An Exploratory Study on the Low Adoption Rate of Smart Canes

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Abstract. People who are blind and visually impaired (BVI) primarily rely on white canes for everyday mobility. Smart canes were introduced to address the limitations of traditional white canes and to inform users of their surroundings more efficiently. While the smart cane's advantages are evident, these devices are not used often in the BVI community. To gain a better understanding of the low adoption rate, we spoke with orientation and mobility specialists for some background on BVI mobility, conducted a survey to gauge user awareness and initial perceptions of the smart cane, and interviewed 16 participants for an in-depth view regarding their smart cane experiences. While most of the participants' apprehension was based on initial product cost, we found that other factors like user personality, durability, battery life, experience bias, as well as the lack of awareness from the users all contribute to the low adoption rate of smart canes. As such, our findings are structured based on four main themes: (1) Impact of Participant Characteristics on Adoption, (2) Perceived Advantages and Disadvantages, (3) Product-Related Concerns, and (4) Building Trust. We contribute a user-centered investigation on the merits of the smart cane and suggestions for future design considerations based on user feedback.

Keywords: Human-centered computing · Accessibility · Individuals with disabilities and assistive technologies · Internet of Things

1 Introduction and Related Work

Navigation safety is key for BVI individuals. They utilize several mobility aids to ensure they are able to efficiently navigate in a safe manner and reduce the risk of bodily injury [20]. Individuals with visual impairment typically rely on a white cane, guide dog, sighted guides, and/or mobile applications (e.g., GPS apps, AIRA), among others [1,3]. The use of the standard white cane dates back to the 1940s [17,34] and has become not just a popular mobility aid but also a symbol for blindness [34]. Despite being widely used, the white cane has several limitations that can make it ineffective. For example, the white cane has a short detection range because it is limited to the length of the cane. This reduces

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the reaction time before bumping into an obstacle which could result in bodily injury. As such, extra care has to be taken while using the cane, leading to a reduced speed in movement [17] and consequently reducing self-confidence when navigating [20]. Another key disadvantage of the white cane is the inability to detect objects that are elevated from the ground such as low-hanging branches; these objects will be missed by the sweeping motion of the user. This might result in some serious injuries that may be detrimental to the individual. In their survey about the nature and causes of head-level and fall accidents, Manduchi *et al.* reported that about 92% of participants had experienced some form of the head level incident and over 45% of blind participants experience this form of an accident once a month or less [20].

The advancement in technology and computing has led to the push for modern ubiquitous devices. This opens up the enhancement of devices, such as the white cane, for better functionality [16]. Smart canes currently exist either as research prototypes in the lab or as commercially available products for purchase. Available products include, but are not limited to, UltraCane (2010) [5], SmartCane ™(2014) [4], WeWalk (2017) [6], and BAWA Cane (2018) [2]—with prices ranging from $100 to over $1000 plus shipping. Researchers share design suggestions that focus on detecting obstacles and providing voice or audio [19,30,35], haptic [8,11,27,31], a combination of both sound and touch [13,22], vibrotactile biofeedback [29] and thermal feedback [26]. Previous research also looked at using more affordable materials and ergonomic-conscious design [7] as well as directly supporting users through a force feedback mechanism built inside a ball attached to the tip of the cane [9]. Although the smart cane has undergone significant development and have previously evaluated better than traditional white canes in terms of obstacle detection and avoidance, it is still beset by the low adoption rate of BVI individuals [17].

As with every technology, increasing penetration among the target population is necessary. Lindley *et al.* discussed that investigation on the implications of technology adoption is essential to HCI research to assess the viability of a product and to determine how it will be used by its intended users as part of their daily lives [18]. Our study was guided by the following research question: ***What are the potential reasons for the low adoption rate of smart canes?***

We first conducted informal discussions with two orientation and mobility (O&M) specialists about BVI mobility and their thoughts on the smart cane. Based on these discussions and our initial research, we designed a survey that was sent out through different channels and received 57 valid responses where only 19.15% of users have tried a smart cane before. We then followed up on 16 participants who agreed to share more of their thoughts in one-on-one interview sessions and analyzed the data resulting in four main themes: (1) *Impact of Participant Characteristics on Adoption* (i.e., different user personalities and how these may affect their decision to use a smart cane), (2) *Perceived Advantages and Disadvantages* (i.e., user impressions and understanding of the smart cane), (3) *Product-Related Concerns* (i.e., concerns and needs related to the cost

and technical aspects of the product), and (4) *Building Trust* (i.e., confidence in the product and other external influences). We found that a large percentage of users have only heard of the smart cane but never tried it. This research provides an in-depth look on the personalities and expectations of BVI users regarding smart cane technology as well as potential ways to promote adoption of the smart canes.

2 Methods

The study began by engaging in an in-person discussion with O&M specialists from the Association for Blind and Visually Impaired (ABVI) in Rochester, NY. We referred to them as subject matter experts to gain more background their thoughts about the smart cane and about the user's mobility experience. They were asked questions related to the process of getting clients, their teaching methodology, and their awareness of smart cane technology. Based on the responses from the O&M specialists and background research, an exploratory survey was designed and distributed through various channels (e.g., Twitter, Reddit). The participants were asked to complete the survey first; a phone interview was then scheduled if they expressed interest in further study. The purpose of the interview was to gather in-depth data and additional context around the survey responses. We received 57 complete survey responses and conducted 16 semi-structured interviews.

2.1 Survey

Survey Design. A survey was conducted to help gauge the users' awareness, understanding, and impression of the smart cane. It consisted of 86 questions exploring the navigation and mobility assistance options used by the BVI community, the mobility challenges they face, resources used to stay updated on new technology, barriers for using a smart cane, and their experience in using a smart cane (if any). The survey was hosted on the Qualtrics XMP Platform and both qualitative and quantitative data were collected. It was tested for accessibility with commonly used screen readers on both desktop and smartphones (Android and iOS). Based on the results from the accessibility tests, the matrix table questions were changed to separate multiple-choice questions as the matrix table was not accessible through the screen readers. The O&M specialists also provided suggestions for appropriate wordings and framing of the sentences to increase understandability. After accommodating their feedback, a pilot study was conducted with 4 people (3 people with vision, 1 person who was blind) and modified the flow of the survey accordingly before sending it out. The survey was posted on Reddit, Twitter, and was sent to more than 30 BVI organizations across the US.

Survey Participants. A total of 97 people responded to the survey. Out of those, 63 people completed the survey and 57 participants (blind: 40, low vision:

14, legally blind: 2, severe low vision: 1) were selected for analysis through purposeful criterion sampling. The sampling criteria for the participants were: (1) must identify as blind or low vision; (2) uses assistance for mobility; (3) equal to or more than 18 years old; (4) has been living in the United States for most of their life as our focus was on the US population. Among the 57 selected participants, 54 used white canes, 39 used smartphone applications, 13 used guide dogs, 6 used smart devices, and 9 used other options (sighted guides and a subset of smart devices). Thus, an overlap was observed in the usage of different navigation options.

Survey Analysis. In the survey, a separate set of questions for people who have heard about smart canes, used a smart cane, and owns a smart cane were added. Out of 57 responses, 41 participants have heard about smart canes but not used it. As such, Likert type questions centered around the reasons for not trying or using a smart cane garnered more neutral (i.e., "Neither Agree nor Disagree") answers than was expected as shown in Table 1. Because of this, data was not analyzed for significance. The large number of neutral responses, however, suggests that users are not familiar enough with the smart cane to make final judgments about the product.

Table 1. Likert scale data from the survey for potential reasons for not trying/using a smart cane

Likert scale question	Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree
I don't know where to get a smart cane	11	16	8	2	4
I don't want to deal with technology	1	6	6	9	19
The smart cane was not available at that time	13	7	14	2	5
I felt that the smart cane was seeking unwanted attention	2	5	14	5	15
No technical assistance was available	4	7	22	3	5
I felt that the smart cane was not safe to use	2	7	19	9	4
I was not confident about using the smart cane	7	5	13	4	12
I felt that the smart cane was not easy to use	2	7	21	4	7

2.2 Interview

Interview Design. In the 45-min semi-structured interview sessions, participants were asked questions related, but not limited to, their experience with mobility and navigation technologies, barriers to adoption, and options to improve smart cane adoption. A few questions were modified based on the participant's survey responses. We also followed up on their smart cane impressions and experiences. The questionnaire was pilot tested 5 times (1 blind person) and modified to get the correct flow and to address any leading questions.

Interview Participants. From the survey given earlier, participants were asked if they were willing to join us for an in-depth interview about their experiences. 16 BVI participants were recruited, ranging between 22–80 years old with an average age of 56.38 years and average cane experience of 27.81 years. Most of the participants used multiple mobility devices such as white canes, guide dogs, smartphone apps, and other smart devices. They were also located in 6 different states in the US which represented diversity in their environment—some lived in bigger cities while others are located in more suburban areas. The participants were chosen because they have some level of smart cane awareness (i.e., have heard of it before).

Interview Data Collection and Analysis. The participants were based at various locations in the United States; all the interviews were conducted using a Zoom conference call. One researcher lead all the interviews; all the other researchers participated in the data analysis. A thematic analysis was completed on Miro by first open coding the data in different post it notes and grouping them together until four main themes were achieved—all of which are highlighted in Table 2.

Table 2. Themes, sub-themes, and the explanation behind each.

Impact of Participant Characteristics on Adoption
Participant Characteristics - who they are, what their abilities are, and how these affect their choice of navigation
Social Acceptability - how others influence their navigation option
Perceived Advantages and Disadvantages
User Impressions - what they know about smart canes
Potential Applications - how they think this can help them that other devices already cannot do
"Smart Cane is Not Needed" - why they think this does not help them
Product-Related Concerns
Financial Constraints - are the added benefits worth the cost
Durability and Portability - is the product reliable and will it withstand daily wear and tear
Cognitive Load - are the additional feedback options too much
Building Trust
Trial and Training - what will encourage them to buy it
Awareness and Influence - how do they gather information and what affects decision-making

3 Findings

The themes informed by our thematic analysis (Table 2) will help guide this section. Because our survey and interview findings support one another, we present the results of both methods in this section so as to prevent repetition. Data from survey participants are labeled S[x], while interview participants are coded as P[x].

3.1 Impact of Participant Characteristics on Adoption

Among the 16 participants we interviewed, many of them described their personalities, abilities, and hobbies in detail by sharing their backgrounds and stories. The data showed a relationship between participant characteristics and their decision to choose specific mobility aid options. This section also discussion participant attitudes regarding the use of smart canes in public in terms of social acceptability.

Participant Characteristics. This section introduces three main personality factors that could affect the utilization of advanced mobility aid tools like smart canes. Although there might be intersections between an individual's independence, curiosity, and self-confidence, those characteristics were separated to make their attitudes clearer.

Independence. Some participants who identified as independent or those who pursued to be more independent under the assistance of mobility devices showed more unwillingness to rely on a sighted guide. P11 was inclined to use a smart cane because *"it would be a huge tool to use to be able to be more independent."* Several participants mentioned that they liked socializing, enjoyed outside activities, and preferred to go out in public without the help of others. For example, P6 stated that:

> *"I'm very independent. So sometimes, it's hard to let other people guide me if I'm out in public and I'm using my cane because I try to really rely on my cane to find any obstacles in everything. So I will rely on people at certain times but I try to be as independent as I can."*

Curiosity. Most of the participants were inquisitive about travelling to new places and experiencing new technologies. Some participants shared that they were frequent travellers. P9 mentioned having friends who travel and *"use their smartphones to get around airports, get around cities, strange cities."* P2 has also travelled all over the country using a white cane.

Tech enthusiasts were also categorized as curious. For example, P1 was *"big into computers and my hobby is home automation and anything smart".* This can also be seen in the survey responses where 68.29% of responses said that they were comfortable dealing with technology. However, it should be noted that there were some participants who mentioned they were not a very *"techy person [P10]"* or that they did not *"rely on technology for navigation because things*

like poor internet and unupdated maps occur [P16].” Curious participants were more inclined to try out smart canes and evaluate if it works for their lifestyle.

Self-confidence. It was observed that participants who felt less confident while navigating used multiple mobility options when they went out. For example, P3 used both cane and sighted guide for safety because they did not *“feel confident enough anymore”* because of deteriorating vision. S48 also said, *“I would like to feel more confident using a white cane and to be able to navigate places that I am not familiar with.”* On the flip side, participants who were very confident in their daily routines did not see the benefit of the smart canes for their current situation.

Of the 30 survey participants that said they were *strongly interested* in learning about smart canes, more than half of them explained in the reasoning part that they were curious about the technology and were striving to be more independent and confident in their daily lives. However, it should be noted that the aforementioned personality types are only reflective of the interview participants. This research does not assume that these personalities represent the entire population and understand that there is a large variety of user characteristics within the BVI community.

Social Acceptability. There were some discussion about the social stigma of using the white cane. The results not only provide more evidence to support prior research but also add some mutual concerns (i.e., those concerning both visually impaired and sighted persons) regarding BVI individuals interacting with others in the social context. These social acceptability concerns could vary depending on the situation (i.e., people travelling alone in crowded places may have different experiences from those walking their daily route). This section presents the feelings and perspectives of participants towards using mobility devices in social settings.

Neutral and Negative Feelings. Participants had mixed feelings on social acceptance with the assistive tools they used in public—some participants had neutral attitudes, some were concerned about social stigma and first impressions, and almost half of the participants did not mention anything about social acceptability. The participants with neutral attitudes, like P2, mentioned that another person’s *“assumption is [not] going to change how I use (the cane).”* Meanwhile, other participants reported that they sometimes get uncomfortable navigating new places, especially crowded areas, with their white canes. P5 shared, *“I’m on parade, everybody, here comes this blind [person]. Let’s look at [them] with [their] cane.”* To add, P12 specifically mentioned avoiding the use of white canes in public because it made them feel different from others. Furthermore, it took them a long time to adapt to the cane technically and accept it emotionally. As P12 shared, *“I didn’t want to look different and I didn’t want to really admit that I was losing more of my sight.”*

These negative feelings elicited by the social stigma against the white cane discouraged the participants from trying out the smart cane. Both commercially

available canes and known research prototypes are usually bulky in design and may attract more attention than a white cane would.

Mutual Influence. Some participants expressed their thoughts on how they tried their best to stay conscious of the surroundings when using their preferred mobility tool. For example, canes may be too bothersome in crowded places, while guide dogs may not be allowed in certain public places. P12 relied on the guide dog most of the time but avoided bringing the dog in places with fireworks or other places that *"wouldn't be good for [the guide dog]."* To add, P7 noted that BVI users needed to be more alert in places like train stations because inadequate information from the white cane could be a safety risk to other people (i.e., accidentally pushing someone off the platform). On the other hand, participants also noted that other people sometimes acted as barriers in their mobility: too much noise from other people hindered their hearing ability, strangers who tried to help ended up being ineffective, and other people suddenly coming up in the participants' central vision promoted feelings of anxiety.

3.2 Perceived Advantages and Disadvantages

This section highlights participants' impressions and the potential applications of smart canes based on their understanding. In some cases, participants thought that smart canes did not provide them with any unique navigation feature.

User Impressions. Most participants have not used a smart cane before. They have only heard of them through conferences, word-of-mouth, social media, or blog posts. Some participants, like P11, thought *"it's a device, for my understanding, that hooks up to your white cane that you already have."* while other participants, including P14, highlighted the obstacle detection capabilities of smart canes (e.g., overhead or waist high, drop offs like in construction):

> *"My understanding is it will give you some information that a dumb cane, just a regular cane won't, won't give you like, for instance, finding obstacles that are like maybe, waist high, something the cane wouldn't find or even maybe lower, like for a barrier, like some kind of construction barrier."*

It is good to note that while smart canes were mostly developed for their obstacle detection capabilities, the notification *"could tell you where the obstacle is but it can't tell you what the obstacle is that you're going to figure out anyway when you touch it with your cane. So there's an obstacle and anyways you touch it with your cane."*, P1 says. This suggests that the information provided by the obstacle detection system of smart canes may not be sufficient.

A lot of participants focused on the feedback notifications like vibration and audio as those were the smart cane features that stood out to them the most. One participant, on the other hand, highlighted the GPS navigational assistance provided by some smart canes. While some of these impressions were true, it should be noted that most participants were unsure of their answer thereby showing a lack of understanding on actual smart cane features.

Potential Applications. Less than half of the participants shared their excitement with the smart cane technology. P7 pointed out that it may *"just become part of an every day thing."* P16 said that the *"smart cane would be of advantage"* and shared specific scenarios where smart canes would be of most use:

> *"If you're going [to] places that you're not familiar with or if you're going in to busy places where there's lots of people or if you have a community with kids in it, with things are left out on the sidewalks."*

P16 said that receiving an earlier warning through the smart cane would help increase the reaction speed in avoiding obstacles.

"Smart Cane Is Not Needed." While there are certainly advantages to the smart cane, a few participants directly mentioned that they will not be purchasing the smart canes as the benefits do not outweigh the cost. Additionally, participants noted that they had already found alternatives solutions (i.e., other mobility devices, apps, or AI-based technologies) that help them combat the limitation of traditional white canes. This sentiment was also echoed in some of the survey responses. According to S37,

"The smart cane a luxury product that will make blind people not use their skills and instead rely on something that can glitch and die."

3.3 Product-Related Concerns

This section details multiple concerns related to the product design that prompted concerns and apprehensions about the smart cane, which contributed to users feeling like the smart canes were not a worthy investment. These included cost, durability, portability, battery constraints, and cognitive load. Some participants were more likely to try the smart cane if these issues were resolved.

Financial Constraints. One resounding concern expressed by all participants involved the costs associated with the purchase of a smart cane (i.e., they were worried about the financial implications of owning a smart cane). 66.67% of survey answers noted that the biggest barrier they had in adopting smart canes is its high cost. Assistive tools are always pricey and as such, the participants were forced to prioritize which ones they need the most and what fits their budget. S64 said,

> *"It all comes down to cost. 99% of the time I don't have a piece of equipment I'm interested in because it's too expensive. I'm trying to complete my masters degree and have no job, not for lack of trying. So if somethings too pricey, no dice".*

Durability and Portability. The participants were concerned about the durability of smart canes and gave examples of various situations to describe their considerations. They talked about water resistance under inclement weather, in particular, such as pouring rain and snow. Participants also pointed out the

weight of the smart cane because some of them suffer from other health issues related to lack of mobility. Also, few participants mentioned that they were concerned if smart canes could hurt them or other people around by quickly unfolding and popping it back up. P4 explains,

> *"I would like to suggest the durability of the cane and then also how compact it is. One of the challenges with the regular cane is folding it up and then trying to keep it together and making it pop too quickly now that you might get hurt."*

They were also concerned about battery life and charging issues while using a smart cane, especially since canes are meant to be used most of the day.

Cognitive Load. Based on their previous experiences, almost all participants mentioned that one prominent feature of the smart cane is obstacle notification through haptic and audio feedback. Participants emphasized the importance of contextual and timely feedback—smart canes should not only randomly vibrate but provide an idea on what type of obstacle is coming up. Additionally, participants noted the balance of different feedback options because it can have an impact on the cognitive load of the user. P10 mentioned that the vibration could cause them to *"lose my focus on my cane technique itself, or I would slow down a lot."* and that users should not *"worry about focusing on some vibration or some other type of sensory input"* while they are walking. Some participants did note that haptic feedback will be useful in noisy environments but were worried they would miss out on the notification if the vibration is too subtle or is uninformative. P5 states, *"I wonder if it's just haptic, Will that tell me? How will that tell you that there's an obstacle in front of you?"*

While some participants thought that accompanying audio can provide more context (e.g., street names and signs), they were worried that multiple feedback methods might disrupt their focus on different environmental cues which may increase the likelihood of accidents and collisions. Several participants mentioned that *"there are other ways of doing it [detecting obstacles] that I think might be as reliable or more reliable than smart canes, namely, that's echolocation [P7]."* With other feedback methods increasing the cognitive load of the user, participants are worried that they may not be able to fully utilize their native navigational skills and in turn, fail to recognize surrounding activities such as the traffic flow.

3.4 Building Trust

This section discusses the importance of access, training, and external influences in the adoption of smart canes. While most interview participants were interested in smart canes and 84.21% of survey participants were trusting of new technologies, access to the product was a large barrier. Survey responses showed 65.85% of the participants did not know where to get a smart cane.

Trial and Training. Some participants mentioned that they were able to try out smart canes through conventions or research studies. Unfortunately, not all

BVI users have the opportunity to join those venues. P7 shares that *"we don't really get a chance to demonstrate it [or] to try this smart cane outside for any length of time."* All the participants want assurance that the smart canes would provide them additional benefits and will work better than their traditional white canes—they believe that trials can promote their confidence in a new product.

Furthermore, participants get confused on what features to expect from a smart cane because of the wide variety of products, both commercially-available ones and those that are still research prototypes. P6 shares that after attending a research study, they were surprised to find that *"it didn't have all of the technology that I've read about in smart canes."* Those who have once been let down by previous iterations have a lesser likelihood of trying out newer versions of the cane. Most participants also emphasized that accompanying training can make a difference in learning new technologies. P15 expands on this in the statement below:

> *"What would really be helpful is when the designers hand something, hand a piece of assistive technology, they should also find a way to arrange for some kind of training. Maybe not just provide a manual, but also provide a human being that you can call and ask questions. That would be helpful."*

Awareness and Influence. While trial and training are crucial, the participants first wanted to be informed about the progress with smart cane technology. According to both the survey and interview participants, the information can be delivered through social media advertising (e.g., blind groups, Facebook, chat rooms), TV ads, or from their friends and family. While others mentioned public places as good places to advertise and try out smart canes (i.e., similar to the availability of electric scooters and bikes as rentals), some participants, including P10, said that those places may not be the best avenue *"because most people wouldn't know how to use them"* unless there was an accompanying lesson or module in the area.

Participants mentioned that the adoption of any new kind of mobility or navigation technique or technologies can be heavily influenced by O&M instructors. These specialists and trusted in their field and as such, participants are more likely to be confident in the product if it is endorsed by the O&M instructor. However, some specialists prioritize mastery of native mobility and navigation skills instead of with the aid of technology, as explained by P2 below:

> *"There's kind of different philosophies of training and I think a lot of them (O&M specialists) would say that it's important for people to like, get the fundamental skills of using a cane, like understanding their environment, without technology [because] technology can always fail."*

Trust in the product can also be improved through word-of-mouth. Some participants mentioned that they follow blind forums or newsletters and only try out new technologies after some of their peers endorse it.

4 Discussion

The work from this research sought to emphasize possible reasons for the low adoption rate of smart canes within the BVI community even after being in development for over 50 years. This study indicates that the participants' concerns with other mobility options, such as the white cane, contributed to the low awareness of the smart cane and directly affected the interest level of potential users. Hence, we critically analyzed the impressions and expectations from the participants' perspectives which we believe would inform the future product and service design process from the manufacturer and designer point of view.

4.1 Impressions Based on White Canes

While HCI researchers think that smart canes are a good way to transition white cane users into smarter technology because of their similar cognitive model [28], we found that the participants' negative experiences with the white cane affected their first impressions of smart canes. For example, white canes need to be replaced often and as such, participants believed that smart canes would also suffer from the same flaw. Issues regarding social stigma against assistive devices like the traditional white cane also get carried over to the smart cane, confirming and extending on previous work from Shinohara *et al.* on social acceptability [33]. This is exacerbated by the fact that smart canes contain additional systems that make them bulkier and more noticeable than the white cane. While social acceptability may be less of a concern as participants get older [25], HCI researchers should consider user's feelings of self-consciousness, vulnerability, or embarrassment [14]. Future studies may consider providing methods to make mobility aids more inconspicuous in terms of aesthetics factors [32]. Additionally, novel features such as built-in OCR readers and indoor navigation should be considered to increase the benefits of the smart cane and make it more appealing to BVI users [24].

4.2 Addressing Concerns and Increasing Awareness

While the smart canes are rich with new features, users still have a lot of reservations regarding their reliability and consistency, especially against other mobility and navigation options [24]. These product-related concerns should be addressed before beginning any trial or training for new smart canes. Previous research have proposed some solutions to smart cane concerns about battery life such as providing Navigation mode, Eco mode and Offline mode [23].

Additionally, the result of our analysis suggested that there was not enough information available about the smart cane to BVI individuals. Leveraging O&M specialists' direct access to individuals within the community would get the word out faster [24]. However, it was also identified that the limited availability of O&M specialists, expensiveness and unavailability of devices, and inadequate

technology training provided to the O&M specialists might lead to reduced exposure of the latest technology to the community [12]. Virtual sessions may be provided to multiple clients at a time; this might be more efficient because it reduces travel time, increases user attendance per session, and speeds up the information relay process. Additionally, up-to-date data on current smart cane developments may be shared through BVI gatherings, conferences, organizations, and other media outlets to help build confidence in newer options.

4.3 User Inclusion into Product and Service Design

As HCI researchers, we need to consider users' needs to get a deeper understanding of the viability of the product from its prototype phase all the way to its adoption. While previous research work in this field tried to address usability issues [15,17,27], our research identified the user's ultimate goals and other combinations of navigation options that BVI users currently take advantage of to help them with mobility and navigation. For example, based on the the characteristics of the participants, the goal is to provide users with better assistive options that will support the independent, curious, and less confident personalities. Although these personal factors are hard to easily reach and define, we propose several guidelines to help stakeholders of smart cane to achieve a better design.

Inclusive Design. BVI users want the smart cane to be able to accommodate all essential environments such as public transportation, sidewalks, crossroads, and noisy places. The feedback method was important across several participants, with most preferring a combination of vibro-tactile and auditory feedback present in a smart cane; this, in their opinion, would aid them in effective commuting. However, this also comes with a possible fallback as there might be an increased cognitive load to the user trying to process both feedback at the same time [15,21]. Also, there are possible situations where the auditory feedback would not be optimal as mentioned in the mutual effect of social acceptance in Sect. 3.1. For example, participants would feel uncomfortable receiving auditory input in places where making noise could easily catch another's attention (e.g., concerts, restaurants). On the contrary, having a lot of background noise might reduce the effectiveness of this feedback method [15]. There was also concern among the participants about the steep learning curve associated with using both feedback methods in a dynamic environment. Adding an easy-to-reach customization option for different feedback mechanisms (e.g., tactile switch, button) may help improve usability.

With the above stated recommendations, it is therefore imperative that future development should dive deeper into designing more ergonomic smart canes that fit well into different scenarios by providing multiple feedback depending on the environment and making the product portable and easy to store [7]. It should also consider the body constraints of users, including, but not limited to, the length of human arms and the weight a person's muscles can handle; we can make smart canes more lightweight and adjustable, for example. In addition, adapting the smart cane design and components to fit people of various

skill levels would make the adoption rate easier as it would require less initial training [31]. As guided by the results stated in Sect. 3.3 and the work by Pariti *et.al.* [27], the cane must be lightweight, compact, portable, and easy to swing to increase the mobility of users and therefore, the usability of the product. The physical constraints BVI users might face such as an occupied hand for the smartphone and muscle fatigue when holding the cane for too long should be considered in the design. We may consider adding built-in features to the smart cane that would otherwise be present in smartphones (e.g., indoor GPS navigation). Additionally, some participants in our study had limited depth perception and a poor sense of direction, which limits self-reliance during a commute. Hence, the content of formal training should be customized based on the ability of the user and any additional limitations caused by different usage scenarios.

Service Design. As mentioned in Sect. 3.4, providing a trial-based service system for the smart cane could lead to an increased interest rate among the community as the end-users would be able to get a first-hand glimpse into the true workings of the smart cane and ways they could benefit from it. To provide availability for trial, smart canes could be placed at some public places—airports, museums, and lending libraries, for example [24]. The participants had some concerns regarding initial training for the smart canes but most of the participants were excited about this idea. While previous research studies allowed users to try out the smart cane, they only typically spend about an hour or less for the whole evaluation which consists of introduction, training, testing, and pre/post interviews or questionnaire, with the training section lasting [10,27]. HCI researchers may choose to provide longer training times or lend their smart cane prototypes to their participants for a longer diary study. We need to actively find ways to integrate and adopt these new technologies into the user's daily lives and not stop in short evaluations or comparisons [18,36]. Conducting training sessions for interested individuals could be one resource for the users to try out the smart cane in an appropriate way. If done right, there would be a cascade of information sharing within the community which would result in an increased interest in the adoption level. This route also opens the smart cane to critique and feedback on its performance in the real world which can be advantageous to manufacturers as the information can be used to make continuous iteration to their product so it meets the standards of the community.

5 Conclusion

Commercial smart canes are available in the market which provide haptic, audio, and other forms of feedback to inform users about upcoming obstacles. Although these smart canes target the limitations of the traditional white canes, it has not been widely adopted by the BVI community for daily use. This research highlights the implications for adoption that HCI researchers should consider in future smart cane studies. While its high price is the biggest deterrent for most users, product-related concerns, low awareness, limited resources for trial, and limited interest from OM specialists also greatly affected user trust and

confidence and therefore, their purchasing decisions. The lack of standardization in the smart cane technology also makes it more difficult for people to judge and manage their expectations on commercially available smart canes. Future smart cane developments should consider user inclusion into product and service design such that participants have a chance to get more acquainted with the smart cane and be able to provide suggestions for improvement.

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