about their approaches with public touchscreens, while the survey asked about personal and public approaches separately. The most common approach indicated by the participants in both phases and across both personal and public devices was asking for help. The need for help reinforces the matter presented throughout this paper, which is the lack of equitable access to touchscreen devices for BLV users. This supports the need for guidelines designed to facilitate the independent use of private and public touchscreens by the BLV population. Another approach discussed in both the review of literature and interview study was the use of adhesive tactile dots or Braille labels on personal devices in the home to indicate target areas (Kane et al., 2008). This approach provided an additional form of available information for interacting with touchscreens that was not reliant on visual cues. The common features described by interview participants for personal devices include screen readers, voice commands, and magnifiers; for public devices: audio commands, text to speech, and increased font sizes. The survey's features presented in the approaches for easier interaction with both personal and public devices included voice commands, audio commands, and magnifying glass. This information was used to ensure the design guidelines include such features that currently allow for independent interactions with touchscreens. The related works section discussed the accessibility of varying features for better interactions with mobile touchscreens for BLV individuals, adding to the list of features used these were VAPAs (Abdolrahmani et al., 2018), simplified keyboards (Rakhmetulla & Arif, 2020), Braille keyboards (Alnfiai & Sampalli, 2016; Li et al., 2017; Seim et al., 2014; Southern et al., 2012; Trindade et al., 2018), and gesture based navigation (Buzzi et al., 2017; Kane et al., 2008).

The second research question (RQ2), "What are the perceptions and experiences of individuals who are blind or have low vision in interactions with touchscreen interfaces?", which was addressed mainly in the interview question about describing an interaction with any type of touchscreen device that was easy and then again with a difficult experience. Perceptions and experiences were also addressed in the question of accessibility sufficiency and shown during the survey in the open text-fields. The only noticeable difference between the interview and survey responses were related to the question of sufficiency in accessibility of touchscreen devices. The interview asked the participants how they felt about the available accessibility for any type of touchscreen device, while the survey asked the same question separately for both personal and public devices. Most participants in the interview phase indicated accessibility was lacking in some areas, while the majority of survey respondents selected the option that indicated the touchscreen devices worked for what they used them for. Although these answers were different on the surface, for those who added onto their response about why they felt that way, the reasonings were similar between the phases. Overall, participants were able to complete some tasks on touchscreen devices, however they avoided or did not utilize features or additional tasks for which they did not have the necessary accessibility to navigate. The experiences that were difficult were indicated and described when the participants did not have access to or accessibility settings were not set up on the device, including interacting with other smart devices that were not their own, devices in the public, and at home appliances. Easy interactions were mainly experiences interacting with their own personal smartphones, tablets, and laptops with their preferred accessibility settings activated. While many BLV individuals stated touchscreen technologies work adequately for them, it is important to note that for the most part, participants stated that about the touchscreens they actually use. Many participants also stated that they often avoid those touchscreen devices both in the home and in the public domain for which they cannot access to use independently, and that they would use touchscreens more often if they were more accessible. Therefore, it is important to design touchscreen interfaces on both personal and public domain devices with accessibility features that allow, not only BLV, but a wider range of users to use the touchscreens independently to meet their needs. In addition to the findings of the studies conducted for this paper, previous research shared BLV participants' experiences with different forms of mobile touchscreen devices. Some of the challenges discussed include misclicks (Guo et al., 2019), social concerns in the public (Abdolrahmani et al., 2018; Kane et al., 2009), situational lighting (Kane et al., 2009), and independently interacting with public touchscreens (Guo et al., 2019; Kane et al., 2008, 2009; Vatavu, 2017).

RQ3 ("What are the conditions and/or constraints that are preventing individuals who are blind or have low vision from having effective interactions with touchscreens?") was an addition to RQ2. The perceptions and experiences gathered were used to determine where the accessibility gaps exist and what challenges BLV individuals face while interacting with touchscreen devices. Some of the challenges that were discussed in the literature review, interview study, and survey study include: trying to use a touchscreen device without their normal accessibility settings activated, not knowing whether a device has customizable accessibility features, having sufficient amount of alternative feedback that provides the same level of information that is presented with visual cues, needing and being about to obtain sighted assistance to complete an interaction, the inability to interact with device due to lighting, and social concerns while using assistive technologies (e.g., standing out in public, security risks, taking too long when there are others around or a line). Participants also discussed challenges with the use of some accessibility settings that needed improvements (e.g., voice commands), systems not being designed universally, and the lack of features for public devices. The review of literature presented studies that focused on specific challenges including gestures, VAPAs, keyboards, and use in the public. Buzzi et al. (2017) reported that the most difficult gestures required several changes in direction and multiple finger movements (e.g., to and fro, swipe, and rotor). Abdolrahmani et al. (2018) described ability challenges with VAPAs such as identifying system status and missing visual cues. VAPAs used in the public domain presented additional challenges including privacy issues, awkwardness, distractions, and impact of accuracy from ambient sounds associated. Several studies addressed the challenges presented in digital keyboard interactions on smartphones and tablets such as low average typing speed (Alnfiai & Sampalli, 2016; Li et al., 2017; Nicolau et al., 2014; Rakhmetulla & Arif, 2020; Seim et al., 2014; Southern et al., 2012; Yfantidis & Evreinov, 2006), difficulties fixing typing errors (Li et al., 2017; Nicolau et al., 2015; Southern et al., 2012), and the distraction of audio feedback (Alnfiai & Sampalli, 2016; Li et al., 2017; Southern et al., 2012). Kane (2009) presented three forms of barriers for interaction with personal touchscreens in the public: situational, fatigue/changing abilities, and device failure. Guo et al. (2019) evaluated interactions with public touchscreen devices, the challenges they focused on were accidental clicks while scanning the screen and the ability to interact independently with the screen.

The thought of more accessible touchscreens in the public was popular among both phases, where all of the participants in the interview study and the majority of those in the survey study indicated that they would use public touchscreens more if they were more accessible to them. By identifying the challenges and barriers of touchscreen use by BLV individuals, effective solutions can then be considered and implemented.

The last research question (RQ4), “What improvements could be made to touchscreen interfaces that could improve interactions and experiences with individuals who are blind or have low vision?”, was answered through the review of literature and the data analysis of the interview and survey studies, with suggestions about what improvements can be made taken into consideration. The future hopes of the interview participants mainly focused on what was lacking in public devices, while the survey participants were asked about their future hopes in the context of both their personal devices and the use of public devices. The survey provided them with a list of features they would like to see, and responses showed that the features discussed in the interview were also desired by those in the survey (e.g., voice command, read aloud, audio commands, the ability to zoom in, and the ability to increase font size). The universal design question related to accessing the features was not asked in the interview study, however the idea of inclusion of all types of users was prevalent in both studies. The suggested improvements to the challenges discussed above included a universal setup activation of accessibility features, alternative feedback that provides the same level of information that is presented with visual cues, the consideration of device's setup and location to allow for easy interaction in different environmental settings, and a design for all mindset. The findings from both the interview and survey studies have shown the need for improvement in the accessibility of touchscreen devices, whether they be devices that the user owns or devices that can be used in the public arena. The findings from the review of literature suggested the use of a user-centered design approach that considers users that are BLV (Huang, 2018). The review also contained developed guidelines from past researchers centered around general accessibility (Vatavu, 2017) and specific accessibility issues such as line profiles on touchscreens (Palani et al., 2020; Tennison & Gorlewicz, 2019) and nativagation (Kane et al., 2008). Guo et al.'s, (2019) study focused on the improvement with public touchscreen interactions. Their solution had the users scan the touchscreen interface with a camera and generate directions for navigating through the interface. Other research papers proposed different design solutions for better interactions with the use of gestures with touchscreen devices such as creating a simplified user interface (Khan & Khusro, 2019), use of gestural cues for input (Grussenmeyer & Folmer, 2017), avoiding multi-touch gestures, using single-stroke gestures, using short gestures (Buzzi et al., 2017; Oh et al., 2015), use of verbal feedback and gesture sonification feedback (Oh et al., 2013; Oh et al., 2015), for more complex gestures using rounded angles instead of sharp angles (Buzzi et al., 2017), and placing common actions in the corners of the screen (Huang, 2018).

Recommended Guidelines

These guidelines were produced through the three phases of this research paper to extend the answer to the final research question (RQ4), "What improvements could be made to touchscreen interfaces that could improve interactions and experiences with individuals who are blind or have low vision?" The set of guidelines was created for designers and developers of touchscreen interfaces to allow creation of interfaces that are easier and more accessible for individuals who are blind and have low vision. These include recommendations for both the software interface and the hardware components. The guidelines would be for any touchscreen device, whether it is a device that the user owns, a device owned by a friend or family member, or a device that is out in the public arena. The guidelines were based on the common themes that arose during the review of literature, interviews, and survey responses of the thoughts and experiences of the participants. The goal of the guidelines are to address the accessibility gaps that were made apparent, and provide solutions. These touchscreen guidelines would be beneficial to engineers and designers who work on the design and build of touchscreen devices. The guidelines will also be helpful to companies that make use of touchscreen devices in their businesses, as these guidelines can show them what is needed to make their devices available to BLV clientele, opening up a wider net for their consumer market.

The guidelines were created by evaluating and noting the challenges and approaches that were presented throughout the review of literature and the results from the interview and survey studies. The gaps and challenges found were listed and examined for solutions. The challenges include: not being able to use devices without preferred accessibility features, devices not having accessibility features, not having the ability to customize accessibility features, not knowing whether the device had accessibility features, setting up accessibility features independently, having equivalent audio and tactile feedback in comparison to visual cues, social concerns in the public , environmental concerns (situational lighting), and availability to get help when needed.

Each guideline below is coupled with a connection to the findings with the conditions and/or constraints that were preventing individuals who are BLV from having effective interactions with touchscreens, utilizing the information gained from answering (RQ3), “What are the conditions and/or constraints that are preventing individuals who are blind or have low vision from having effective interactions with touchscreens?” The explanations given before each guideline stem from both the review of literature and the findings of this paper. Guidelines 2, 3, and 5 were developed based on the findings obtained from this study, and Guidelines 1, 4, 6, and 7 used both the findings from these studies and previous studies.

Guideline 1: Universal Feature Setup

Based on the interview findings, individuals can be unaware of whether or not a device has accessibility features. Even if a device has accessibility features it is not always clear to a BLV user how to access or configure them. These issues can lead to a BLV user needing to ask for assistance because they can not interact independently with the device. Participants shared their struggles with trying to use their friends' smartphones without their normal accessibility setting activated, and their lack of awareness that some devices they avoided did have features that would allow them to access them.

Guideline 1 is the use of a setup gesture that activates the accessibility features that would allow people to quickly get into the settings that are customizable to the user and adjust them to their preferences. The setup would be for any touchscreen device, whether it is a device that the user owns, a device owned by a friend or family member, or a device that is out in the public arena. There were two approaches that were presented to survey participants about setting up a universal way to access the accessibility features available, the first being a phone application that saved the user's preferences and connected to the other touchscreen devices, this can be done via Bluetooth, and the second approach was to have a universal tap sequence, where the example given was 3 taps in the top, right corner of the screen. The results were pretty close, as 81 (76.42%) out of the 106 survey participants (Blind, n = 18 (78.26%); Low Vision, n = 63 (75.90%)) selected the phone application, while 64 (60.38%) (Blind, n = 9

(39.13%); Low Vision, n = 54 (65.06%)) selected the universal tap. Both approaches could be set up on devices, so if the user does not have the phone application, they could perform the universal gesture to still access the settings and set them up manually based on their needs and preferences.

Guideline 2: Accessibility Settings

Without accessibility settings, BLV touchscreen users can be prevented from interacting with touchscreen devices or face difficulties. During the interviews participants focused on the accessibility gap of household appliances and public touchscreen devices due to the inability to customize the devices to their needs. When asked about situations that they found difficult, all of the participants discussed attempting to use touchscreen devices without their accessibility features already set up. The survey data supported this guideline as well, with participants leaving comments about what features they would like to see in touchscreen devices, mainly screen readers, voice commands, and audio commands.

This guideline provided for the installation of accessibility settings to any and all types of touchscreen devices. Touchscreen devices have the ability to be customized to the user's preferences, currently most common in smartphones, tablets, computers, and smartwatches. All touchscreen devices, whether they are personally owned by the user or placed in public spaces, should have customizable settings that the user can adjust. These settings should provide an easier interaction experience for the user, including people with and without disabilities and older adults. The features discussed in the findings sections of this paper are a good start for what should be included in the accessibility settings, however other settings should be included that benefit people other than BLV individuals. A list of some features that should be included in the accessibility settings for touchscreen devices includes:

1. Screen Reader
2. Voice / Audio Commands
3. Magnification (Zoom)
4. Increasing Font Size
5. Bigger Icons
6. High Contrast Mode
7. Brightness Adjustment
8. Simple Mode - text only
9. Vibrations and Haptic Feedback
10. Live Captions
11. Sound Amplifier
12. Audio Adjustment

Guideline 3: Standardized Headphone Jack Position

The inconsistency of hardware setup makes it difficult for BLV individuals to use and interact with various forms of technology. This guideline was developed from the interview study results. During the interviews, participants were asked if they have used this feature while interacting with ATMs, and while some participants did use the headphone jack, other participants said that they were unaware of the jack or did not know if they were on the machines around them. Others mentioned wanting to use the feature but not having or owning wired headphones. Headphone jacks on the ATMs that provide audio commands to users are often located in different places on the machine (seen in Figure 17).

Figure 17

Images of various ATM Headphone Jack Placements

Note. a) generic ATM headphone jack located mid section of the machine to the right side, b) Bank of America headphone jack located on the mid section of the machine on the left side, c) Citizens Bank headphone jack located on the right side of the machine and screen underneath the keypad, d) PNC Bank headphone jack located to the left of the keypad below the screen, e) PNC Bank headphone jack located on the right side of the machine and screen, and f) generic ATM headphone jack located in the center of the machine below the screen

This guideline is the standardization of headphone jacks on touchscreen devices, and the suggestion to include headphone capabilities to public devices to allow for discrete use of audio commands. If headphones jacks are able to be used with a touchscreen device, the jack should be placed in the same place on all such touchscreen devices. For example, on an ATM machine, the headphone jack could be placed an inch away from the bottom right corner of the touchscreen. This allows the BLV user to obtain tactile feedback of both the corner of the screen, and then sliding to the left to feel the indent of the jack. The same setup should be used on other devices, both personal and public, such as coffee makers, laundry machines, self-checkout machines, ordering machines in restaurants, and kiosks in airports. The machines could also include a Bluetooth option to allow for bluetooth headphones to be connected to the device. This setting can reside in the accessibility setting discussed in guideline two.

Guideline 4: Tactile Feedback

Touchscreen devices are highly visually dependent and in most cases are not tactile without any physical notches or buttons to feel inputs, which creates opportunity for BLV individuals to miss out on important information. This guideline was created based on the research of Tennison and Gorlewicz, (2019), Vatavu (2017), Kane et al. (2008), as discussed in the feedback section in the review of literature. Tennison and Gorlewicz (2019) as well as Vatavu's (2017) research focused on the use of haptic feedback being used by BLV users as a tactile response on a non-tactile flat touchscreen. Their research showed tactile and audio feedback delivery techniques being used to provide the same level of information that is presented with visual cues, and were beneficial in the experience of interaction of the touchscreen devices by BLV users. As for providing tactile feedback with raised letters and Braille, both Kane et al, 2008 and this research reported participants who indicate using high markings or Braille labeling on their own personal devices for a better and easier interaction with the device. In addition, participants in the interview study of this paper discussed using high markings on their own personal devices for a better interaction experience. Audio and haptic feedback allow for better understanding by BLV users than visual cues. This guideline focuses on providing the user with different forms of tactile feedback, while Guideline 2 provides means for audio feedback.

This guideline is the inclusion of tactile and haptic feedback. If there are labels on the device there should also be a tactile alternative, including raising the letters on the label and providing a Braille alternative alongside the label. This would also include keypads with numbers on them. Another form of tactile feedback is when a selection is made on the screen there should be a haptic response that indicates to the user that they have done something with the device. These options should be in the accessibility settings allowing this functionality to be switched on and off.

Guideline 5: Ask for Help Button

Even with accessibility at the forefront, BLV individuals may run into unaccounted for questions or challenges about the interaction. This guideline was created based on the number of participants in both the interview and survey study who indicated that they would ask for help if needed. While the goal of this research is to create a more independent environment for BLV touchscreen users, the option for getting help in any situation should be available. Participants in both the interview study and survey study indicated the desire for independence, while still wanting a backup option for help in case there is a function that they are unable to complete themselves.

This guideline is the availability of a help function. This can be accomplished with a physical ask for help button on public devices, that can either ask the user what they are trying to do and give verbal feedback if applicable or it could connect to an employee if it is placed in a business setting. For personal devices, a “help” feature could again have the user input a voice command about what they are trying to do and get verbal feedback.

Guideline 6: Situational Lighting

The accessibility challenges due to lighting and screen brightness supported the creation of this guideline, and these challenges were found in both the interview study and in previous research. During the interview phase, participants with low vision mentioned that the lighting in the room was a factor on whether they would be able to interact with the machine independently, or if they would have to ask for help. One participant mentioned carrying a flashlight around with them and using it in poorly lit areas, and when talking about the lighting in a room they said “I know it's very situational, because that lighting has got to be just right or just wrong.” Kane et al.’s (2009) research also reported participants having difficulty interacting with devices in settings that were in very bright or very dim light.

This guideline is the examination of the environmental setting for devices in a fixed spot, as the location and surrounding environment of a touchscreen device is an important factor of consideration. If the lighting is too dim or produces a glare on the screen, it can make the interaction with the screen difficult or impossible. The placement of the device should be evaluated based on window location, as well as how the raising and setting of the sun would affect the visibility of the screen to the user, and if there is too much or not enough light directed around the screen.

Guideline 7: Time Consideration

Does the amount of time it takes to complete the intended task take more time than it would using an alternative that involves human services, or than it would take a sighted user? Previous research has shown BLV users experience embarrassment in social settings while using assistive technologies. For example, Abdolrahmani's (2018) study on the use of VAPAs in public spaces presented some challenges or concerns from their participants, including their privacy and the draw of attention while using VAPAs. Another concern that presented itself during some of the interviews in this study was feeling pressured, where participants mentioned that they feel time pressure when interacting with some devices in the public. Those participants noted that if there are other people around, they would end up not using the machine at all.

This guideline is the consideration of the time it takes to complete a task with various accessibility features engaged. The time it takes to complete the interaction with the touchscreen device should not take considerably more time for someone who is using different features than others, as this can create pressure on the user and guilt if there is a line waiting to use the same device. The features that make the interaction easier should not add too much time for the user to complete their task. For example, completing a task with audio commands requires the users to listen to the instructions before continuing on with their interactions. This type of infrastructure should take into consideration how much time is added onto the interaction while completing the same task with and without the feature activated.

Evaluation of Guidelines

The original plan for this research study was to conduct semi-structured interviews and a Delphi panel (Avella, 2016). The interview phase was planned to gather intel about the current experience and barriers of BLV participants and then create a set of design guidelines that would address the barriers presented. The Delphi panel was going to review the created guidelines and offer feedback so that the guidelines could be modified, as needed, based on the feedback from the BLV community. That process of review and modification was to continue until the Delphi panel was satisfied with the set of guidelines. However, after the interviews were conducted as originally planned, the Delphi panel approach was changed into a survey study. The reasoning behind this change occurred because the researcher that conducted the interviews believed a wider pool of participants was necessary before determining the common gaps in accessibility for BLV touchscreen users. This decision is discussed further in the limitation and future work sections of the paper. Due to this decision, previous guidelines were evaluated and compared to the guidelines developed based on this research approach.

Previous guidelines for more accessible interactions with touchscreens tended to focus on mobile devices such as smartphones and tablets, some of which focused on specific functionalities. The research process of creating the guidelines also varied and included using one or more of the following approaches: interviews, diary studies, experimental tasks, and qualitative review of works. In efforts to compare the guidelines created in this study and the previous guidelines created, previous works have been divided into two groups: overall accessibility and specific accessibility.

Overall Accessibility

Huang (2018), Kane et al. (2009), McGookin et al. (2008), and Vatavu (2017) created design guidelines for accessible touchscreen interfaces for BLV users based on their research around mobile device accessibility. Huang (2018) created their set of guidelines through experimental tasks followed by Likert scales and open-ended questions based on their BLV participants' accessibility requirements and experience with smartphones. Huang established seven guidelines, one of which connected back to guideline four of this paper: accurate voice control, noticeable touch button, two interface layers, clear information design and arrangement, **personalized vibrotactile assistance**, speak screen that avoids advertising, and two-stage touch process. Their fifth guideline related to the use of vibrational feedback being used to provide the users with additional information of their actions, which is similar to the Guideline 4 of this paper that discusses providing tactile alternatives for labels and haptic feedback for actions performed on the touchscreen devices.

Kane et al. (2009) created four guidelines based on the research they conducted through interviews and a diary study: **access methods on commodity devices, increased configurability, contextual adaptation**, and integrating assistive devices. Of the four, the first three related to or support the guidelines created in this paper. The first guideline related to the finding that individuals who are BLV use the common mobile device found in stores instead of specifically designing devices for people with disabilities. As such, this guideline focuses on making accessibility a top priority for the mass-produced mobile devices in efforts to support any and all users. Guideline one of this study relates to universal design, which by definition is the design of making things available for use by anyone, regardless of ability. Kane’s second guideline relates to the availability of adjustable settings and the ability of consumers to customize their devices to their preferences, which coincides with the second guideline of this paper ensuring that all touchscreen devices have available accessibility settings. Lastly, Kane’s third guideline discusses the impacts of accessibility through environmental conditions focusing on the device being unusable or unsafe to use in certain situations, which in turn relates to guideline six, situational lighting. While Kane’s guideline focused on using mobile sensors to detect the user’s location and activity and adjust accordingly, and the guideline here focused on the placement of a device, the reasoning for the creation of the guidelines was very similar: the lighting in the location of use.

McGookin et al. (2008) created their set of guidelines with a comparative experimental approach, comparing a raised paper overlay and gesture based approach for interacting with touchscreen devices. An important note of their study was that the participants were sighted except for one that identified as low vision. Five guidelines were created: do not use short impact related gestures (e.g. tap), avoid “localized” gestures or provide touchscreen awareness, provide a discernible tactile “home”, use different button shapes, and provide feedback for all actions. While none of these guidelines related closely to the guidelines created for this study, their guidelines did indicate a form of tactile feedback being used and that any action provided should have some form of feedback. This could lightly support the claim of guideline four of providing different forms of feedback.

Vatavu’s (2017) guidelines were created through an overview of existing research focusing on the improvement of accessibility in mobile devices. Fifteen guidelines were designed and discussed: design new form factors for accessible mobile devices, design for a wide range of wearable devices, **design interactions for multiple mobile devices**, design mobile device interactions to reduce encumbrance when using other accessibility devices, **allow configurable visual settings**, detect and use context, design discrete interactions, detect and deal appropriately with unintended touch, design usable touch gestures for people with visual impairments, **deliver appropriate feedback for all visual abilities**, **deliver appropriate feedback during and after gesture articulation**, design appropriate techniques for learning gestures, design new assistive features for screen readers, and evaluate assistive technology in real-world scenarios. Four of their guidelines provided similar means as the guidelines created for this research paper. The guideline related to designing interactions for multiple mobile devices discusses the idea that BLV individuals use additional pieces of technologies to better interact with their touchscreen devices (e.g., refreshable braille display), which helps support Guideline 1 that indicates using a smart application to connect to other devices and automatically set up the user's accessibility preferences. Their next guideline was focused on allowing users to configure their accessibility setting, which supports Guideline 2 here that indicates customizable settings should be available on all devices. The final two guidelines that relate to this paper were to deliver appropriate feedback for all visual abilities and deliver appropriate feedback during and after gesture articulation. Both of these connect to Guideline 4's discussion of tactile feedback and the importance of providing different forms of feedback to match user preferences and to provide feedback during and after actions are performed.

Specific Accessibility

Branham and Roy (2019), Palani et al. (2020), and Tennison & Gorlewicz (2019) created their design guidelines for accessible touchscreen interfaces for BLV users based on their research around specific approaches such as VAPAs and perception of lines. Branham and Roy (2019) conducted a review of literature (qualitative document review) of VAPA design guidelines. They reviewed the big VAPA companies' guidelines such as Amazon, Google, and Apple. The three guidelines created were focused on the design and setup of VAPAs: allow preferences to be defined on-the-fly, **allow preferences to be defined in advance**, and allow custom voice commands to be defined in advance. Although the guidelines' primary focus was on VAPAs they could be used to evaluate the type of voice commands implemented into devices being built based on this study's guidelines. Branham and Roy's (2019) second guideline also related to the BLV users being able to customize their settings, such as voice speed of audio feedback which can relate back to this study's guideline two.

Palani et al. (2020) and Tennison and Gorlewicz (2019) created guidelines based on the perception of lines on touchscreen devices. Their guidelines discuss the conditions that allow for the creation of multimodal graphical components on touchscreens, such as line width, distances, and feedback (audio and haptic). Both studies performed experiments of various tasks in efforts to create their guidelines. The only type of connection between the guidelines created in these studies and this research was the discussion of using alternative feedback mechanisms to provide additional information to the users.

While not all of the guidelines created during this study had a relation or connection to past research, the approach in creating the guidelines was similar to other researchers. This study also used three approaches for gathering information in its efforts to create the design guidelines, while other studies only used one approach.

Limitations

While the number of participants recruited for each of the studies was relatively similar to other research works with participants who are blind or have low vision, the division of participants by vision status (Blind vs Low Vision) was uneven. The majority of participants in the interview study identified as low vision, making it difficult to compare the groups. Another limitation of this research study was the research design process, which lacked in evaluating the guidelines developed and experimental usability testing. In addition, the analysis of the interview phase had only one coder, the validity of the codes created was not evaluated by others that may interpret the same response differently. The interview and survey studies provide informational understanding of what works and does not work with the touchscreen devices, but an experimental study could provide real-scenario data that the participant did not think about while completing the interview or survey. This approach could also assist in evaluating the use or effectiveness of the guidelines being implemented. For the survey study, there were not enough participants to perform a Chi-Square Test of Independence, as the number of cells with expected values greater than or equal to five was less than 80%. Further research with an increased number of participants recruited would allow for the tests to be rerun for validity. The last limitation was the survey responses, as the survey data had a high rate of invalid responses that needed to be cleaned out for data analysis, which opens the probability that some of the responses included within data analysis were not valid.

Conclusion and Future Work

This study consisted of three phases, investigating the available accessibility of touchscreen devices both owned personal users or used in the public arena based on gathering of information and data from previous work; followed by semi-structured interviews where the questions were based off the gaps in previous work; and the final phase was a survey to cast a wider net for participants. The findings showed that the accessibility of touchscreens is lacking in the public domain, and with household appliances (eg., dishwasher, microwave, and laundry machines). To this end, the thoughts and experiences of the participants were used to create a set of recommended guidelines for designers and developers of touchscreen interfaces to allow for easier and more accessible interactions for individuals who are blind and have low vision.

The next step to further this research would be to conduct a Delphi panel or focus group interviews that discuss the recommended guidelines created in this study, and make adjustments accordingly. This could be followed by prototyping different types of touchscreen devices to be set up with the recommended guidelines. These prototypes would then be used to conduct experimental usability testing to provide a better understanding on how intuitive the design setup is.

References

Abdolrahmani, A., Kuber, R., & Branham, S. M. (2018). “Siri Talks at You”: An Empirical Investigation of Voice-Activated Personal Assistant (VAPA) Usage by Individuals Who Are Blind. *Proceedings of the 20th International ACM SIGACCESS Conference on Computers and Accessibility*, 249–258. https://doi.org/10.1145/3234695.3236344

Aira Tech Corp. (n.d.). *Visual Interpreting – Get Live, On-demand Access to Visual Information*. Retrieved April 5, 2022, from https://aira.io/

Alnfiai, M., & Sampalli, S. (2016). An Evaluation of SingleTapBraille Keyboard: A Text Entry Method that Utilizes Braille Patterns on Touchscreen Devices. *Proceedings of the 18th International ACM SIGACCESS Conference on Computers and Accessibility*, 161–169. https://doi.org/10.1145/2982142.2982161

Araújo, M. C. C., Silva, A. R. S., Darin, T. G. R., de Castro, E. L., Andrade, R. M. C., de Lima, E. T., Sánchez, J., de C. Filho, J. A., & Viana, W. (2016). Design and usability of a braille-based mobile audiogame environment. *Proceedings of the 31st Annual ACM Symposium on Applied Computing*, 232–238. https://doi.org/10.1145/2851613.2851701

Avella, J. (2016). Delphi Panels: Research Design, Procedures, Advantages, and Challenges. *International Journal of Doctoral Studies*, *11*, 305–321.

Blythe, M., Monk, A., & Park, J. (2002). Technology biographies: Field study techinques for home use product development. *CHI ’02 Extended Abstracts on Human Factors in Computing Systems*, 658–659. https://doi.org/10.1145/506443.506532

Branham, S. M., & Roy, A. R. M. (2019). Reading Between the Guidelines: How

Commercial Voice Assistant Guidelines Hinder Accessibility for Blind Users. *The 21st International ACM SIGACCESS Conference on Computers and Accessibility*, 446–458. https://doi.org/10.1145/3308561.3353797

Buzzi, M. C., Buzzi, M., Leporini, B., & Trujillo, A. (2017). Analyzing visually impaired people's touch gestures on smartphones. *Multimedia Tools and Applications*, *76*(4), 5141–5169. https://doi.org/10.1007/s11042-016-3594-9

Csapó, Á., Wersényi, G., Nagy, H., & Stockman, T. (2015). A survey of assistive technologies and applications for blind users on mobile platforms: A review and foundation for research. *Journal on Multimodal User Interfaces*, *9*(4), 275–286. https://doi.org/10.1007/s12193-015-0182-7

Ferati, M., Mannheimer, S., & Bolchini, D. (2011). Usability evaluation of acoustic interfaces for the blind. *Proceedings of the 29th ACM International Conference on Design of Communication*, 9–16. https://doi.org/10.1145/2038476.2038479

Grussenmeyer, W., & Folmer, E. (2017). Accessible Touchscreen Technology for People with Visual Impairments: A Survey. *ACM Transactions on Accessible Computing*, *9*(2), 6:1-6:31. https://doi.org/10.1145/3022701

Guo, A., Kong, J., Rivera, M., Xu, F. F., & Bigham, J. P. (2019). StateLens: A Reverse Engineering Solution for Making Existing Dynamic Touchscreens Accessible. *Proceedings of the 32nd Annual ACM Symposium on User Interface Software and Technology*, 371–385. https://doi.org/10.1145/3332165.3347873

Hakobyan, L., Lumsden, J., O'Sullivan, D., & Bartlett, H. (2013). Mobile assistive technologies for the visually impaired. *Survey of Ophthalmology*, *58*(6), 513–528. https://doi.org/10.1016/j.survophthal.2012.10.004

Huang, H. (2018). Blind users' expectations of touch interfaces: Factors affecting interface accessibility of touchscreen-based smartphones for people with moderate visual impairment. *Universal Access in the Information Society*, *17*(2), 291–304. https://doi.org/10.1007/s10209-017-0550-z

Kane, S. K., Bigham, J. P., & Wobbrock, J. O. (2008). Slide rule: Making mobile touch screens accessible to blind people using multi-touch interaction techniques. *Proceedings of the 10th International ACM SIGACCESS Conference on Computers and Accessibility*, 73–80. https://doi.org/10.1145/1414471.1414487

Kane, S. K., Jayant, C., Wobbrock, J. O., & Ladner, R. E. (2009). Freedom to roam: A study of mobile device adoption and accessibility for people with visual and motor disabilities. *Proceedings of the 11th International ACM SIGACCESS Conference on Computers and Accessibility*, 115–122. https://doi.org/10.1145/1639642.1639663

Khan, A., & Khusro, S. (2019). Blind-friendly user interfaces—A pilot study on improving the accessibility of touchscreen interfaces. *Multimedia Tools and Applications*, *78*(13), 17495–17519. https://doi.org/10.1007/s11042-018-7094-y

Li, M., Fan, M., & Truong, K. N. (2017). BrailleSketch: A Gesture-based Text Input Method for People with Visual Impairments. *Proceedings of the 19th International ACM SIGACCESS Conference on Computers and Accessibility*, 12–21. https://doi.org/10.1145/3132525.3132528

McGookin, D., Brewster, S., & Jiang, W. (2008). Investigating touchscreen accessibility for people with visual impairments. *Proceedings of the 5th Nordic Conference on Human-Computer Interaction: Building Bridges*, 298–307.

https://doi.org/10.1145/1463160.1463193

Milne, L. R., Bennett, C. L., Ladner, R. E., & Azenkot, S. (2014). BraillePlay: Educational smartphone games for blind children. *Proceedings of the 16th International ACM SIGACCESS Conference on Computers & Accessibility*, 137–144. https://doi.org/10.1145/2661334.2661377

Nicolau, H., Montague, K., Guerreiro, T., Guerreiro, J., & Hanson, V. L. (2014). B#: Chord-based correction for multitouch braille input. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 1705–1708. https://doi.org/10.1145/2556288.2557269

Nicolau, H., Montague, K., Guerreiro, T., Rodrigues, A., & Hanson, V. L. (2015). Typing Performance of Blind Users: An Analysis of Touch Behaviors, Learning Effect, and In-Situ Usage. *Proceedings of the 17th International ACM SIGACCESS Conference on Computers & Accessibility*, 273–280. https://doi.org/10.1145/2700648.2809861

Oh, U., Branham, S., Findlater, L., & Kane, S. K. (2015). Audio-Based Feedback Techniques for Teaching Touchscreen Gestures. *ACM Transactions on Accessible Computing*, *7*(3), 9:1-9:29. https://doi.org/10.1145/2764917

Oh, U., Kane, S. K., & Findlater, L. (2013). Follow that sound: Using sonification and corrective verbal feedback to teach touchscreen gestures. *Proceedings of the 15th International ACM SIGACCESS Conference on Computers and Accessibility*, 1–8. https://doi.org/10.1145/2513383.2513455

Palani, H. P., Fink, P. D. S., & Giudice, N. A. (2020). Design Guidelines for Schematizing and Rendering Haptically Perceivable Graphical Elements on

Touchscreen Devices. *International Journal of Human–Computer Interaction*, *36*(15), 1393–1414. https://doi.org/10.1080/10447318.2020.1752464

Rakhmetulla, G., & Arif, A. S. (2020). Senorita: A Chorded Keyboard for Sighted, Low Vision, and Blind Mobile Users. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems* (pp. 1–13). Association for Computing Machinery. https://doi.org/10.1145/3313831.3376576

Seim, C., Chandler, J., DesPortes, K., Dhingra, S., Park, M., & Starner, T. (2014). Passive haptic learning of Braille typing. *Proceedings of the 2014 ACM International Symposium on Wearable Computers*, 111–118. https://doi.org/10.1145/2634317.2634330

Southern, C., Clawson, J., Frey, B., Abowd, G., & Romero, M. (2012). An evaluation of BrailleTouch: Mobile touchscreen text entry for the visually impaired. *Proceedings of the 14th International Conference on Human-Computer Interaction with Mobile Devices and Services*, 317–326. https://doi.org/10.1145/2371574.2371623

Steinfeld, E., Maisel, J., & Levine, D. (2012). *Universal Design: Creating Inclusive Environments*. John Wiley & Sons, Incorporated. http://ebookcentral.proquest.com/lib/rit/detail.action?docID=821663

Tennison, J. L., & Gorlewicz, J. L. (2019). Non-visual Perception of Lines on a Multimodal Touchscreen Tablet. *ACM Transactions on Applied Perception*, *16*(1), 6:1-6:19. https://doi.org/10.1145/3301415

Trindade, D., Rodrigues, A., Guerreiro, T., & Nicolau, H. (2018). Hybrid-Brailler: Combining Physical and Gestural Interaction for Mobile Braille Input and Editing.

In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (pp. 1–12). Association for Computing Machinery. https://doi.org/10.1145/3173574.3173601

Vatavu, R.-D. (2017). Visual Impairments and Mobile Touchscreen Interaction: State-of-the-Art, Causes of Visual Impairment, and Design Guidelines. *Int. J. Hum. Comput. Interact.* https://doi.org/10.1080/10447318.2017.1279827

Yfantidis, G., & Evreinov, G. (2006). Adaptive blind interaction technique for touchscreens. *Universal Access in the Information Society*, *4*(4), 328–337. https://doi.org/10.1007/s10209-004-0109-7

Appendices

Appendix A: IRB Study Approval and Modification Forms

R·I·T

Rochester Institute of Technology

RIT Institutional Review Board for the Protection of Human Subjects in Research
141 Lomb Memorial Drive
Rochester, New York 14623-5604
Phone: 585-475-7673
Fax: 585-475-7990
Email: hmfsrs@rit.edu

Form C
IRB Decision Form
FWA# 00000731

TO: Elizabeth Codick

FROM: RIT Institutional Review Board

APPROVAL DATE: October 26, 2021

RE: Decision of the RIT Institutional Review Board

Project Title – Evaluation of the Accessibility of Touchscreens for Individuals who are Blind or have Low Vision and Where to go from here

HSRO #06101421

The Institutional Review Board (IRB) has taken the following action on your project named above.

☒ Exempt _46.104 (d) (2ii)_

Now that your project is approved, you may proceed as you described in the Form A.

You are required to submit to the IRB any:
- **Proposed** modifications and wait for approval before implementing them,
- Unanticipated risks, and
- Actual injury to human subjects.

Heather M Foti
Digitally signed by Heather M Foti
Date: 2021.11.09 10:08:20 -05'00'

Heather Foti, MPH
Associate Director
Office of Human Subjects Research

Revised 10.5.20

Appendix B: Interview Participation Form

Below is some information about the interview study:

The purpose of the research study is to gain a better understanding of current approaches to interacting with touchscreen interfaces by people who are blind or have low vision. This interview research will explore your opinions of, perceptions of, and current practices while interacting with touchscreens, such as cell phones, tablets, and coffee makers.

Participation in the interview includes a $35 gift card upon completion. This will be provided in the form of an Amazon gift card that will be sent to provided emails.

If you have questions at any time about the study or the procedures, you may contact the Principal Investigators, Lizzie Codick at emc6595@rit.edu or Elissa Weeden at Elissa.Weeden@rit.edu. If you have other questions please contact the Human Subjects Research Office at hmfsrs@rit.edu.

By filling out this form you agree that:

- You are 18 years of age or older
- You would like to be contacted to participant in this interview study

1. What is your full name?

   ____

2. What is your age group?
   - ○ 18 - 24 years
   - ○ 25 - 35 years
   - ○ 36 - 44 years
   - ○ 45 - 54 years
   - ○ 55 - 70 year
   - ○ Above 70 years
3. What is your gender identity?
   - ○ Woman
   - ○ Man
   - ○ Transgender
   - ○ Non/conforming
   - ○ Prefer not to respond
   - ○ Other: __________________________
4. What is your ethnicity?
   - ○ White/Caucasian
   - ○ Hispanic/Latino
   - ○ Black/African American
   - ○ Native American/American Indian
   - ○ Asian/Pacific Islander
   - ○ Other: __________________________

5. What is your vision status?
   - ○ Blind
   - ○ Low Vision
   - ○ Sighted
   - ○ Other: ________________________
6. What is your email address?

   ____
7. What is your current occupation?

   ____
8. Do you have experience with interacting with personal touchscreen devices (e.g.,
9. smartphones, tablets, laptops, coffee makers)?
   - ○ Yes
   - ○ No
   - ○ I am not sure
10. Do you have experience with interacting with public touchscreen devices (e.g., mall kiosk, work coffee maker, ordering screen at food places)?
   - ○ Yes
   - ○ No
   - ○ I am not sure

Appendix C: Interview Consent

What are some general things you should know about research studies?

We invite you to take part in a research study. Your participation in this study is voluntary. You have the right to be a part of this study, to choose not to participate or to stop participating at any time without penalty. You are not guaranteed any personal benefits from participating in this study.

What is the purpose of this study?

The purpose of the research study is to gain a better understanding of current approaches to interacting with touchscreen interfaces by people who are blind or have low vision. This interview research will explore your opinions of, perceptions of, and current practices while interacting with touchscreens, such as cell phones, tablets, and coffee makers.

What will happen if you take part in the study?

You will participate in a semi-structured interview, where you will be asked about touchscreen technologies that you may currently use and your thoughts and opinions about how accessible the technologies are and whether they can be improved. There are no right or wrong answers; we are just interested in your opinions. The interview is estimated to last for an hour, and will be recorded. Your participation in this research is voluntary and it is your choice whether to participate or not. You may choose not to participate or to stop participating at any time without penalty or loss of benefits.

Risks

We don’t anticipate any risks to you if you participate, but there may be some we don’t know about.

Benefits

Knowledge gained from this study may help to inform organizations about the approaches to be taken when designing and developing touchscreen interfaces and technologies.

Confidentiality

Your identity will be kept confidential. This means we will do our best to make sure only people connected with the research will see your data. Data will be stored securely on password protected servers and computers within Rochester Institute of Technology (RIT). Only the researchers will have access to the data. Video recordings will not be shared or viewed by anyone other than the researchers, they are for data collection purposes only.

The results will be presented together and demographic data will only be used to describe the group of people who provided information. The results of the study will be shared only for academic purposes and may be presented at conferences or in journal articles. In rare instances, there may be safety or compliance issues that arise and require authorized representatives of Rochester Institute of Technology, including members of the Human Subjects

Research Office (HSRO) or Institutional Review Board (IRB), or federal officials to access research records that identify you by name.

Compensation

Participation in the interview includes a $35 gift card upon completion. This will be provided in the form of an Amazon gift card that will be sent to provided emails.

What if you have questions about this study?

If you have questions at any time about the study or the procedures, you may contact the Principal Investigators, Lizzie Codick at emc6595@rit.edu or Elissa Weeden at Elissa.Weeden@rit.edu. If you have other questions please contact the Human Subjects Research Office at hmfsrs@rit.edu.

ELECTRONIC CONSENT: You may print a copy of this consent form for your records. Consent will be given by the participant sending a reply email as “I consent to include my data in the research study.” or “I do not consent to include my data in the research study.”

By consenting to this study you agree that:

- You have read the above information
- You voluntarily agree to participate
- You are alright with being video recorded
- You are 18 years of age or older

Appendix D: Interview Questions

- How would you describe your vision status?
- What current personal touchscreen devices do you use (e.g., smartphone, tablet, smartwatch, coffee makers)?
- What touchscreens have you used in the past that were in public places (e.g., office coffee maker, digital map at the mall)?
    - If you have used public touchscreen devices in the past, what approaches have you used for easier interaction with the screen?
    - If you haven't used public devices is there a reason (e.g., accessibility, availability)?
    - If public touchscreen devices were more accessible, would you use them?
- What features do you use when interacting with a personal touchscreen device?
- What features do you use when interacting with a public touchscreen device?
- How do you feel about the available accessibility, do you think it works for what you use them for or are they lacking in some areas?
    - If they are lacking, can you think of any examples?
    - Have you experienced a situation where you were unable to access a function or feature? If yes, how did you go about to access it?
- Do you think additional accessible technologies (meaning additional devices) are inconvenient?
- Are there any applications that you use to better interact with touchscreen devices?

- Can you think of an experience that you have had with any type of touchscreen interface that was
    - Difficult? Why?
    - Easy or was a smooth interaction? How?
- Do you have any other information to share about your personal experience with touchscreen devices?
- Do you have experience with group communication platforms such as Slack, Microsoft teams, or others? If others, which?
    - Which communication platforms do you find most accessible? Why?
- Would you like to be contacted about further studies related to this type of research?
    - If yes, what is the best way to contact you (email, phone, etc.)?

Appendix E: Table 2 Text Description

Table 2 includes the frequencies of personal devices owned by interview participants by vision status. For each device the total and percentage is provided out of the 20 interview participants and then further broken down by vision status based on the two blind interview participants and the 18 low vision interview participants. The following data is reported: smartphone (*N* = 20 (100%); Blind, *n* = 2 (100%); Low Vision, *n* = 18 (100%)), tablet (*N* = 13 (65%); Low Vision, *n* = 13 (72.22%), computer/laptop (*N* = 11 (55%); Low Vision, *n* = 11 (61.11%)), smartwatch (*N* = 9 (45%); Blind, *n* = 2 (100%); Low Vision, *n* = 7 (38.89%)), coffee maker (*N* = 3 (15%); Low Vision, *n* = 3 (16.67%)), washing machine/dryer (*N* = 3 (15%); Low Vision, *n* = 3 (16.67%)), air fryer (*N* = 1 (5%); Low Vision, *n* = 1 (5.56%)), dishwasher (*N* = 1 (5%); Low Vision, *n* = 1 (5.56%)), refrigerator (*N* = 1 (5%); Low Vision, *n* = 1 (5.56%)), GPS in the car (*N* = 1 (5%); Low Vision, *n* = 1 (5.56%)), microwave (*N* = 1 (5%); Low Vision, *n* = 1 (5.56%)), oven (*N* = 1 (5%); Low Vision, *n* = 1 (5.56%)), printer (*N* = 2 (10%); Low Vision, *n* = 2 (11.11%)), and TV remote (*N* = 1 (5%); Blind, *n* = 1 (50%)).

Appendix F: Table 3 Text Description

Table 3 includes the frequencies of personal features used by interview participants by vision status. For each feature the total and percentage is provided out of the 20 interview participants and then further broken down by vision status based on the two blind interview participants and the 18 low vision interview participants. The following data is reported: screen reader (*N* = 12 (60%); Blind, *n* = 2 (100%); Low Vision, *n* = 10 (55.56%)), voice commands (*N* = 9 (45%); Low Vision, *n* = 9 (50%)), screen magnifiers (*N* = 4 (20%); Low Vision, *n* = 4 (22.22%)), text-to-speech (*N* = 4

(20%); Blind, *n* = 1 (50%); Low Vision, *n* = 3 (16.67%)), increase font size (*N* = 3 (15%); Low Vision, *n* = 3 (16.67%)), adjust screen brightness (*N* = 2 (10%); Low Vision, *n* = 2 (11.11%)), high marking (*N* = 2 (10%); Low Vision, *n* = 2 (11.11%)), larger icons (*N* = 2 (10%); Low Vision, *n* = 2 (11.11%)), adjust contrast (*N* = 1 (5%); Low Vision, *n* = 1 (5.56%)), audio commands (*N* = 1 (5%); Low Vision, *n* = 1 (5.56%)), bold text (*N* = 1 (5%); Low Vision, *n* = 1 (5.56%)), Braille screen input (*N* = 1 (5%); Blind, *n* = 1 (50%)), refreshable Braille display (*N* = 1 (5%); Low Vision, *n* = 1 (5.56%)), and voice messages (*N* = 1 (5%); Low Vision, *n* = 1 (5.56%)).

Appendix G: Table 4 Text Description

Table 4 includes the frequencies of applications used by interview participants with their personal touchscreen devices by vision status. For each application the total and percentage is provided out of the 20 interview participants and then further broken down by vision status based on the two blind interview participants and the 18 low vision interview participants. The following data is reported: Siri (*N* = 5 (25%); Blind, *n* = 1 (50%); Low Vision, *n* = 4 (22.22%)), Alexa (*N* = 4 (20%); Blind, *n* = 1 (50%); Low Vision, *n* = 3 (16.67%)), Aira (*N* = 3 (15%); Blind, *n* = 2 (100%); Low Vision, *n* = 1 (5.56%)), Be My Eye (*N* = 2 (10%); Low Vision, *n* = 2 (11.11%)), Google Maps (*N* = 2 (10%); Blind, *n* = 1 (50%); Low Vision, *n* = 1 (5.56%)), National Libraries Braille Reading Download Program (*N* = 2 (5%); Low Vision, *n* = 2 (11.11%)), screen reader (*N* = 2 (10%); Low Vision, *n* = 2 (11.11%)), Audible/Kindle (*N* = 1 (5%); Low Vision, *n* = 1 (5.56%)), Banking application(s) (*N* = 1 (5%); Low Vision, *n* = 1 (5.56%)), Call Announcer (*N* = 1 (5%); Low Vision, *n* = 1 (5.56%)), dark mode (*N* = 1 (5%); Low Vision, *n* = 1 (5.56%)), Dictation (*N* = 1 (5%); Low Vision, *n* = 1 (5.56%)), FitBit (*N* = 1 (5%);

Low Vision, *n* = 1 (5.56%)), Google Assistant (*N* = 1 (5%); Blind, *n* = 1 (50%)), Google Translate (*N* = 1 (5%); Low Vision, *n* = 1 (5.56%)), Braille and Audio Reading Download (BARD) (*N* = 1 (5%); Low Vision, *n* = 1 (5.56%)), Look Around (*N* = 1 (5%); Blind, *n* = 1 (50%)), magnifier (*N* = 1 (5%); Low Vision, *n* = 1 (5.56%)), medical application(s) (*N* = 1 (5%); Low Vision, *n* = 1 (5.56%)), Rejected Capacitive Touch (*N* = 1 (5%); Low Vision, *n* = 1 (5.56%)), scheduling application(s) (*N* = 1 (5%); Low Vision, *n* = 1 (5.56%)), Speak (*N* = 1 (5%); Blind, *n* = 1 (50%)), Voice Dream Scanner and Meter (*N* = 1 (5%); Low Vision, *n* = 1 (5.56%)), and Voice Record (*N* = 1 (5%); Low Vision, *n* = 1 (5.56%)).

Appendix H: Table 5 Text Description

Table 5 includes the frequencies of type of public touchscreen devices used by interview participants by vision status. For each device the total and percentage is provided out of the 20 interview participants and then further broken down by vision status based on the two blind interview participants and the 18 low vision interview participants. The following data is reported: ATM machines (*N* = 14 (70%); Low Vision, *n* = 14 (77.78%)), self-checkout (*N* = 5 (25%); Blind, *n* = 1 (50%); Low Vision, *n* = 4 (22.22%)), computer/laptop (*N* = 4 (20%); Low Vision, *n* = 4 (22.22%)), restaurant kiosks (*N* = 4 (20%); Blind, *n* = 1 (50%); Low Vision, *n* = 3 (16.67%)), coffee maker (*N* = 3 (15%); Low Vision, *n* = 3 (16.67%)), airport kiosks (*N* = 2 (10%); Low Vision, *n* = 2 (11.11%)), tablet (*N* = 2 (10%); Low Vision, *n* = 2 (11.11%)), touchpads (*N* = 2 (10%); Low Vision, *n* = 2 (11.11%)), TV/remote (*N* = 2 (10%); Low Vision, *n* = 2 (11.11%)), voting machines (*N* = 2 (10%); Low Vision, *n* = 2 (11.11%)), fingerprint security (*N* = 1 (5%); Low Vision, *n* = 1 (5.56%)), digital maps at the mall (*N* = 1 (5%); Low Vision, *n* = 1 (5.56%)), post office kiosks (*N* = 1 (5%); Low Vision, *n* = 1 (5.56%)), printer (*N* = 1 (5%);

Low Vision, *n* = 1 (5.56%)), soda machines (*N* = 1 (5%); Low Vision, *n* = 1 (5.56%)), and no experience with public touchscreens (*N* = 2 (10%); Blind, *n* = 2 (100%)).

Appendix I: Table 6 Text Description

Table 6 includes the frequencies of features used by interview participants with public touchscreen devices by vision status. For each feature the total and percentage is provided out of the 20 interview participants and then further broken down by vision status based on the two blind interview participants and the 18 low vision interview participants. The following data is reported: audio commands (*N* = 4 (20%); Low Vision, *n* = 4 (22.22%)), increased font size (*N* = 3 (15%); Low Vision, *n* = 3 (16.67%)), text-to-speech (*N* = 3 (15%); Low Vision, *n* = 3 (16.67%)), AIRA (*N* = 2 (10%); Low Vision, *n* = 2 (11.11%)), voice commands (*N* = 2 (10%); Low Vision, *n* = 2 (11.11%)), adjusted brightness (*N* = 1 (5%); Low Vision, *n* = 1 (5.56%)), larger icons (*N* = 1 (5%); Low Vision, *n* = 1 (5.56%)), magnifiers (physical/digital) (*N* = 1 (5%); Low Vision, *n* = 1 (5.56%)), depends (*N* = 1 (5%); Low Vision, *n* = 1 (5.56%)), and none (*N* = 5 (25%); Blind, *n* = 2 (100%); Low Vision, *n* = 3 (16.67%)).

Appendix J: Table 7 Text Description

Table 7 includes the frequencies of approaches used by interview participants with public touchscreen devices by vision status. For each approach the total and percentage is provided out of the 20 interview participants and then further broken down by vision status based on the two blind interview participants and the 18 low vision interview participants. The following data is reported: ask for help/assistants (*N* = 9 (45%); Blind, *n* = 1 (50%); Low Vision, *n* = 8 (44.44%)), eye glasses (*N* = 4 (20%); Low Vision, *n* = 4 (22.22%)), learn the layout/muscle memory (*N* = 4 (20%); Low Vision, *n* =

4 (22.22%)), look closely (*N* = 4 (20%); Low Vision, *n* = 4 (22.22%)), magnifiers (physical/digital) (*N* = 4 (20%); Low Vision, *n* = 4 (22.22%)), use smartphone (*N* = 4 (20%); Low Vision, *n* = 4 (22.22%)), audio commands (*N* = 3 (15%); Low Vision, *n* = 3 (16.67%)), flashlight (*N* = 1 (5%); Low Vision, *n* = 1 (5.56%)), increase brightness (*N* = 1 (5%); Low Vision, *n* = 1 (5.56%)), increase font size (*N* = 1 (5%); Low Vision, *n* = 1 (5.56%)), larger icons (*N* = 1 (5%); Low Vision, *n* = 1 (5.56%)), and avoid/don't use (*N* = 4 (20%); Blind, *n* = 2 (100%); Low Vision, *n* = 2 (11.11%)).

Appendix K: Table 8 Text Description

Table 8 includes the frequencies of interview participants' future hopes for touchscreen devices by vision status. For each hope the total and percentage is provided out of the 20 interview participants and then further broken down by vision status based on the two blind interview participants and the 18 low vision interview participants. The following data is reported: voice commands (*N* = 9 (45%); Blind, *n* = 1 (50%); Low Vision, *n* = 8 (44.44%)), increased font size (*N* = 8 (40%); Low Vision, *n* = 8 (44.44%)), audio commands (*N* = 5 (25%); Low Vision, *n* = 5 (27.78%)), screen readers (*N* = 5 (25%); Blind, *n* = 2 (100%); Low Vision, *n* = 3 (16.67%)), larger icons (*N* = 4 (20%); Low Vision, *n* = 4 (22.22%)), magnifiers (zoom in) (*N* = 4 (20%); Low Vision, *n* = 4 (22.22%)), adjust brightness (*N* = 3 (15%); Low Vision, *n* = 3 (16.67%)), adjust contrast (*N* = 2 (10%); Low Vision, *n* = 2 (11.11%)), bold text (*N* = 2 (10%); Low Vision, *n* = 2 (11.11%)), connecting devices (*N* = 2 (10%); Blind, *n* = 1 (50%); Low Vision, *n* = 1 (5.56%)), consideration of lighting (*N* = 2 (10%); Low Vision, *n* = 2 (11.11%)), design for all (*N* = 2 (10%); Blind, *n* = 1 (50%); Low Vision, *n* = 1 (5.56%)), physical keypads (*N* = 2 (10%); Blind, *n* = 1 (50%); Low Vision, *n* = 1 (5.56%)), simple mode (*N* = 2 (10%); Low

Vision, *n* = 2 (11.11%)), gestures (*N* = 1 (5%); Low Vision, *n* = 1 (5.56%)), larger screens (*N* = 1 (5%); Low Vision, *n* = 1 (5.56%)), sturdier devices (*N* = 1 (5%); Low Vision, *n* = 1 (5.56%)), and tactile feedback (*N* = 1 (5%); Low Vision, *n* = 1 (5.56%)).

Appendix L: Survey Consent Form

Your Right as a Participant

We invite you to take part in a research study. Your participation in this study is voluntary. You have the right to be a part of this study, to choose not to participate or to stop participating at any time without penalty. You are not guaranteed any personal benefits from participating in this study.

What is the purpose of this study?

The purpose of the research study is to gain a better understanding of current approaches to interacting with touchscreen interfaces by people who are blind or have low vision. This survey research will explore your opinions of, perceptions of, and current practices while interacting with touchscreens, such as cell phones, tablets, and coffee makers. In addition, the survey will ask questions about what you would want to see in future applications of touchscreen devices.

What will happen if you take part in the study?

You will be asked to complete a survey, where you will be asked about touchscreen technologies that you may currently use and your thoughts and opinions about how accessible the technologies are and whether they can be improved. There are no right or wrong answers; we are just interested in your opinions. The survey is estimated to last for about 10 to 15 minutes. Your participation in this research is voluntary and it is your choice whether to participate or not. You may choose not to participate or to stop participating at any time without penalty or loss of benefits.

Risks

We don't anticipate any risks to you if you participate, but there may be some we don't know about.

Benefits

Knowledge gained from this study may help to inform organizations about the approaches to be taken when designing and developing touchscreen interfaces and technologies.

Confidentiality

Your identity will be kept confidential. This means we will do our best to make sure only people connected with the research will see your data. Data will be stored securely on password protected servers and computers within Rochester Institute of Technology (RIT). Only the researchers will have access to the data. The results will be presented together and demographic data will only be used to describe the group of people who provided information. The results of the study will be shared only for academic purposes and may be presented at conferences or in journal articles. In rare instances, there may be safety or compliance issues that arise and require authorized representatives of Rochester Institute of Technology, including members of the Human Subjects Research Office (HSRO) or Institutional Review Board (IRB), or federal officials to access research records that identify you by name.

Compensation

The first 100 qualifying participants to complete the survey and provide an email address will be emailed a $5 Amazon gift card. This can take a few days to be processed and sent out to the participant's email address. Participants thereafter will be put into a raffle for a $5 Amazon gift card, this will be completed once the survey is closed.

What if you have questions about this study?

If you have questions at any time about the study or the procedures, you may contact the Principal Investigators, Lizzie Codick at emc6595@rit.edu or Elissa Weeden at Elissa.Weeden@rit.edu. If you have other questions please contact the Human Subjects Research Office at hmfsrs@rit.edu.

ELECTRONIC CONSENT: You may print a copy of this consent form for your records, with a screenshot of this screen. Clicking on the arrow (→) button indicates that:

- You have read the above information
- You voluntarily agree to participate
- You are 18 years of age or older
- You are blind or have low vision

Appendix M: Survey Questions

Start of Block: Vision Status

What is your vision status?

- o Blind
- o Low Vision
- o Sighted
- o Other (Please specify in the text box below)

____

Optional: How would you describe your vision status?

____

____

____

End of Block: Vision Status

Start of Block: Section 1: Current Experiences - Personal

What current **personal touchscreen devices** do you use (devices that you own)?

- ▢ Smartphone
- ▢ Tablet
- ▢ Smartwatch
- ▢ Coffee Maker
- ▢ Microwave/Microwave Oven
- ▢ Washing Machine/Dryer
- ▢ Dishwasher

- ▢ Other (please specify in the text box below; if multiple separate with a comma) ____
- ▢ I don't own any personal touchscreen devices

What approaches have you used for easier interaction with the screen on your **personal touchscreen devices** (please select all that apply)?

- ▢ Asked someone for help
- ▢ Audio Commands (audio instructions given)
- ▢ Voice Commands
- ▢ Learned the layout
- ▢ Magnifying glass
- ▢ Flashlight
- ▢ Other (please specify in the text box below; if multiple separate with a comma) ____

Since you do not own any **personal touchscreen devices**, what are your reasonings?

- ▢ The devices are not accessible
- ▢ I use alternative devices with physical buttons
- ▢ No reasoning
- ▢ Other (please specify in the text box below)

____

Is the accessibility of **personal touchscreen devices** sufficient for you?

- ○ They work for what I use them for. (You may provide additional information below) ____
- ○ They are lacking in some areas. (You may provide additional information below) ____
- ○ It depends. (You may provide additional information below) ____
- ○ I don't know

What type of features do you hope to see in the future for **personal touchscreen devices**?

- ▢ Voice command
- ▢ Read aloud
- ▢ Audio commands (Number commands)
- ▢ The ability to zoom in
- ▢ The ability to increase font size
- ▢ An option for bigger Icons
- ▢ Physical buttons
- ▢ Brightness adjustment
- ▢ High contrast
- ▢ Simple mode (text only, would hide images)
- ▢ Tactile feedback
- ▢ Gestures (swipes, taps, press and hold, etc...)

▢ Other (please specify in the text box below; if multiple separate with a comma) ____

Do you have any other thoughts or comments to add about your experiences with **personal touchscreens devices**? (Optional)

____

____

____

____

____

End of Block: Section 1: Current Experiences - Personal

Start of Block: Section 2: Current Experiences - Public

What touchscreens have you used that were in **public places**?

▢ ATM Machines

▢ Digital maps at the mall

▢ Ordering Machines (e.g., McDonald's touchscreens)

▢ Kiosks (in airports, bus stations, post office, etc)

▢ Other (please specify in the text box below; if multiple separate with a comma) ____

▢ I have never used public touchscreen devices

Since you haven't used **public touchscreen devices**, what are your reasonings?

▢ The devices are not accessible

▢ Take more time than alternatives that involve human services

▢ Haven't come across any touchscreen devices to use

▢ No reasoning

▢ Other (please specify in the text box below)

____

What approaches have you used for easier interaction with touchscreens in **public places** (please select all that apply)?

▢ Asked someone for help

▢ Audio Commands (audio instructions given)

▢ Voice Commands

▢ Learned the layout

▢ Magnifying glass

▢ Flashlight

▢ Avoided having to use such devices

▢ Other (please specify in the text box below; if multiple separate with a comma) ____

If **public touchscreen devices** were more accessible, would you use them more? Optional: include your reasoning in the text box.

○ Yes (You may provide additional information below)

____

○ Maybe (You may provide additional information below)

____

○ No (You may provide additional information below)

____

Is the accessibility of **public touchscreen devices** sufficient for you?

○ They work for what I use them for. (You may provide additional information below)

____

○ They are lacking in some areas. (You may provide additional information below) ____

○ It depends. (You may provide additional information below)

____

○ I don't know

What type of features do you hope to see in the future for **public touchscreen devices**?

▢ Voice command

▢ Read aloud

▢ Audio commands (Number commands)

▢ The ability to zoom in

▢ The ability to increase font size

▢ An option for bigger Icons

▢ Physical buttons

▢ Brightness adjustment

▢ High contrast

- ▢ Simple mode (text only, would hide images)
- ▢ Tactile feedback
- ▢ Gestures (swipes, taps, press and hold, etc...)
- ▢ Other (please specify in the text box below; if multiple separate with a comma) ____

Which of the following options would you prefer to use to access the accessibility features of a **public touchscreen device**?

- ▢ A universal tap sequence (e.g., 3 taps in the top right corner of the screen)
- ▢ Phone application that can save your preferences and connect to the touchscreen device
- ▢ I don't like any of the available option
- ▢ Other (please specify in the text box below)

____

Do you have any other thoughts or comments to add about your experiences with **public touchscreens**? (Optional)

____

____

____

____

____

End of Block: Section 2: Current Experiences - Public

Start of Block: Demographics

What is your gender?

- ○ Male
- ○ Female
- ○ Non-binary / third gender
- ○ Prefer not to say
- ○ Other (Optional: Please specify in the text box below)

____

What is your age?

- ○ Under 18
- ○ 18 - 24
- ○ 25 - 34
- ○ 35 - 44
- ○ 45 - 54
- ○ 55 - 64
- ○ 65 - 74
- ○ 75 - 84
- ○ 85 or older

How would you describe yourself? Please select all that apply.

- ▢ White

- ▢ Black or African American
- ▢ American Indian or Alaska Native
- ▢ Asian
- ▢ Native Hawaiian or Pacific Islander
- ▢ Other

What is the highest degree or level of school you have completed?

- ○ Less than a high school diploma
- ○ High school degree or equivalent (e.g. GED)
- ○ Some college, no degree
- ○ Associate degree (e.g. AA, AS, AAS)
- ○ Bachelor's degree (e.g. BA, BS)
- ○ Master's degree (e.g. MA, MS, MEd)
- ○ Doctorate or professional degree (e.g. MD, EdS, DDS, PhD)

What is your current employment status?

- ○ Employed full time (40 or more hours per week)
- ○ Employed part time (up to 39 hours per week)
- ○ Unemployed and currently looking for work
- ○ Unemployed not currently looking for work
- ○ Student
- ○ Retired
- ○ Homemaker

- ○ Self-employed
- ○ Unable to work

Would you like to be contacted for further studies (if yes, email will need to be provided in the next question)?

- ○ Yes
- ○ No

Optional: Please provide your email, an email address is needed for compensation to be provided to participants who qualify. If you selected "No" to being contacted for further studies, and provide your email here, the email will only be used for the purpose of compensation.

____

End of Block: Demographics

Appendix N: Table 9 Text Description

Table 9 includes the frequencies of personal devices owned by survey participants by vision status. For each device the total and percentage is provided out of the 106 survey participants and then further broken down by vision status based on the 23 blind survey participants and the 83 low vision survey participants. The following data is reported: smartphone (*N* = 86 (81.13%); Blind, *n* = 12 (52.17%); Low Vision, *n* = 74 (89.16%)), tablet (*N* = 67 (63.21%); Blind, *n* = 11 (47.83%); Low Vision, *n* = 56 (67.47%)), smartwatch (*N* = 44 (41.51%); Blind, *n* = 2 (8.70%); Low Vision, *n* = 42 (50.60%)), microwave/microwave oven (*N* = 34 (32.08%); Blind, *n* = 3 (13.04%); Low

Vision, *n* = 31 (37.35%)), coffee maker (*N* = 33 (31.13%); Blind, *n* = 7 (30.43%); Low Vision, *n* = 26 (31.33%)), washing machine/dryer (*N* = 32 (30.19%); Blind, *n* = 1 (4.35%); Low Vision, *n* = 31 (37.35%)), dishwasher (*N* = 27 (25.47%); Blind, *n* = 3 (13.04%); Low Vision, *n* = 24 (28.92%)), other (*N* = 2 (1.89%); Low Vision, *n* = 2 (2.41%)), and do not own personal touchscreen devices (*N* = 5 (4.72%); Blind, *n* = 5 (21.74%)).

Appendix O: Table 10 Text Description

Table 10 includes the frequencies of personal devices owned by survey participants by age. For each device the total and percentage is provided by the age groups based on the 39 survey participants between 18-24 years old, 43 survey participants between 25-34 years old, 17 survey participants between 35-44 years old, 5 survey participants between 45-54 years old, and two survey participants between 55-64 years old. The following data is reported: smartphone (18-24, *n* = 23 (58.97%); 25-34, *n* = 40 (93.02%); 35-44, *n* = 17 (100%); 45-54, *n* = 4 (80%); 55-64 *n* = 2 (100%)), tablet (18-24, *n* = 19 (48.72%); 25-34, *n* = 31 (72.09%); 35-44, *n* = 12 (70.59%); 45-54, *n* = 3 (60%); 55-64 *n* = 2 (100%)), smartwatch (18-24, *n* = 8 (20.51%); 25-34, *n* = 21 (48.84%); 35-44, *n* = 12 (70.59%); 45-54, *n* = 3 (60.00%); 55-64, *n* = 0 (0%)), microwave/microwave oven (18-24, *n* = 5 (12.82%); 25-34, *n* = 15 (34.88%); 35-44, *n* = 9 (52.94%); 45-54, *n* = 3 (60%); 55-64, *n* = 2 (100%)), coffee maker (18-24, *n* = 9 (23.08%); 25-34, *n* = 14 (32.56%); 35-44, *n* = 6 (35.29%); 45-54, *n* = 3 (60%); 55-64, *n* = 1 (50%)), washing machine/dryer (18-24, *n* = 7 (17.95%); 25-34, *n* = 14 (32.56%); 35-44, *n* = 6 (35.29%); 45-54, *n* = 3 (60%); 55-64, *n* = 2 (100%), dishwasher (18-24, *n* = 3 (7.69%); 25-34, *n* = 14 (32.56%); 35-44, *n* = 7 (41.18%); 45-54, *n* = 2 (40%); 55-64, *n* =

1 (50%), other (18-24, *n* = 0 (0%); 25-34, *n* = 0 (0%); 35-44, *n* = 0 (0%); 45-54, *n* = 1 (20%); 55-64, *n* = 1 (50%)), and do not own personal touchscreen devices (18-24, *n* = 5 (12.82%); 25-34, *n* = 0 (0%); 35-44, *n* = 0 (0%); 45-54, *n* = 0 (0%); 55-64, *n* = 0 (0%)).

Appendix P: Table 11 Text Description

Table 11 includes the frequencies of approaches used by survey participants with personal touchscreen devices by vision status. For each approach the total and percentage is provided out of the 106 survey participants and then further broken down by vision status based on the 23 blind survey participants and the 83 low vision survey participants. The following data is reported: ask someone for help (*N* = 77 (72.64%); Blind, *n* = 20 (86.96%); Low Vision, *n* = 57 (68.67%)), voice commands (*N* = 74 (69.81%); Blind, *n* = 13 (56.52%); Low Vision, *n* = 61 (73.49%)), audio commands (audio instructions given) (*N* = 70 (66.04%); Blind, *n* = 10 (43.48%); Low Vision, *n* = 60 (72.29%)), magnifying glass (*N* = 44 (41.51%); Blind, *n* = 3 (13.04%); Low Vision, *n* = 41 (49.40%)), learned the layout (*N* = 39 (36.79%); Blind, *n* = 5 (21.74%); Low Vision, *n* = 34 (40.96%)), flashlight (*N* = 23 (21.70%); Blind, *n* = 1 (4.35%); Low Vision, *n* = 22 (26.51%)), and other (*N* = 3 (2.83%); Blind, *n* = 3 (13.04%)).

Appendix Q: Table 12 Text Description

Table 12 includes the frequencies of approaches used by survey participants with personal touchscreen devices by age. For each approach the total and percentage is provided by age groups based on the 39 survey participants between 18-24 years old, 43 survey participants between 25-34 years old, 17 survey participants between 35-44 years old, 5 survey participants between 45-54 years old, and two survey participants between 55-64 years old. The following data is reported: ask someone for help (18-24, *n* = 28 (71.79%); 25-34, *n* = 30 (69.77%); 35-44, *n* = 13 (76.47%); 45-54, *n* = 4 (80%); 55-64, *n* = 2 (100%)), voice commands (18-24, *n* = 20 (51.28%); 25-34, *n* = 33 (76.74%); 35-44, *n* = 15 (88.24%); 45-54, *n* = 4 (80%); 55-64, *n* = 2 (100%)), audio commands (18-24, *n* = 19 (48.72%); 25-34, *n* = 31 (72.09%); 35-44, *n* = 14 (82.35%); 45-54, *n* = 4 (80%); 55-64, *n* = 2 (100%)), magnifying glass (18-24, *n* = 8 (20.51%); 25-34, *n* = 21 (48.84%); 35-44, *n* = 13 (76.47%); 45-54, *n* = 1 (20%); 55-64, *n* = 1 (50%)), learned the layout (18-24, *n* = 3 (7.69%); 25-34, *n* = 22 (51.16%); 35-44, *n* = 9 (52.94%); 45-54, *n* = 3 (60%); 55-64, *n* = 2 (100%)), flashlight (18-24, *n* = 3 (7.69%); 25-34, *n* = 11 (25.58%); 35-44, *n* = 5 (29.41%); 45-54, *n* = 3 (60%); 55-64, *n* = 1 (50%)), and other (18-24, *n* = 0 (0%); 25-34, *n* = 2 (4.65%); 35-44, *n* = 0 (0%); 45-54, *n* = 0 (0%); 55-64, *n* = 1 (50%)).

Appendix R: Table 13 Text Description

Table 13 includes the frequencies of survey participants' thoughts about the accessibility of personal touchscreen devices by vision status. For each response the total and percentage is provided out of the 106 survey participants and then further broken down by vision status based on the 23 blind survey participants and the 83 low vision survey participants. The following data is reported: they work for what I use them for (*N* = 70 (66.04%); Blind, *n* = 15 (65.22%); Low Vision, *n* = 55 (66.27%)), they are lacking in some areas (*N* = 24 (22.64%); Blind, *n* = 2 (8.70%); Low Vision, *n* = 22 (26.51%)), it depends (*N* = 6 (5.66%); Blind, *n* = 1 (4.35%); Low Vision, *n* = 5 (6.02%)), and none of the participants selected “I don’t know”.

Appendix S: Table 14 Text Description

Table 14 includes the frequencies of survey participants' thoughts about the accessibility of personal touchscreen devices by age. For each response the total and percentage is provided by age groups based on the 39 survey participants between 18-24 years old, 43 survey participants between 25-34 years old, 17 survey participants between 35-44 years old, 5 survey participants between 45-54 years old, and two survey participants between 55-64 years old. The following data is reported: they work for what I use them for (18-24, *n* = 27 (69.23%); 25-34, *n* = 30 (69.77%); 35-44, *n* = 9 (52.94%); 45-54, *n* = 4 (80%); 55-64, *n* = 0 (0%)), they are lacking in some areas (18-24, *n* = 5 (12.82%); 25-34, *n* = 11 (25.58%); 35-44, *n* = 7 (41.18%); 45-54, *n* = 0 (0%); 55-64, *n* = 1 (50%)), it depends (18-24, *n* = 2 (5.13%); 25-34, *n* = 2 (4.65%); 35-44, *n* = 0 (0%); 45-54, *n* = 1 (20%); 55-64, *n* = 1 (50%)), and none of the participants selected "I don't know".

Appendix T: Table 15 Text Description

Table 15 includes the frequencies of public touchscreens used by survey participants by vision status. For each device the total and percentage is provided out of the 106 survey participants and then further broken down by vision status based on the 23 blind survey participants and the 83 low vision survey participants. The following data is reported: ATM machines (*N* = 91 (85.85%); Blind, *n* = 16 (69.57%); Low Vision, *n* = 75 (90.36%)), ordering machines (*N* = 54 (50.94%); Blind, *n* = 7 (30.43%); Low Vision, *n* = 47 (56.63%)), digital maps in the mall (*N* = 45 (42.45%); Blind, *n* = 10 (43.48%); Low Vision, *n* = 35 (42.17%)), kiosks (*N* = 45 (42.45%); Blind, *n* = 3 (13.04%); Low Vision, *n* = 42 (50.60%)), other (*N* = 3 (2.83%); Blind, *n* = 1 (4.35%); Low

Vision, *n* = 2 (2.41%)), and never used (*N* = 10 (9.43%); Blind, *n* = 6 (26.09%); Low Vision, *n* = 4 (4.82%)).

Appendix U: Table 16 Text Description

Table 16 includes the frequencies of survey participants' reasonings for not having past experiences with public touchscreen by vision status. For each reason the total and percentage is provided out of the 106 survey participants and then further broken down by vision status based on the 23 blind survey participants and the 83 low vision survey participants. The following data is reported: haven't come across any touchscreen devices to use (*N* = 5 (4.72%); Blind, *n* = 5 (21.74%)), the devices are not accessible (*N* = 3 (2.83%); Low Vision, *n* = 3 (3.61%)), take more time than alternatives that involve human services (*N* = 2 (1.89%); Low Vision, *n* = 2 (2.41%)), no reasoning (*N* = 1 (0.94%); Blind, *n* = 1 (4.35%)), and other (*N* = 1 (0.94%); Blind, *n* = 1 (4.35%)).

Appendix V: Table 17 Text Description

Table 17 includes the frequencies of public touchscreens used by survey participants by age. For each device the total and percentage is provided by age groups based on the 39 survey participants between 18-24 years old, 43 survey participants between 25-34 years old, 17 survey participants between 35-44 years old, 5 survey participants between 45-54 years old, and two survey participants between 55-64 years old. The following data is reported: ATM machines (18-24, *n* = 29 (74.36%); 25-34, *n* = 40 (93.02%); 35-44, *n* = 15 (88.24%); 45-54, *n* = 5 (100%); 55-64, *n* = 2 (100%)), ordering machines (18-24, *n* = 10 (25.64%); 25-34, *n* = 28 (65.12%); 35-44, *n* = 12 (70.59%); 45-54, *n* = 3 (60%); 55-64, *n* = 1 (50%)), digital maps in the mall (18-24, *n* = 12 (30.77%); 25-34, *n* = 18 (41.86%); 35-44, *n* = 11 (64.71%); 45-54, *n* = 3 (60%); 55-

64, *n* = 1 (50%)), kiosks (18-24, *n* = 12 (30.77%); 25-34, *n* = 21 (48.84%); 35-44, *n* = 9 (52.94%); 45-54, *n* = 2 (40%); 55-64, *n* = 1 (50%)), other (18-24, *n* = 0 (0%); 25-34, *n* = 0 (0%); 35-44, *n* = 1 (5.88%); 45-54, *n* = 1 (20%); 55-64, *n* = 1 (50%)), and never used (18-24, *n* = 9 (23.08%); 25-34, *n* = 1 (2.33%); 35-44, *n* = 0 (0%); 45-54, *n* = 0 (0%); 55-64, *n* = 0 (0%)).

Appendix W: Table 18 Text Description

Table 18 includes the frequencies of approaches used by survey participants with public touchscreen devices by vision status. For each approach the total and percentage is provided out of the 106 survey participants and then further broken down by vision status based on the 23 blind survey participants and the 83 low vision survey participants. The following data is reported: ask someone for help (*N* = 74 (69.81%); Blind, *n* = 17 (73.91%); Low Vision, *n* = 57 (68.67%)), audio commands (*N* = 55 (51.89%); Blind, *n* = 9 (39.13%); Low Vision, *n* = 46 (55.42%)), voice commands (*N* = 49 (46.23%); Blind, *n* = 9 (39.13%); Low Vision, *n* = 40 (48.19%)), magnifying glass (*N* = 43 (40.56%); Blind, *n* = 3 (13.04%); Low Vision, *n* = 40 (48.19%)), learned the layout (*N* = 32 (30.19%); Blind, *n* = 2 (8.70%); Low Vision, *n* = 30 (36.14%)), flashlight (*N* = 18 (16.98%); Blind, *n* = 1 (4.35%); Low Vision, *n* = 17 (20.48%)), avoid (*N* = 15 (14.15%); Blind, *n* = 2 (8.70%); Low Vision, *n* = 13 (15.66%)), and other (*N* = 1 (0.94%); Low Vision, *n* = 1 (1.20%)).

Appendix X: Table 19 Text Description

Table 19 includes the frequencies of approaches used by survey participants with public touchscreen devices by age. For each approach the total and percentage is provided by age groups based on the 39 survey participants between 18-24 years old, 43 survey participants between 25-34 years old, 17 survey participants between 35-44 years old, 5 survey participants between 45-54 years old, and two survey participants between 55-64 years old. The following data is reported: ask someone for help (18-24, *n* = 23 (58.97%); 25-34, *n* = 33 (76.74%); 35-44, *n* = 12 (70.59%); 45-54, *n* = 4 (80%); 55-64, *n* = 2 (100%)), audio commands (18-24, *n* = 16 (41.03%); 25-34, *n* = 25 (58.14%); 35-44, *n* = 10 (58.82%); 45-54, *n* = 3 (60%); 55-64, *n* = 1 (50%)), voice commands (18-24, *n* = 14 (35.90%); 25-34, *n* = 20 (46.51%); 35-44, *n* = 10 (58.82%); 45-54, *n* = 4 (80%); 55-64, *n* = 1 (50%)), magnifying glass (18-24, *n* = 9 (23.08%); 25-34, *n* = 21 (48.84%); 35-44, *n* = 10 (58.82%); 45-54, *n* = 2 (40%); 55-64, *n* = 1 (50%)), learned the layout (18-24, *n* = 4 (10.26%); 25-34, *n* = 20 (46.51%); 35-44, *n* = 5 (29.41%); 45-54, *n* = 2 (40%); 55-64, *n* = 1 (50%)), flashlight (18-24, *n* = 2 (5.13%); 25-34, *n* = 10 (23.26%); 35-44, *n* = 3 (17.65%); 45-54, *n* = 2 (40%); 55-64, *n* = 1 (50%)), avoid (18-24, *n* = 1 (2.56%); 25-34, *n* = 8 (18.60%); 35-44, *n* = 4 (23.53%); 45-54, *n* = 2 (40%); 55-64, *n* = 0 (0%)), and other (18-24, *n* = 0 (0%); 25-34, *n* = 0 (0%); 35-44, *n* = 0 (0%); 45-54, *n* = 0 (0%); 55-64, *n* = 1 (50%)).

Appendix Y: Table 20 Text Description

Table 20 includes the frequencies of survey participants' thoughts about the accessibility of public touchscreen devices by vision status. For each response the total and percentage is provided out of the 106 survey participants and then further broken down by vision status based on the 23 blind survey participants and the 83 low vision survey participants. The following data is reported: they work for what I use them for (*N* = 63 (59.43%); Blind, *n* = 13 (56.52%); Low Vision, *n* = 50 (60.24%)), they are lacking in some areas (*N* = 27 (25.47%); Blind, *n* = 2 (8.70%); Low Vision, *n* = 25 (30.12%)), it depends (*N* = 6 (5.66%); Blind, *n* = 2 (8.70%); Low Vision, *n* = 4 (4.82%)), and none of the participants selected “I don’t know”.

Appendix Z: Table 21 Text Description

Table 21 includes the frequencies of survey participants' thoughts about the accessibility of public touchscreen devices by age. For each response the total and percentage is provided by age groups based on the 39 survey participants between 18-24 years old, 43 survey participants between 25-34 years old, 17 survey participants between 35-44 years old, 5 survey participants between 45-54 years old, and two survey participants between 55-64 years old. The following data is reported: they work for what I use them for (18-24, *n* = 24 (61.54%); 25-34, *n* = 27 (62.79%); 35-44, *n* = 9 (52.94%); 45-54, *n* = 3 (60%); 55-64, *n* = 0 (0%)), they are lacking in some areas (18-24, *n* = 5 (12.82%); 25-34, *n* = 12 (27.91%); 35-44, *n* = 7 (41.18%); 45-54, *n* = 1 (20%); 55-64, *n* = 2 (100%)), it depends (18-24, *n* = 1 (2.56%); 25-34, *n* = 3 (6.98%); 35-44, *n* = 1 (5.88%); 45-54, *n* = 1 (20%); 55-64, *n* = 0 (0%)), and none of the participants selected “I don’t know”.

Appendix AA: Table 22 Text Description

Table 22 includes the frequencies of survey participants’ future hopes in personal and public touchscreen devices by vision status. For each response the total and percentage is provided out of the 106 survey participants and then further broken down by vision status based on the 23 blind survey participants and the 83 low vision survey participants. The following data is reported for personal devices: voice commands (*N* = 73 (68.87%); Blind, *n* = 20 (86.96%); Low Vision, *n* = 53 (63.86%)), read aloud (*N* = 64 (60.38%); Blind, *n* = 14 (60.87%); Low Vision, *n* = 50 (60.24%)), audio commands (*N* =

52 (49.06%); Blind, *n* = 10 (43.48%); Low Vision, *n* = 42 (50.60%)), the ability to zoom in (*N* = 52 (49.06%); Blind, *n* = 5 (21.74%); Low Vision, *n* = 47 (56.63%)), the ability to increase font size (*N* = 47 (44.34%); Blind, *n* = 5 (21.74%); Low Vision, *n* = 42 (50.60%)), an option for bigger icons (*N* = 33 (31.13%); Blind, *n* = 3 (13.04%); Low Vision, *n* = 30 (36.14%)), physical buttons (*N* = 38 (35.85%); Blind, *n* = 8 (34.78%); Low Vision, *n* = 30 (36.14%)), high contrast (*N* = 31 (29.25%); Blind, *n* = 3 (13.04%); Low Vision, *n* = 28 (33.73%)), adjust brightness (*N* = 32 (30.19%); Blind, *n* = 2 (8.70%); Low Vision, *n* = 30 (36.14%)), gestures (*N* = 29 (27.36%); Blind, *n* = 6 (26.09%); Low Vision, *n* = 23 (27.71%)), tactile feedback (*N* = 31 (29.25%); Blind, *n* = 3 (13.04%); Low Vision, *n* = 28 (33.73%)), simple mode (*N* = 22 (20.75%); Blind, *n* = 1 (4.35%); Low Vision, *n* = 21 (25.30%)), and other (*N* = 1 (0.94%); Low Vision, *n* = 1 (1.20%)).

The following data is reported for public devices: voice commands (*N* = 81 (76.42%); Blind, *n* = 20 (86.96%); Low Vision, *n* = 61 (73.49%)), read aloud (*N* = 61 (57.55%); Blind, *n* = 15 (65.22%); Low Vision, *n* = 46 (55.42%)), audio commands (*N* = 67 (63.21%); Blind, *n* = 18 (78.26%); Low Vision, *n* = 49 (59.04%)), the ability to zoom in (*N* = 44 (41.51%); Blind, *n* = 5 (21.74%); Low Vision, *n* = 39 (46.99%)), the ability to increase font size (*N* = 38 (35.85%); Blind, *n* = 3 (13.04%); Low Vision, *n* = 35 (42.17%)), an option for bigger icons (*N* = 36 (33.96%); Blind, *n* = 2 (8.70%); Low Vision, *n* = 34 (40.96%)), physical buttons (*N* = 30 (28.30%); Blind, *n* = 6 (26.09%); Low Vision, *n* = 24 (28.92%)), high contrast (*N* = 31 (29.25%); Blind, *n* = 3 (13.04%); Low Vision, *n* = 28 (33.73%)), adjust brightness (*N* = 29 (27.36%); Blind, *n* = 2 (8.70%); Low Vision, *n* = 27 (32.53%)), gestures (*N* = 28 (26.41%); Blind, *n* = 3 (13.04%); Low Vision, *n* = 25 (30.12%)), tactile feedback (*N* = 25 (23.58%); Blind, *n* = 3 (13.04%); Low Vision, *n* = 22 (26.51%)), simple mode (*N* = 19 (17.92%); Blind, *n* = 2 (8.70%); Low Vision, *n* = 17 (20.48%)), and other (*N* = 2 (1.89%); Low Vision, *n* = 2 (2.41%)).

Appendix AB: Table 23 Text Description

Table 23 includes the frequencies of survey participants' preferences for accessing accessibility features in public devices by vision status. For each response the total and percentage is provided out of the 106 survey participants and then further broken down by vision status based on the 23 blind survey participants and the 83 low vision survey participants. The following data is reported: phone application that can save your preferences and connect to the touchscreen device (*N* = 81 (76.42%); Blind, *n* = 18 (78.26%); Low Vision, *n* = 63 (75.90%)), a universal tap sequence (e.g., 3 taps in the top right corner of the screen) (*N* = 63 (59.43%); Blind, *n* = 9 (39.13%); Low Vision, *n* = 54 (65.06%)), I don't like any of the available option (*N* = 6 (5.66%); Low Vision, *n* = 6 (7.23%)), and none of the participants selected “Other”.