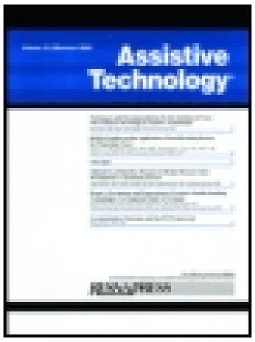

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Assistive Technology
The Official Journal of RESNA

ISSN: 1040-0435 (Print) 1949-3614 (Online) Journal homepage: http://www.tandfonline.com/loi/uaty20

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To cite this article: Jared M. Batterman MS, Vincent F. Martin MS, Derek Yeung MS & Bruce N. Walker PhD (2017): Connected cane: Tactile button input for controlling gestures of iOS voiceover embedded in a white cane, Assistive Technology, DOI: 10.1080/10400435.2016.1265024

To link to this article: http://dx.doi.org/10.1080/10400435.2016.1265024

Published online: 31 Jan 2017.

ASSISTIVE TECHNOLOGY
http://dx.doi.org/10.1080/10400435.2016.1265024

Connected cane: Tactile button input for controlling gestures of iOS voiceover embedded in a white cane

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ABSTRACT
Accessibility of assistive consumer devices is an emerging research area with potential to benefit both users with and without visual impairments. In this article, we discuss the research and evaluation of using a tactile button interface to control an iOS device's native VoiceOver Gesture navigations (Apple Accessibility, 2014). This research effort identified potential safety and accessibility issues for users trying to interact and control their touchscreen mobile iOS devices while traveling independently. Furthermore, this article discusses the participatory design process in creating a solution that aims to solve issues in utilizing a tactile button interface in a novel device. The overall goal of this study is to enable visually impaired white cane users to access their mobile iOS device's capabilities navigation aids more safely and efficiently on the go.

ARTICLE HISTORY
Accepted 21 November 2016

KEYWORDS
accessibility; cane; navigation; visual impairment; voiceover

Introduction

There is an increasing prevalence of blind and visually impaired persons as a subset of the overall population. According to the 2012 American Community Survey, approximately 6,670,300 of American adults aged 16 to 75+ report some form of visual disability (National Federation of the Blind, 2014). Although a priority for becoming independent with a visual impairment is to master the skills of orientation and mobility (O&M), doing so while interacting with technology can be difficult tasks (Kim & Cho, 2013; Ye, Malu, Oh, & Findlater, 2014).

The integration of the VoiceOver screen reading software on Apple iOS devices has changed how blind and visually impaired users interact with their mobile technology (Apple Accessibility, 2014). A large portion of the visually impaired population has adapted smartphones; however, there are still issues with the interaction experience for these users (WebAIM, 2012; Ye et al., 2014). In a study conducted by Ye and colleagues (2014), findings highlighted that among the sample surveyed, iPhones were more popular with users with visual impairments compared to sighted users, and that of those respondents with visual impairments utilized their phones for entertainment, messaging, calls, social networking, navigation, and banking/shopping services. Users with visual impairments also reported a higher tendency to utilize optional connecting technologies with their smartphones, such as headphones or Bluetooth keyboards (Azenkot & Lee, 2013; Ye et al., 2014).

In a web accessibility study conducted by WebAIM (2014) concerning the preferences of screen readers, 82% of respondents reported using screen readers on a mobile device with 65.2% of all respondents utilizing iOS. Of this user sample, 95% reported utilizing a screen reader platform due to disability. One mobile device with the advent of millions of applications (apps) has begun to replace stand-alone devices that serve singular needs. Two examples of such devices are Hand-held Money Identifiers and Close Circuit Television (CCTV)/Video Magnifiers (MaxiAids, n.d.). Both of these devices and their associated functioning can be accessed with an iOS device and a free app.

This shift to accessible mobile technology presents new issues of accessibility for potential users. Many advances in this domain provide new solutions for navigation and mobility aids that promote safety and independence for travel (Hersh & Johnson, 2008). In regards to navigation, there are integrated solutions for the iOS ecosystem such as Seeing Eye GPS and BlindSquare (Sendero Group, n.d. and BlindSquare, 2014, respectively). These utilize embedded Global Positioning Satellite technology (GPS) and are accessible via VoiceOver, but require the user to often stop and directly interact with the mobile touch screen to access important features (Kornowski, 2012). Other solutions promote an external tactile input, like the Trekker Breeze, but are stand-alone systems that lack connectivity to a larger ecosystem (HumanWare USA, n.d.).

Of the blind and visually impaired community members that may utilize those apps, the white cane is still the most commonly used mobility aid (American Foundation for the Blind, 2013; Lighthouse International, 1997). Because of its usage, it is a frequently researched area for embedding "smart" electronics to enhance its ability as a mobility aid. In this domain, previous electronic canes attempted to reinvent how a cane user would actually navigate their environment. Different examples utilize ultrasonic waves, laser range detection, and force sensors to try to improve environment detection (Bolgiano & Meeks, 1967; Bureau, 2013; Gallo et al., 2010; Garg, 2007; Hoydal & Zelano, 1991; Shoval, Ulrich, & Borenstein, 2003; Tahat, 2009). None of these alternative electronic canes have been successful and very

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Color versions of one or more of the figures in the article can be found online at www.tandfonline.com/UATY.

few are still being manufactured (McGir, n.d.). Although previous electronic canes provide better object detection, most often, these devices run into similar usability issues with cognitive overload and an overabundance of information provided by haptic feedback in the handle (Kim & Cho, 2013). Normal cane usage relies on the feedback coming from the ground to inform the user of texture changes and "smart" canes may overwhelm that feedback (Queensland Blind Association, n.d.). In addition, these canes rarely address issues associated with ergonomics: The addition of other technical innovations can add extra weight and add size to the handle in addition to forcing a certain handgrip or wrist flexion that may cause fatigue with extended use (Rodgers & Emerson, 2005; Sound Foresight Technology Ltd., n.d.). Our goal is not to reinvent or change the way a user interacts with their cane. Rather, we would like to provide a method to enable a user to conveniently do more with their mobile technology without inhibiting their functionality with a cane.

Safety is also a factor for blind and visually impaired users attempting to live independently. Although Kane, Bigham, and Wobbrock (2008) concluded that mobile devices make people with disabilities feel safer, theft of smartphone devices is now an increasing fear among these users. There were a reported 1.6 million thefts nationwide in the past year—a 40% increase of device thefts in large urban cities like New York City alone (Allen, 2014; KGW News Staff, 2013; National Consumers League, n.d.). With theft of smartphone devices being an issue for the general population, some blind and low vision individuals expressed a heightened sense of perceived vulnerability associated with the use of a white cane. One interviewee noted: "I'm not an idiot, I know how things are… I don't take it out because I know what happens when someone sees me with something like this". This individual carried multiple devices with him and only used his iPhone when he was in a safe location. If he needed to do anything while traveling, he had a second feature phone that he used in public. Even if this is a perceived vulnerability only by parts of the community, we believe it is a serious issue that needs to be taken into consideration.

The primary issues we aim to address in our research are inconvenience of access to a user's mobile device on the go, and lowering the risks of using the device in public. Currently, if a cane user needs to access their smartphone on the go, they have to stop, reposition their cane, and take the smartphone from storage to interact directly with the screen using gestures. Studies show that users also report concerns with the ability to hear their phones while on the go (Kane et al., 2008). In addition, when the phone is out in public, this creates increased risks of damage due to drops, weather, or theft. Although such tasks may be necessary for adjusting a running GPS program on an iOS device, or even checking the weather for later that day, there are issues and concerns with this interaction that have yet to be solved in an accessible manner. This is an opportunity to facilitate the use of a traditional tool for the visually impaired while leveraging new interactions to modern devices.

While there has been promising research with improving tactile input for touchscreen devices, our goal is to leverage tactile controls and allow for remote interface with the smartphone (El-Glaly, Quek, Smith-Jackson, & Dhillon, 2013). Instead of addressing the touchscreen directly, we have augmented the gestural screen experience by employing a multi-modal interaction with physical button controls (Cohen & McGhee, 2004). We have embedded electronic components in the handle of a white cane to augment mobile technology accessibility without inhibiting the primary function of the cane itself.

The connected cane

We hypothesized that a tactile interface would be most efficient in providing accessibility to the mobile device on the go. This would allow a user to augment their experience of the touch screen by providing tactile buttons in situations when it would be appropriate, as well as placing them where they would be readily accessible. With this goal, we started to assess an appropriate location in which to employ an interface that would be most accessible and useable by users with visual impairments. After surveying the range of different types of equipment, technology, and most common objects carried by the ideal end user, we hypothesized that the cane could be an appropriate vessel for this technology.

Design

Understanding the proper techniques used in holding the white cane was the first step in approaching the design of such a prototype. Expertise was sought from O&M instructors about what is considered to be a standard cane grip. We discovered that there was some contention about what is considered to be a proper grip and that there are differing grips that can be employed effectively (Sauerburger, 2014). Additional interviews with end users highlighted that grip style seemed to deviate among users. Some users customized their grip for their own purposes after becoming experienced cane users. Even with the customization, the most popular opinion on cane grip was the National Federation of the Blind (NFB) style with the cane resting in the palm of the hand and index finger extending forward for control (National Federation of the Blind, 1996; Openshaw, 2006; Sauerburger, 2014). In addition, we heard fairly consistent complaints concerning the comfort level associated with holding the cane for an extended period.

With those considerations in mind, we initiated the design process. We wanted to both ascertain the appropriate location for the controls and also address the ergonomic needs of the traditional cane handle. We took into account the details that are inherent in the ergonomics of the cane, including how the weight, length, and balance affect a user (Rodgers & Emerson, 2005). In addition, we wanted to understand how to improve the cane grip in order to facilitate extended periods of use throughout the day (National Federation of the Blind, 1996; Openshaw, 2006). This design was a heavily participatory and iterative process with a fellow blind PhD student with an extensive Rehabilitation Engineering and Research background. Basic concept sketches were made, but we quickly progressed toward concept modeling with foam. This enabled us to create variations in form, and to also understand how it felt in a user's hand. In addition, we placed a small marker near where the thumb could reach in order to determine a comfortable distance for controls and identify a place to rest the thumb when not in use. These foam models and the small marker for thumb control placement are shown in Figure 1. We iterated through different foam models until we

Figure 1. This figure depicts the foam models and the small marker for thumb control placement used in the design and construction of the cane handle.

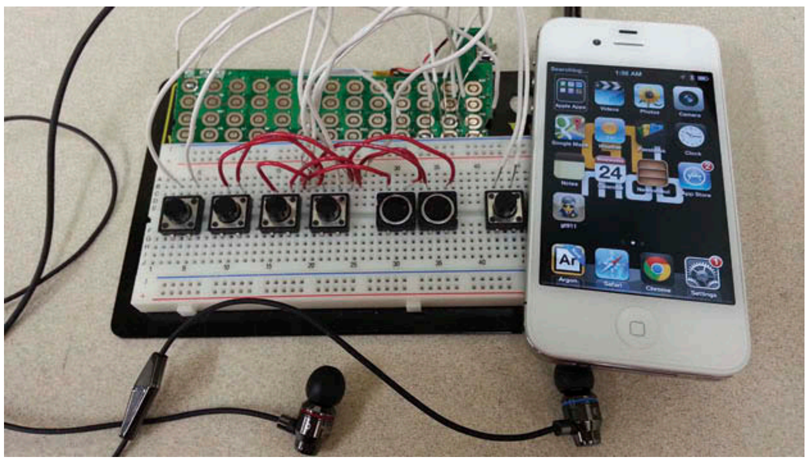

Figure 2. This figure depicts a Breadboard model with electronic components that were prototyped and tested for necessary functionality.

determined one that not only felt comfortable to grip, but also allowed for the user to retain a familiar style to the common NFB standard. We also surveyed preferences of different control styles. These included joysticks, rotary wheels, directional pads, directional arrows, and scroll wheels. This was done by taking existing examples of each of these controls and gauging a preference opinion to which felt most comfortable and intuitive with a one-handed thumb interaction. From our survey, it was determined that a 5-button directional arrow configuration was most preferred, and the one that would be later tested.

Process

The functionality and electronics required to prototype this device were integral aspects of the design process. Breadboard models with electronic components were prototyped and tested for necessary functionality, as shown in Figure 2. Some electronics were able to be repurposed for the prototype, but some were designed specifically for what we needed. Our goal was to utilize existing Apple VoiceOver navigation interactions, but be able to map them to a corresponding tactile button. This would mean that a physical button press would mimic a gesture that was already programmed into the accessibility software.

With the space allocation for the electronics in mind, we graduated the foam model design to three-dimensional (3D) Computer Aided Design (CAD). In this stage, we were able to determine more specific dimensions for the handle size, button size, and button placement. We designed the housing for the electronics and maintained the form factors of the foam prototype closely with the 3D model. These designs were then 3D printed out of Acrylonitrile Butadiene Styrene (ABS) Plastic using an additive manufacturing process. The housing was then integrated with the electronics and assembled to a testable device.

The iterative design process continued through three different rounds until we had a stable prototype. After each iteration, we were able to receive feedback and identify areas for improvement. This participatory design process allowed us to be flexible to changes, and to develop a device that works for the potential end user as they provided consistent input. The different iterations of the cane handle and progression are shown in Figure 3. For each iteration of the cane handle, feedback concerning issues of ergonomics, placement of buttons, and overall reliability of the electronics were collected and addressed.

Figure 3. This figure depicts the different iterations of the cane handle and its progression.

Figure 5. This figure depicts the controls layout used in the most recent prototype.

The prototype

The most recent iteration shares a similar form factor with a telescoping style cane. There is an indention on the front that promotes the usage of the index finger along the front and keeps it as close as possible to the metal cane extension as shown in Figure 4. The form factor is elongated vertically to fit more comfortably in the palm for extended use (Openshaw, 2006).

Embedded electronics

The electronics enable the device to be connected wirelessly to any iOS device via Bluetooth 3.0 Protocol. The device as is has a running battery life of about 30 hours connected, which reduces the amount it would need to be recharged. More importantly, for the syncing process, it is capable of Bluetooth pairing without the use of a 4-digit passcode, as with most Human Interface Device (HID) Protocol Devices (Bluetooth SIG INC, n.d.). This would enable a blind or visually impaired individual to hold the pairing button, select the device from the list on their phone, and the device will automatically pair.

Directional controls

The final design features four directional navigation arrows with a center selector button. Each of the four directional arrows corresponds to a swipe gesture embedded in VoiceOver Accessibility, and the center selector functions as a single finger double tap. In addition, there is an indented round button below the down arrow that functions as the home key. The controls layout used in the most recent prototype is shown in Figure 5. The controls were directly mapped one-to-one to a gesture to reduce the cognitive load required to adapt to the new device. For example, clicking the right arrow would function the same as if a user swiped directly on the screen from the left to the right. These controls enable a user with direct navigation through an iOS device when VoiceOver is speaking the menu item that the system is currently highlighting.

In its current iteration, the device is now able to handle remote input, but is best utilized when combined with a safe output. For the purpose of our prototype, we are utilizing AfterShokz Sportz 3 wired bone conduction headphones directly plugged into the phone. These headphones enable stereo audio output without blocking the environmental sound that is required for safe pedestrian travel (AfterShokz, n.d.).

Figure 4. This figure depicts the indention on the cane handle that promotes the usage of the index finger along the front and keeps it as close as possible to the metal cane extension.

Evaluation

The embedded controls in the handle of a white cane were evaluated upon the efficiency in which a user was able to use the device in conjunction with the ergonomics and placement of the controls. This study was evaluated and approved by the Georgia Tech Institutional Review Board.

Participants

Participants in this evaluation were screened with three inclusionary criteria:

- Blind, legally blind, or low vision;
- Must have used Apple VoiceOver Accessibility on an iOS device for more than 3 months; and
- Certified as an expert cane user by an O&M instructor.

A total of seven participants, both blind and visually impaired, were recruited via word of mouth and email flyers among the visually impaired for this study. Each participant brought their own iOS smartphone device and their white cane used to travel.

Procedure

In order to study the efficacy of the device, video recording was used throughout the study to capture quantitative data.

Tasks completed

The study design consisted of asking the participants to complete four everyday tasks on their iOS smartphones. These tasks included:

- Make a Phone Call—asked to call the test phone. Phone number was previously given to them and stored under the most recently called tab;
- Check the Weather—asked to check the weather of the current city using the native iOS weather app;
- Check a Text Message—message was sent from the test phone and the participant was asked to read the contents aloud; and
- Receive a Phone Call—asked to answer a phone call from the test phone.

Participants were asked to use their cane to navigate around a designated course and to complete each of these tasks in pre-marked locations along the course. An overhead view of the course map is shown in Figure 6. Each participant was asked to walk through this course a total of three times. As the participant navigated through the course, a certified O&M instructor would follow the participant to ensure safety in navigation.

Briefing

Participants were given background information pertaining to the research including its purpose and what would be asked of them upon arriving to the study location. Consent forms were presented either by large text or read aloud to the participant and signed before starting the study.

O&M certification (Round 1)

Since the purpose of the study was to determine efficacy of task completion, we did not want to test the user's ability to use a cane. In order to certify that the participant was fully capable with a cane, he or she was first asked to navigate through the course followed by an O&M instructor. During this navigation, the O&M instructor followed the participant through the course without stopping. At the end of the round, the O&M instructor would certify them as an expert cane user by pre-defined standards and determine if they were eligible to complete the task study.

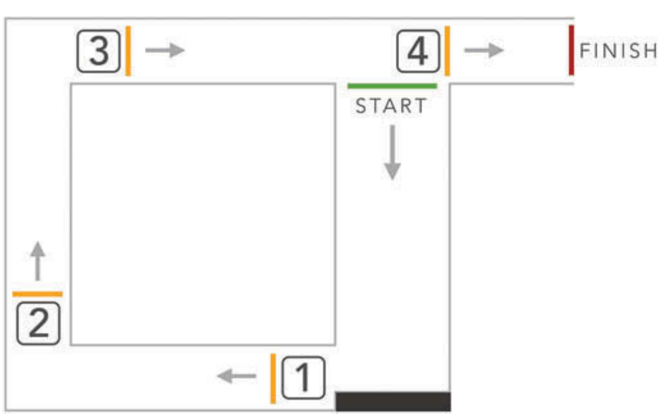

Figure 6. This figure depicts an overhead view of the course map that participants completed over the course of the experiment.

Task completion with their cane (Round 2)

Once certified by the O&M instructor, participants were asked to navigate a second time around the course. For this round, participants were asked to complete the four everyday tasks mentioned above using their personal cane and their phone. As a participant came to a designated task area, they were asked to stop and prompted to complete the designated task. These tasks were given in a pre-randomized order per participant and per round. A short post-task survey was given at the end of this round.

Task completion with new cane (Round 3)

In the final round, participants were asked to navigate the course once again while stopping at each of the designated task areas to complete one of the listed tasks with the new cane prototype. This list was again randomized per participant and per round. The purpose of this round was to record the completion times of the same tasks as round two, but this time using the new cane handle device paired with their phone. We asked each participant to use their phones to eliminate the issue of having different apps and layouts on the home screens. After the completion of this round, there was another short post-task survey coupled with a more detailed qualitative survey about the device itself.

Data collection

Quantitative data collected during this study was largely based on completion time of all of the tasks observed. In addition, participants were asked to rank the perceived difficulty of each task completed with their phone and their cane compared to their phone and the new cane prototype.

Results

Timed data

In order to assess whether there was a difference between how participants performed the various tasks with the new cane prototype as compared to their current cane, a 2 (first lap around the course with their cane versus the second lap with our cane) × 4 (the four different tasks: making a phone call, checking the weather, checking a text message, and receiving a call) repeated measures Analysis of Variance (ANOVA) was conducted on the time it took to complete each task once participants arrived at a checkpoint. There was a significant main effect of task type [$F_{(1.967,\ 11.804)} = 8.620$, $p < 0.05$ corrected for sphericity with Hyunh-Feldt], but no other significant effects. This means that the various task types took significantly more time than others (i.e., making a phone call took longer than receiving one), but these differences did not occur across laps with the different canes. This suggests that participants performed the tasks equally as quickly with their own device as they did with our novel prototype. With this in mind, it is fairly safe to assume that with extended practice and exposure, performance with our device could surpass that of their current canes. Figure 7 depicts the time it took for

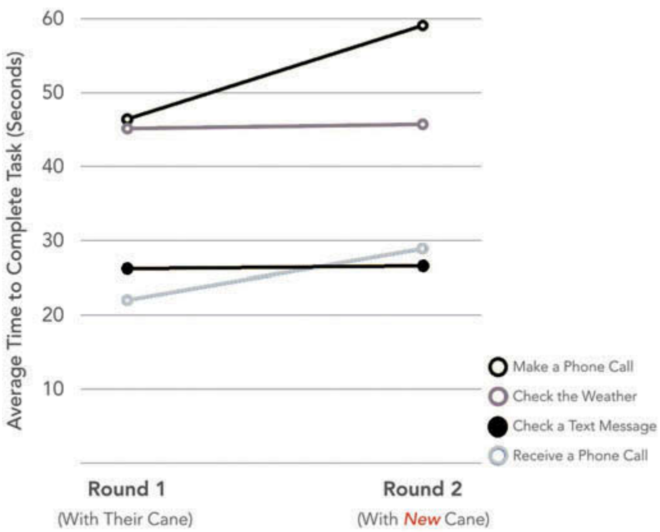

Figure 7. This figure depicts the time it took participants to complete each task both with their own cane and with our prototype.

participants to complete each task with both their current cane and the newly designed prototype.

Observations

With the design of this study, we were able to observe a sample of the different methods blind and visually impaired persons use to store and interact with their smartphone technology. During the participants' second round completing the course, they were asked to complete the tasks as they normally would do while traveling. Aligned with our hypothesis, we saw almost all participants go through the motions of holstering their cane from their dominant hand before reaching for their iPhone with the same hand. In addition, participants were observed needing two hands to properly navigate the home screen with VoiceOver. One hand was used to hold the device, the other hand was used to actually interact with the device and utilize gestures. When asked about this interaction during the post-task survey, most participants commented similarly by stating that it had become an understood motion and is required for them to access their technology.

Other significant observations concerned the cane grip style. All participants had a fairly consistent grip style when using their cane, but differences were seen when they were asked to use the cane prototype handle. The large majority of participants held the new device as they would their regular cane and interacted with the buttons from a rested position near their hip. One participant utilized a different style where he would hold the cane vertically and used the controls from the handle with his index and middle finger while his thumb provided support. An example of these varying cane grip styles used during button interactions are shown in Figure 8.

Even with the differences in how they held the new cane handle, and how they interacted with the controls on the handle, it was observed that almost all the participants readily understood the controls and seemed comfortable using it with the relatively short previous exposure.

Participant feedback

After the final round for each participant, a more in-depth, structured interview was given to gain qualitative input from the participants. The goal for this feedback was to learn more about the impression of the form factor and the use of the tactile directional arrows as a method for interaction. In addition, we wanted to hear how the entire system worked for the participant as a user and if it is something they could see themselves using in place of their normal cane.

Overall, the feedback was very positive and the external controls were well received. Most participants, although accepting the stopping and two-handed phone interaction as standard, expressed their interest in this remote one-handed interaction method. This change from gestures would take some time for adjusting to, but as one participant said: "what's going to make me want to adjust is having that quick access to all the controls" (personal communication, March/April 2014).

In addition, most participants provided positive comments about the tactile feedback of the controls with one participant mentioning: "I like these arrows, especially these triangles. Tactile feel, I know which way they go" (personal communication, March/April 2014).

And also how intuitive the controls were: "The arrows are intuitive, up is a swipe, right is a swipe, and I got use to it pretty quickly" (personal communication, March/April 2014).

When asked if this was something they could imagine themselves purchasing, all participants were interested in knowing when this device could be bought. Participants added: "I would use this as my primary cane, I mean, with the functionality, I could replace mine with it" (personal communication, March/April 2014) and "So where can I buy this thing?" (Answered that it is just a prototype) "That's alright I'll just take this one I have in my hand" (personal communication, March/April 2014).

Participants also commented how they could imagine this device fitting into their lifestyle. Whether it is subtle interactions in public or addressing concerns while traveling: "When you're at a restaurant, you can lay it in your lap and answer the phone" (personal communication, March/April 2014) and "I walk in the rain, and I don't want to get it wet so I don't answer my phone" (personal communication, March/April 2014).

All the participants mentioned in some way how it could improve an aspect of how they interact with their phone. Finally, all participants believed this could address the issue of safety. One participant mentioned an example from her travels: "Since I sit on the train by the door, that's a snatch zone for my device… so something like this would be useful" (personal communication, March/April 2014).

Feedback on design alternatives

The most constructive feedback we received was about the size and weight of the cane handle. For prototyping purposes, the size of the handle was significantly larger than what we would prefer. All of the participants commented on this fact and said they would all like it more if it was smaller. We had another handle printed out in a more ideal size without the functioning technology and presented it to the participants. This form factor followed the traditional cane with a rounder grip area but still provided the finger indentation near the front to promote

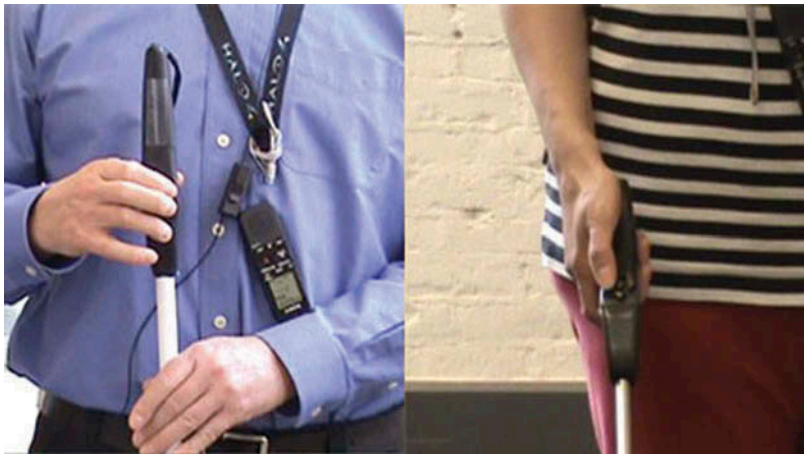

Figure 8. This figure depicts examples of varying cane grip styles used during button interactions throughout the study.

comfort while using the cane. The smaller size was much better received and well supported by the feedback.

Feedback was also collected concerning alternative button arrangements. We presented a version of the controls that followed a round form factor: These controls were deemed more elegant but less useable. More than half the participants preferred the directional arrow configuration, and the others did not have a preference and mentioned they would be able to learn either.

In regards to the style of the metal cane extension, there was fairly consistent support of a segmented folding cane style compared to the telescoping cane that we had used for the prototype. We hypothesized that the telescoping cane would be well accepted due to the compact nature and storability of the device, but quickly learned that structural integrity of the cane was the largest consideration taken into account in regards to the cane style. In the feedback, we also learned that the biggest complaint about telescoping is the fact that even though this prototype was designed to be collapsible, it would collapse without the user wanting it to. We were unsure if this particular cane was defective since others on the market claim to retain their integrity with proper use. A telescoping cane that retains its integrity was proposed and received positive feedback from participants.

In regards to the parameters related to weight and balance of the new cane handle and the cane, we received very contrasting feedback in regards to it being either too light or too heavy. It was determined that the weight of a cane is very subjective and is determined by personal preference in the heft of a cane. Some participants prefer an extremely light cane, referencing graphite canes on the market, while others prefer the heavy aluminum canes, commenting on the fact that it feels like it provides extra stability. The balance of the cane's weight and the cane handle's weight was also directly related to the preference of cane weight.

Discussion

This research project investigated various design features and the usability of a Bluetooth-connected white cane handle. The overall goal of this project was to design a handle that would allow a user to securely interact with iOS on their mobile phone while on the go. Several iterations of a handle prototype were developed and refined, and visually impaired users that were experienced with the white cane handle tested a final model.

During usability testing, participants performed tasks in comparable times with their own device as they did with the cane prototype. From this, we conclude that with further testing and familiarity with the cane prototype would increase performance speed. Previous studies of usability guidelines for white canes indicate that familiarity and experience are major factors of performance (Blackler, Popovica, & Maharb, 2010; Kim & Cho, 2013; Ye et al., 2014).

Participants who tried the device even in its prototyping stage were all very interested in the possibilities of what they were able to do with a remotely-controlled device. The feedback was consistent pertaining to how the participants felt that the form factor was too large. We intend to address those form factor issues in future iterations.

The concept of the potential capabilities of this technology was well received and begins to frame a solution for the problems we set out to address. Participants were able to successfully interact with their phones while safely leaving it stowed. This addresses safety concerns with individuals using their device in public along with any fear of damage by dropping it or using it in bad weather. In addition, participants were able to control their device without having to go through the motions of holstering their cane before using both hands to interact with the screen. This is a solution that addresses inconvenience, and grants control to the user without having to take their hand off of their primary mobility device.

Future works

We gathered an extensive and rich amount of data from the participants in the study of the Bluetooth cane handle. The results from the analysis of the quantitative and qualitative data led to several possibilities for continued studies in the future. We intend to continue to explore the use of this technology as a viable solution to these issues and want to extend the range of convenience and safety a device like this could offer. Currently, the prototype has a simple control interface of six buttons for quick navigations and interactions on the go. We would like to investigate what other actions would be available if we were to add additional buttons to enable multi-button interactions (i.e., shift clicks). We also plan to explore interfacing with other existing navigational and mobility software to determine if incorporating their usage (and potentially leveraging users existing familiarity with them) could improve our device.

Utilizing the principles of universal design, future iterations of our prototype will look to improve the ergonomics of our form factor even further. With improvements in the technology's hardware, we will be able to create a smaller form factor that is closer to the ideal and takes into account participant feedback as well as the anthropometric variation in a wide range of users. With additional iterations of the form factor, we could more formally test the ergonomics and comfort of a redesigned cane handle made for extended usage over a full day, and one that provides more safety in pedestrian travel. This would include investigating performance in a more rigorous and "realistic" course that could incorporate various types of terrain (including curbs, inclines, etc.). In addition, we would like to explore the use of this tactile button interaction in different form factors entirely. From our feedback, we believe this technology could be utilized in a different form—like the handle of a guide dog harness, or even as a stand-alone device.

For the purpose of this study, participants recruited were seasoned VoiceOver and cane users, but for future studies, we would like to test the usability of this device with a larger sample from a more diverse population of cane users in the general population. In addition, we would like to investigate the effects that a similar simple directional button tactile interface may have in teaching users how to interact with VoiceOver. This includes users who may be having difficulty cognitively understanding swiping navigational gestures, as well as users in which dexterity issues may make it inappropriate to use iOS accessibility otherwise. This could be especially useful for a demographic such as the elderly, who may want to adopt the use of this accessible technology.

This prototype attempts to accomplish remote access to a touch screen device with a tactile button input. This is most useful when a user is not able to—or the time is not appropriate for them to—interact with their smart technology directly. This app attempts to address safety concerns or inconveniences related to the blind and visually impaired community, but may also provide benefits for sighted individuals as well. This input device combined with auditory menu capabilities and an appropriate output device enables the use of smart devices when someone cannot see, or in other apps when they should not be looking. These apps include, but are not limited to, controlling a GPS while road biking or even automotive heads up display (HUD) interactions. Furthermore, we plan to evaluate future iterations of our prototype in different weather conditions (making sure to incorporate the use of gloves and other impediments common in colder weather) and under different noise levels to ensure that it functions optimally in these scenarios.

References

AfterShokz. (n.d.). *AfterShokz Sportz 3*. Retrieved from http://www.aftershokz.com/product/sportz-3/

Allen, T. (2014). *The American foundation for the blind announces America's five best places to live for people who are blind or visually impaired——American foundation for the blind*. Retrieved from http://www.afb.org/info/programs-and-services/professional-development/experts-guide/livable-communities/1235

American Foundation for the Blind. (2013). *Facts and figures on adults with vision loss*. Retrieved from http://www.afb.org/info/living-with-vision-loss/blindness-statistics/adults/facts-and-figures/1235#mobility

Apple Accessibility. (2014). *Accessibility*. Retrieved from https://www.apple.com/accessibility/ios/

Azenkot, S., & Lee, N. B. (2013, October). *Exploring the use of speech input by blind people on mobile devices*. In Proceedings of the 15th International ACM SIGACCESS Conference on Computers and Accessibility (pp. 11). Bellevue, WA: ACM.

Blackler, A., Popovic, V., & Mahar, D. (2010). Investigating users' intuitive interaction with complex artefacts. *Applied Ergonomics*, *41*(1), 72–92. doi:10.1016/j.apergo.2009.04.010

BlindSquare. (2014). *What is BlindSquare*. Retrieved from http://blindsquare.com/about/

Bluetooth SIG INC. (n.d.). *Human interface device profile*. Retrieved from https://developer.bluetooth.org/TechnologyOverview/Pages/HID.aspx

Bolgiano, D., & Meeks, E. (1967). A laser cane for the blind. *IEEE Journal of Quantum Electronics*, *3*(6), 268–268. doi:10.1109/JQE.1967.1074528

Bureau, S. (2013, April 11). Helping the visually impaired with smart cane technology. *University News*. Retrieved from http://www.rit.edu/news/story.php?id=49921

Cohen, P. R., & McGee, D. R. (2004). Tangible multimodal interfaces for safety-critical applications. *Communications of the ACM*, *47*(1), 41–46. doi:10.1145/962081.962103

El-Glaly, Y. N., Quek, F., Smith-Jackson, T., & Dhillon, G. (2013, February). *Touch-screens are not tangible*. Proceedings of the 7th International Conference on Tangible, Embedded and Embodied Interaction—TEI '13, Barcelona, Spain: ACM. doi:10.1145/2460625.2460665

Gallo, S., Chapuis, D., Santos-Carreras, L., Kim, Y., Retornaz, P., Bleuler, H., & Gassert, R. (2010, September). *Augmented white cane with multimodal haptic feedback*. In 2010 3rd IEEE RAS and EMBS International Conference on Biomedical Robotics and Biomechatronics (BioRob) (pp. 149–155). Tokyo, Japan: IEEE.

Garg, A. (2007). The 'smart' cane project knee above obstacle detection and warning system for the visually impaired. *Department of Computer Science and Engineering Indian Institute of Technology Delhi*. Retrieved from http://goo.gl/xvU0wF

Hersh, M., & Johnson, M. A. (2008). *Electronic travel aids: An assessment. Assistive technology for visually impaired and blind people* (Limited ed.). London, UK: Springer-Verlag.

Hoydal, T. O., & Zelano, J. A. (1991, April). *An alternative mobility aid for the blind: The "ultrasonic cane."* Proceedings of the 1991 IEEE Seventeenth Annual Northeast Bioengineering Conference. Hartford, CT: IEEE. doi:10.1109/nebc.1991.154627

HumanWare USA. (n.d.). *Trekker Breeze+ handheld talking GPS*. Retrieved from http://www.humanware.com/en-usa/products/blindness/talking_gps/trekker_breeze/_details/id_101/trekker_breeze_handheld_talking_gps.html

Kane, S. K., Bigham, J. P., & Wobbrock, J. O. (2008, October). *Slide rule: Making mobile touch screens accessible to blind people using multi-touch interaction techniques*. In Proceedings of the 10th International ACM SIGACCESS Conference on Computers and Accessibility (pp. 73–80). Halifax, Nova Scotia, Canada: ACM.

KGW News Staff. (2013, August 2). Thief snatches blind man's iPhone at bus stop. *KGW News*. Retrieved from http://www.kgw.com/news/Thief-snatches-blind-Keizer-mans-phone-at-bus-stop-218167561.html

Kim, S. Y., & Cho, K. (2013). Usability and design guidelines of smart canes for users with visual impairments. *International Journal of Design*, *7*(1), 99–110.

Kornowski, L. (2012, May 2). How the blind are reinventing the iPhone. *The Atlantic*. Retrieved from http://www.theatlantic.com/technology/archive/2012/05/how-the-blind-are-reinventing-the-iphone/256589/

Lighthouse International. (1997). *Use of assistive equipment*. Retrieved from http://www.lighthouse.org/research/statistics-on-vision-impairment/use-of-assistive-equipment/

MaxiAids. (n.d.). *Low vision products & tools for the blind*. Retrieved from http://www.maxiaids.com/store/default.asp

McGir, R. (n.d.). *Sonar traveller cane*. Retrieved from http://www.sonarcane.com/order.html

National Consumers League. (n.d.). *Smartphone theft a "national epidemic"?* Retrieved from http://www.nclnet.org/technology/150-cell-phones/804-smartphone-theft-a-national-epidemic

National Federation of the Blind. (1996). Getting the cane ready. *Future Reflections*. Retrieved from https://nfb.org/images/nfb/publications/fr/fr15/issue1/f150117.html

National Federation of the Blind. (2014). *Statistical facts about blindness in the United States*. Retrieved from https://nfb.org/blindness-statistics

Openshaw, S. (2006). *Ergonomics and design a reference guide*. Retrieved from http://oregonstate.edu/ehs/sites/default/files/pdf/ergo/ergonomicsanddesignreferenceguidewhitepaper.pdf

Queensland Blind Association. (n.d.). *Mobility*. Retrieved from http://www.qba.asn.au/graphic/mobility.shtml

Rodgers, M. D., & Emerson, R. W. (2005). Human factor analysis of long cane design: Weight and length. *Journal of Visual Impairment & Blindness*, *99*(10), 622.

Sauerburger, D. (2014, January 1). An introduction to orientation and mobility skills. *Everyday Living—VisionAware*. Retrieved from http://www.visionaware.org/section.aspx?FolderID=8&SectionID=115&TopicID=515

Sendero Group. (n.d.). The Seeing Eye GPS™ app for cell-enabled iOS devices. *Sendero Group News RSS*. Retrieved from https://www.senderogroup.com/products/

Shoval, S., Urich, I., & Borenstein, J. (2003). IEEE Xplore document—NavBelt and the guide-cane [Obstacle-avoidance systems for the blind and visually impaired]. *Robotics & Automation Magazine, 10*. Retrieved from http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=1191706&isnumber=26709 10.1109/MRA.2003.1191706

Sound Foresight Technology Ltd. (n.d.). *UltraCane*. Retrieved from http://www.ultracane.com/ultracanecat

Tahat, A. A. (2009, June). *A wireless ranging system for the blind long-cane utilizing a smart-phone*. In ConTEL 2009: 10th International Conference on Telecommunications, 2009 (pp. 111–117). Zagreb, Croatia: IEEE.

WebAIM. (2012). *WebAIM: Screen reader user survey # 4 results*. Retrieved from http://webaim.org/projects/screenreadersurvey4/

WebAIM. (2014). *WebAIM: Screen reader user survey #5 results*. Retrieved from http://webaim.org/projects/screenreadersurvey5/

Ye, H., Malu, M., Oh, U., & Findlater, L. (2014, April). *Current and future mobile and wearable device use by people with visual impairments*. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (pp. 3123–3132). Toronto, Canada: ACM.