# Enhancing Independence and Safety for Blind and Deaf-Blind Public Transit Riders

**Shiri Azenkot, Sanjana Prasain, Alan Borning, Emily Fortuna, Richard E. Ladner, Jacob O. Wobbrock†**
Computer Science and Engineering, †The Information School
DUB Group
University of Washington
Seattle, Washington USA 98195
{shiri, prasains, borning, fortuna, ladner}@cs.washington.edu, wobbrock@uw.edu

### ABSTRACT
Blind and deaf-blind people often rely on public transit for everyday mobility, but using transit can be challenging for them. We conducted semi-structured interviews with 13 blind and deaf-blind people to understand how they use public transit and what human values were important to them in this domain. Two key values were identified: *independence* and *safety*. We developed *GoBraille*, two related Braille-based applications that provide information about buses and bus stops while supporting the key values. GoBraille is built on *MoBraille*, a novel framework that enables a Braille display to benefit from many features in a smartphone without knowledge of proprietary, device-specific protocols. Finally, we conducted user studies with blind people to demonstrate that GoBraille enables people to travel more independently and safely. We also conducted co-design with a deaf-blind person, finding that a minimalist interface, with short input and output messages, was most effective for this population.

**Author Keywords:** Blind, deaf-blind, accessibility, Value Sensitive Design, autonomy, safety, public transit usability.

### ACM Classification Keywords
H5.2. Information interfaces and presentation (e.g., HCI): User Interfaces.

**General Terms:** Design, Human Factors.

### INTRODUCTION
People need to travel to places such as work, grocery stores, and doctors' offices as part of leading productive, healthy, and independent lives. Because people who are blind or deaf-blind (i.e, with severe vision impairments, or both severe vision and hearing impairments) cannot drive, they often rely on public transit for daily mobility.

However, the use of public transit typically relies on visual cues that are unavailable to people who are blind or deaf-blind. For example, people see the route number of an approaching bus, the stop number on an overhead sign, and the landmarks that indicate their stop is near. Blind and deaf-blind people currently rely on advance planning, training, and the help of transit vehicle drivers and other riders. Deaf-blind people face additional challenges because they cannot communicate verbally with others.



We turned to the Value Sensitive Design theory and methodology [5] to help identify key values at stake, develop technical solutions that support those values, and assess the solutions. Motivated by these value considerations, our work included the following:

1. We interviewed blind and deaf-blind people, and an orientation and mobility (O&M) instructor, and surveyed public transit drivers. We learned about the patterns, challenges, and important values related to public transit use by blind and deaf-blind people.
2. We developed GoBraille, two related Braille-based applications that provide real-time bus arrival information and crowdsourced information about bus stop landmarks.
3. We conducted co-design with a deaf-blind person, and user studies and semi-structured interviews with blind people to evaluate our technology.

Our key findings include identifying independence and safety as important values for blind and deaf-blind public transit riders. The main challenges experienced by blind people were locating a stop and disembarking a bus at the correct stop. Deaf-blind people experienced these challenges as well, but their primary difficulty was communication with the bus driver. During our final user studies and interviews, all participants said GoBraille would increase their sense of independence and desire to travel to new places. Participants who were concerned about safety (6 out of 10 participants in the final user study), also said they would feel safer when using GoBraille.

GoBraille is built on *MoBraille*, a novel framework that connects an Android phone to any WiFi-enabled Braille display. MoBraille allows a Braille reader to benefit from many of an Android phone's features in an efficient and private way. Furthermore, MoBraille facilitates the development of third-party smartphone applications that interface with any WiFi-enabled Braille display, without knowledge of proprietary, device-specific protocols.

In summary, our main contributions are:

1. A discussion of patterns, challenges, and values that are important to blind and deaf-blind people when using public transit.
2. MoBraille, a framework that facilitates the development of third-party Braille-based applications that can use many features of a smartphone.
3. GoBraille's novel use of crowdsourcing that enables blind people to navigate to specific locations (e.g. bus stops) more independently.
4. Guidelines for designing mobile interfaces for deaf-blind people.
5. Methodology recommendations for conducting studies with deaf-blind people.

## RELATED WORK

To the best of our knowledge, our work is the first in the HCI literature to investigate the patterns and challenges regarding (1) deaf-blind people's use of mobile computing devices and (2) blind people's use of devices where Braille is the primary output modality. Most of the research related to technology for people with visual impairments focuses on devices with speech output. Prior work has addressed several other related topics as well.

OneBusAway [3] improves satisfaction with and the convenience of using public transit for the general population by providing real-time arrival information for buses in the Seattle region. However, OneBusAway has significant limitations for blind and deaf-blind users, since among other things it requires that users identify a bus stop using a map interface or reading (or already knowing) a posted stop number.

Fischer and Sullivan [4] describe a process of participatory design for technology that enables people with cognitive disabilities to use the public transit system. Our work deals with a different population but we also work closely with the intended users of the technology (deaf-blind people) in its development.

Narasimhan *et al.* [14] present a system that provides real-time arrival information for blind people on smartphones. However, their system uses text-to-speech (TTS), which is not usable by deaf-blind people and is often not preferred by blind people. Minifie and Coady [12] discuss challenges encountered by blind people when using public transit, and an approach to ameliorating these problems based on smartphone applications and accessible web interfaces. They do not describe an implemented system. Their approach uses TTS, while ours uses Braille input and output.

Kane et al. [11] discuss challenges and patterns faced by people with visual impairments when using mobile devices on-the-go, but not specifically when using public transit. Our study found similar patterns regarding a preference for Braille and challenges related to high-cost, specialized mobile devices.

The technology we developed is related to Priedhorsky's work [15] on crowdsourced geographic data in the context of a geowiki and a route-finding service for bicyclists. Our system uses crowdsourcing for identifying non-visual landmarks at bus stops to enable blind people to locate the stops more easily and be alert to potential problems.

## BLIND AND DEAF-BLIND PEOPLE

In the United States there are 1.3 million legally blind people [13]. A person who is legally blind may have functional vision, but with poor acuity or a narrow field of vision. Blind people read large print (if they have enough vision), Braille, or listen to automated or human speech.

There are far fewer people who are deaf-blind (i.e, have severe visual and hearing impairments). There are roughly 50,000 deaf-blind people in the United States [7]. According to the Deaf-Blind Service Center in Seattle, 61 deaf-blind people live in the Seattle area. Nearly all of them use public transit.

Most deaf-blind people, including all participants in our work, are born deaf or hard-of-hearing and lose their sight as adults. As such, many deaf-blind people were raised speaking sign language and learn blindness skills as adults.

Deaf-blind people commonly communicate with tactile sign language. The most efficient way for a deaf-blind person to communicate with a person who does not know sign language is through an interpreter. Another way to communicate is by printing letters on a deaf-blind person's palm. This is slow and error-prone, however, because deaf-blind people are often not fluent in English.

When out and about, deaf-blind people commonly use cards with printed messages in both standard type and Braille to convey information to people around them. For example, a card may read, "I am deaf and blind. Can you help me cross the street?"

Like some blind people, deaf-blind people read and write English using Braille. Many read slowly because they may not be proficient in English or Braille.

Deaf-blind people can access digital information on Braille displays [1]. These devices display a row of refreshable Braille cells. The DeafBlind Communicator [10] facilitates communication between a hearing-sighted person and a deaf-blind person by displaying input from a mobile phone on a Braille display. As with many assistive technologies [17], these devices are very expensive (perhaps prohibitively so) and have limited functionality.

## CONCEPTUAL INVESTIGATION

Following the Value Sensitive Design methodology, we conducted a conceptual investigation in which we identified key stakeholders in applications to support blind and deaf-blind people in using public transit. The direct stakeholders are, of course, the blind and deaf-blind transit riders. The indirect stakeholders include the bus drivers, other passengers, pedestrians near the bus stop (who might, for example, be asked for help), family and friends of the blind or deaf-blind person, and supporting personnel such as Orientation and Mobility (O&M) instructors. Bus drivers in particular are likely to be significantly affected by applications for blind and deaf-blind riders—they may have an easier time driving such passengers, or could have additional difficulties if the application fails.

Another component of a conceptual investigation is an initial identification of the values at stake in the domain. The UN Convention on the rights of people with disabilities [18], for example, lists as general principles respect for inherent *dignity*, individual *autonomy*, and *independence*. Autonomy and independence are closely related; in this paper we primarily use the term "independence" since that was the word typically used by our participants. We also identified other values that might be at stake, including safety, trust, and privacy. The first of these, safety, emerged as centrally important to our participants.

## EMPIRICAL INVESTIGATION 1: PATTERNS AND CHALLENGES OF PUBLIC TRANSIT USE

In our first empirical investigation phase, we conducted semi-structured interviews with 6 blind and 7 deaf-blind people, and one O&M instructor who provides orientation and mobility training to deaf-blind people.

### Interviews with Blind People

We conducted 30 to 45 minute semi-structured interviews with 6 blind adults (2 men, 4 women). All participants had no functional vision and used (currently or sometime in the past) public transit regularly to get to places such as work, doctors' offices, and run errands. Five participants lived in the Seattle area and one lived in Southern California.

All participants used the bus, which was their preferred mode of public transit. When buses weren't available, they used paratransit (e.g., Access Vans), an alternate service offered by the transit agency that provides shared door-to-door rides. Participants disliked paratransit because it was inefficient and had to be reserved up to a week in advance. One participant said that Access Van drivers treat her like an "invalid."

When planning a trip, participants used the transit agency website to get information about bus schedules, travel times, and bus stop locations. The website was difficult to use because it was not fully accessible when using a screen reader. One participant also used the Metro Transit website to get information about her stops when planning a trip at home. The Metro Transit website provides brief information about the location of a stop ("Direction and position: Southbound / after the cross street or landmark") and the presence of shelters or benches ("Shelter: yes").

Finding the exact location of a stop was a major challenge for all participants. Once they reached a stop's identifying intersection, they would search for a stop pole or shelter, a group of people waiting at the stop, or ask a nearby pedestrian for information. Some participants called the transit agency help line. Knowing which landmarks were at the stop (a pole but no shelter) and where they were located (middle of the block and close to the curb) was helpful.

> *"I have to ask people for information a lot. Sometimes I call Metro to figure out where the stop is [located] approximately, but they still can't exactly tell you where the stop is if it's in the middle of the block."*

When a bus arrived at a stop, participants asked the driver or other riders for the route of the bus. They felt stressed when multiple buses reached a stop at the same time.

Participants relied on the bus driver to know when to disembark the bus on unfamiliar routes.

> *"I have to breathe down the driver's neck to make sure I don't miss my stop at an unfamiliar location. I must be assertive. I make a note of how long it should take to reach a stop and sit in front if a seat is available."*

While participants were mostly satisfied with the bus drivers, occasionally bus drivers forgot to announce a stop. When disembarking the bus at an unfamiliar location, participants relied on a GPS system if they had one, or asking other people for information.

> *"Once I missed my stop late at night and I called 911. I was afraid. There were no people around at 10:30 pm... I would have asked people for help but there were none. If I could get to a main intersection I would have been okay, but I was on a residential street. I was afraid."*

All participants carried mobile phones and Braille notetakers [1] when on-the-go. Three participants had GPS systems [16] that were designed for people who are blind and two had iPhones (that had a built-in screen reader) with applications that provided GPS-related information. Participants disliked carrying multiple devices in addition to a cane or a guide dog. Additionally, the GPS system, like most assistive technologies, was expensive (almost $1,000) and complicated to operate.

Most participants were unable to use technology with speech output comfortably on-the-go. Speech output was difficult to hear on a busy street, and 2 participants were concerned with lack of privacy. Most participants felt unsafe using headphones because they used audio cues to navigate and understand their surroundings.

> *"I would feel safer using Braille. I like it better. People can't see what you're doing; it's good for*

*short bus rides. I need Braille if I really want to retain something."*

Our participants prioritized the values of independence and confidence, and expressed concerns about safety. They often asked other people for information about their surroundings, but reliable people were not always available. All participants preferred to access information themselves from an iPhone or a GPS system (in line with the importance of independence). Yet speech output could be distracting and unsafe or difficult to hear when on-the-go. Specialized assistive technology is expensive [17] and inconvenient to carry.

*"Having more information enables you to be more independent, safer, and more confident."*

### Interviews with Deaf-Blind People

We conducted 30-minute semi-structured interviews with 7 deaf-blind adults (4 men, 3 women) and one O&M instructor. Two of our deaf-blind participants train other deaf-blind people on using assistive technology. Five of the deaf-blind participants had no functional vision while 2 had low-vision. We communicated with the deaf-blind participants with professional interpreters or the assistance of one of the authors, who is fluent in sign language.

Five participants currently use buses on a regular basis. One participant had used buses regularly in the past, but now uses paratransit because of medical conditions. Another participant preferred to travel with a volunteer, but occasionally took taxis.

Deaf-blind people experience many of the same challenges faced by blind people when using public transit, such as finding the exact location of a stop, boarding the correct bus, and knowing when to disembark. Unlike blind people who can hear, however, deaf-blind people cannot communicate verbally with others. They rely on advance training from an O&M instructor and pre-printed cards (see Figure 1) to convey messages to the bus drivers and other transit riders.


**Figure 1. A deaf-blind person holds a card he uses to communicate with a bus driver. (Note the Braille letters at the top that allow him to tell the cards apart.)**

Planning a new transit trip involved printing cards and being shown where a stop was. Most participants printed cards that included their route number and destination with their O&M instructor up to a week before their trip. The O&M instructor would also show most participants where exactly a stop was.

Participants relied on the bus driver to lead them onto the correct bus and help them disembark at the right stop. The bus driver would step outside the bus when leading a deaf-blind participant. Some participants were nervous and concerned when a bus or taxi would not show up at the expected time or when they thought the driver forgot their stop.

Communication with a transit vehicle driver was a major challenge for all participants. Three participants occasionally used the DBC [10] and most were able to receive messages spelled out on their palms. These forms of communication were too slow for the bus, however, and all participants preferred using cards.

*"Communication is very important. I want to get confirmation that I was understood. It's hard to trust another person to make a call for you… I prefer to be as independent as possible."*

Unexpected events were rare but costly and upsetting. One participant recalled that a bus driver once forgot to help him disembark at the correct stop. A transit manager was called and drove the participant home, resulting in stress and significant delay. Two participants reported drivers forgetting their stops a small number of times in a few years.

Another participant described a time when the bus driver tapped her knee repeatedly but the participant knew she wasn't at the right stop (it was a familiar route). She didn't move and felt nervous, confused, and embarrassed to draw the attention of other passengers. She found out eventually that the driver wanted her to move so a passenger in a wheelchair could sit in her spot.

*"I felt like I was performing in front of a full bus of people. I was not comfortable."*

Three of the deaf-blind participants used a DBC [10], which included a Braille notetaker [1] and a MiniGuide [10]. The DBC was used mostly for sending and receiving SMS messages and occasionally for face-to-face communication. One of our participants said he had eight weeks of initial training on the DBC and an additional year of training to become proficient. Other participants agreed that using the DBC required months of training. The two participants with low-vision had Blackberries which they mostly used for SMS messaging.

The O&M instructor said access to information was a key issue for deaf-blind people using public transit. Travel was "extremely dangerous," he said, and that people need better access to information when planning a trip and real-time information en-route. They also need a backup support system, such as a designated van service, if something goes wrong.

As with our blind participants, the values of independence, confidence, and safety emerged as key in our interviews. All deaf-blind participants and the O&M instructor associated access to information with safety and confidence. This includes information about one's physical surroundings (trees in the middle of sidewalks), bus arrival times, imminent bus stops, and communication with the driver.

### Bus Driver Surveys

As prompted by the Value Sensitive Design methodology, we surveyed bus drivers, perhaps the most important indirect stakeholders for our application. The bus drivers transport blind and deaf-blind people and are responsible for communicating with these passengers and ensuring that they get safely to their destinations.

In cooperation with Amalgamated Transit Union Local 587, we mailed a survey regarding driver views and values to 500 drivers. Surveys were filled out anonymously and we assured participants that their responses would only be used by researchers working on this project. There were 237 responses (47% response rate). The survey focused primarily on real-time transit information tools like OneBusAway for the general public (these results will be reported elsewhere [19]). However, it included several questions regarding riders who are blind or deaf-blind.

One question in the survey asked:

> *Which of the feelings below best describe how you feel about driving riders who are **blind**? (You may choose more than one answer.)*

- *Glad to help*
- *It's part of the job*
- *Frustrated*
- *Fascinated/interested*
- *Stressed*
- *Uninterested*
- *Never drove a blind person*

A second question was exactly the same except that it asked about riders who are deaf-blind. The results for both questions are reported in Table 1.

We coded the responses following the method used in prior Value Sensitive Design work [6], namely by grouping Glad/Interested, Job/Uninterested, and Frustrated/Stressed answers into positive, neutral, and negative feelings respectively about driving these passengers. Some drivers responded with answers that included both positive and negative feelings (e.g., glad to help but also stressed), and this is reported as well. Overall, the responses were strongly positive, with a very small number of negative responses for blind riders, and more negative responses (but still the minority) for deaf-blind riders. A note of caution regarding the results: even though the survey was anonymous, the responses may be more positive than the drivers actually feel, due to a perception of what the right answer ought to be.)

Another question followed up regarding technology:

> *Let's say that there was a website or mobile application that allowed blind and deaf-blind riders to better get around by giving them next bus arrival information and alerting them that their stop was approaching once they were on the bus. Which of the following applies to your views?*

- *This application **should** be built.*
- *This application should **not** be built.*
- *Why?*

Again, the responses were strongly positive: 211 drivers thought the application should be built, 14 thought it should not, and 12 did not respond.

**Table 1. Bus driver views on driving blind or deaf-blind passengers.**

| Feeling about driving *blind* passengers | Number of responses |
|---|---|
| Positive | 70 |
| Positive or neutral | 114 |
| Neutral | 29 |
| Neutral or negative | 2 |
| Negative | 1 |
| Glad/interested but stressed/frustrated | 2 |
| All three | 8 |
| Never had such a passenger | 2 |
| No response | 9 |

| Feeling about driving *deaf-blind* passengers | Number of responses |
|---|---|
| Positive | 59 |
| Positive or neutral | 81 |
| Neutral | 16 |
| Neutral or negative | 5 |
| Negative | 7 |
| Glad/interested but stressed/frustrated | 8 |
| All three | 23 |
| Never had such a passenger | 28 |
| No response | 10 |

The free-form comments supported these results. One set of comments focused on the responsibility of the agency and drivers to serve the public, including blind and deaf-blind riders: "we have a responsibility to the public and we should do everything in our power to make it simple," and, "They are courageous to be doing it in the first place. Let's encourage that and make the system as user friendly as possible." Another set of positive comments focused on making the driver's job easier or on saving time for all passengers: "Takes some of the stress off us. There are many things going on at once so we may forget they are even on the bus," and, "This save[s] time vs. securing the coach, getting off, tapping rider and finger spelling on palm." Negative comments primarily concerned the relatively small number of deaf-blind riders and the cost: "It would be helpful, but do we really have that many deaf-blind riders to off set the cost. I would guess they would be with a helper & not alone."

Overall, these results were encouraging with respect to the value of applications such as the ones described in this paper.

## TECHNICAL INVESTIGATION

### Assessing Current Technology

Current technology that was discussed in our first empirical investigation phase, including accessible GPS systems, Braille notetakers, and DBC's, provides access to some amount of information, supporting the value of independence. Yet participants often depended on other people to get information about the exact location of a bus stop, the route of a bus at a stop, or an imminent stop on a bus ride. Several other values that were important to our participants were not supported by current technology, including affordability and comfort. Participants disliked carrying around multiple specialized devices that were also very expensive.

Blind participants said that Braille output had several advantages over speech output. For example, Braille technology supported the values of safety (less distracting) and privacy, while enabling the user to better retain the outputted information. However, Braille displays are significantly more expensive than devices with speech output. A Braille display may cost from $1700 to over $5,000 while an iPhone may cost $200.

Unlike blind people, deaf-blind people could not use speech output and needed Braille devices to access digital information.

### The MoBraille Framework

To better support the values identified, we designed a system that enables blind and deaf-blind people to access information from a small, mainstream smartphone in Braille. We developed *MoBraille* ("mobile Braille"), which enables Braille notetakers to benefit from many features of an Android phone, including the GPS, compass, and 3G network connectivity.

Despite the advantages of using Braille, little work has been done in HCI that explores the use of Braille applications. We thus decided to focus on applications with Braille output for both blind and deaf-blind people. By connecting the Braille display to a smartphone, participants would not need an additional special-purpose GPS device or compass. Furthermore, new Braille applications could be developed that use remote web services and other sensors on a smartphone such as the camera.

MoBraille enables an Android application to interface with a Braille notetaker through HTTP requests over a WiFi connection. To use a MoBraille application, the user connects the Braille notetaker to the Android phone over WiFi. Next, the user loads a MoBraille webpage on the notetaker's built-in browser. The webpage sends requests to the phone that are processed by a Java servlet running on the phone. The servlet can access the Android's sensors like any other Android application.

MoBraille is powerful because it enables developers to write applications that interface with Braille notetakers with no proprietary, device-specific knowledge—all that is necessary is writing an HTML page and a Java servlet that runs on Android. MoBraille can thus facilitate the development of low-cost third-party networked Braille applications.

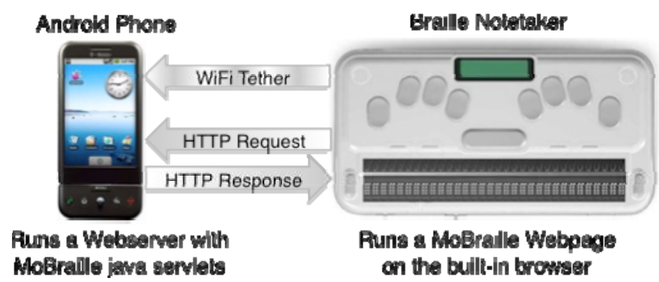


**Figure 2. With MoBraille, a webpage loaded on a Wi-Fi-enabled Braille display sends HTTP requests to an Android phone and receives HTTP responses.**

### GoBraille for Blind Public Transit Riders

We developed GoBraille, a MoBraille application for blind people that enables them to get (1) the nearest intersection and nearest address, (2) real-time bus arrival information for nearby stops, and (3) non-visual landmark and specific location information about nearby stops. The interface is a minimalist web application, generated by servlets running on the Android phone.

The nearest intersection, address, and real-time bus arrival information are obtained from OneBusAway and from Geonames [9], a free third-party web service. The application sends requests to these services with latitude and longitude coordinates from the Android's GPS unit.

Non-visual landmarks and specific location information about bus stops are obtained via crowdsourcing, where users of the system (who are blind) contribute its content. This ensures that the information is relevant to its intended users. A user can fill out a form that states whether the stop has a shelter or a bench, the stop's relative direction from the intersection, and open-ended comments about the stop. A user can quickly fill out the form while waiting for a bus.

A simple rating system is used to add a measure of reliability to the crowdsourced information. When requesting information about a stop, the user is presented with two entries that he or she can rate. The currently highest-rated entry for the stop is always presented, along with another random entry to help avoid a bias towards older entries.

### GoBraille for Deaf-Blind Public Transit Riders

The version of GoBraille for deaf-blind people provides real-time arrival information for a user's bus at his or her current stop. Based on iterative feedback from a deaf-blind participant, we designed a much more minimalist interface for deaf-blind people than for blind people.

The user's interaction with the application follows specific steps. When waiting at a stop, the user points the Android phone in the direction of the street and presses a button, capturing the phone's compass reading. This is used to determine exactly which stop the user is standing at. When the GPS reading is not sufficiently accurate to disambiguate between stops that are across the street from one another, GoBraille uses the compass reading to identify which side of the street the user is standing at, given that buses at the user's stop are headed right when facing the street. The user enters a route number in his Braille notetaker. GoBraille queries OneBusAway to get arrival information for the route at the current stop.

## EMPIRICAL INVESTIGATION 2: EVAULATING OUR TECHNOLOGY

### Evaluating GoBraille for Blind People

We evaluated GoBraille by conducting user studies with 10 blind adults who rode the bus regularly. We focused the evaluation on the novel aspects of GoBraille: having real-time arrival information available for buses, and using and entering crowdsourced landmark information for stops. Studies were conducted on a sidewalk by a busy street and near several bus stops, so there was no need to ride a bus to evaluate these aspects of the system. After briefly explaining GoBraille, we gave participants a set of tasks to complete using the application, and then conducted a 20-minute semi-structured interview.

Using our application, participants were asked to do the following tasks:

1. Find the nearest intersection and address.
2. Find the arrival times of buses at a specified stop.
3. Find landmark and location information for a stop.
4. Add landmark and location information for a stop.

We chose a nearby stop for tasks 2–4. Participants completed Task 4 by filling in information from memory or by exploring the stop with their canes or guide dogs.

The semi-structured interview that followed the tasks aimed to determine how access to the different information from GoBraille would affect a participant's sense of independence and safety when using public transit. We also aimed to understand the role of Braille input and output in the interaction with the system.

All participants completed the 4 tasks with little guidance. Most of the guidance we provided involved teaching participants the device-specific browser shortcuts for selecting the next element or going to the previous page. Participants found the interface easy to use and fast to learn. After completing the tasks, one participant independently looked up the arrival time of the bus she actually planned to take after completing the study.

**Table 2. Questions and mean answers from the semi-structured interviews conducted with 10 blind people.**

*Section 1*: Describe how you feel about each statement.
1 = strongly disagree, 2 = somewhat disagree, 3 = neutral,
4 = somewhat agree, 5 = strongly agree.

| | Statement | Mean |
|---|---|---|
| 1.1 | The system would provide me with useful information. | 5.0 |
| 1.2 | Getting information from the system would be faster than getting similar information from the bus driver. | 4.6 |
| 1.3 | I would prefer to ask the bus driver or other people for information rather than use the system. | 1.1 |
| 1.4 | I feel that the system would enable me to use public transit more independently. | 4.6 |
| 1.5 | Using the system would make my ride on public transit less stressful. | 4.6 |
| 1.6 | The system was difficult to use. | 1.3 |
| 1.7 | It was easy to learn how to use the system. | 5.0 |
| 1.8 | I trust that the information that would be provided by the system is correct. | 4.5 |
| 1.9 | I prefer to have this information in speech on a mobile phone than to have it in Braille. | 2.2 |

*Section 2*: How important was each of the following for enabling you to feel independent while using public transit?
1 = irrelevant, 2 = not important, 3 = neutral 4 = important,
5 = critically important.

| | Type of information | Mean |
|---|---|---|
| 2.1 | Nearest intersection and nearest address | 4.9 |
| 2.2 | Bus arrival information | 4.8 |
| 2.3 | Stop location and landmark information | 4.7 |

Satisfaction with the system was high. Mean results from questions asked during the semi-structured interviews are reported in Table 2. All participants felt that the information provided by the application would enhance their sense of independence, which was related to increased comfort and confidence. It would enable them to explore new places.

*"[GoBraille] would reduce my sense of trepidation. Part of that is not knowing exactly where the stops are, not knowing if you're really at the stop at a new place. Having this information [about stop landmarks] to independently confirm what you're thinking…I'd feel more comfortable about going out and exploring."*

All participants preferred to get information from the system than asking people around them. Also, when depending on other people, there is a risk that you get incorrect information or that no one is available to ask.

*"[With this information] I can ask for help better and not look like I really need it. I would need confirmation. I'd rather be like a tourist, rather than 'oh, this guy is blind and has no clue.'"*

Six participants felt the information provided would make them feel safer, but for different reasons. Three participants felt that knowing more about their surroundings (e.g., about obstacles or potential dangers from traffic) made them feel safer, while 2 other participants felt that looking confident made them less vulnerable to attacks or harassment. Two participants said that knowing the actual bus arrival times would increase their sense of safety if they felt threatened by people around them, especially at night.

The remaining 4 participants were not concerned about safety issues; they did not feel that the information provided by GoBraille would increase their sense of safety. One participant said that carrying an additional device, the Braille notetaker, would be cumbersome and make him feel less safe.

While all participants found the crowdsourced landmark and location information about bus stops important for traveling independently, they had reservations about the current system. Most participants wanted to know about additional landmarks such as trash bins, the location of the stop pole (was it near the curb?), details of the stop pole (whether it was a single square pole, or two larger posts for a large display), and whether the stop was in the middle of the block or close to the intersection. Figure 3 shows an example of crowdsourced information added by participants in our user studies, showing both the sorts of information added and its format.

The following were concerns raised about crowdsourced information:

- Getting incorrect or outdated information.
- Getting information that may be relevant to others but not to the current user.
- Having enough users to populate the system for the stops the user needs.

Assessments of receiving information in Braille were mixed and typically situation-dependent. Most participants preferred Braille because it was faster, more private, or better for retaining information—but not in the rain, because of the potential for damage to the Braille notetaker, or when wearing gloves. Many wanted to have the option of speech output on a mobile phone. All were concerned with the added cost of a Braille notetaker and the fact that a small minority of blind people read Braille [2].

*"I do like Braille output but the [Braille notetaker] is so expensive. It is a big piece of hardware—it's a drag. You can throw a phone in a clutch purse, but not the Braille device."*

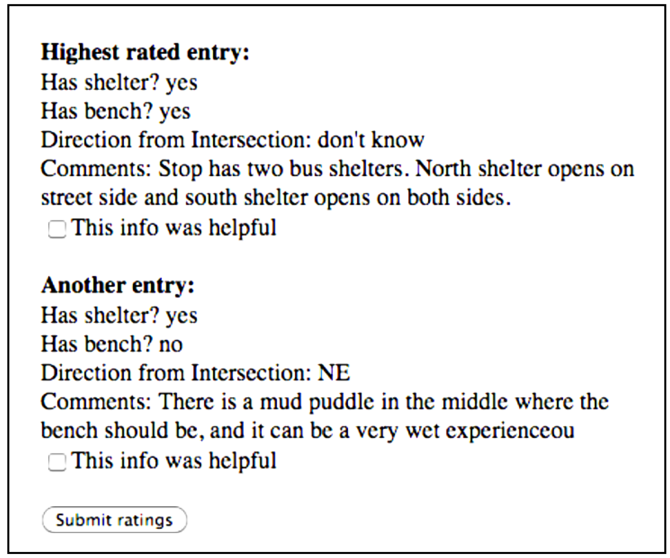


**Figure 3. Crowdsourced information about a bus stop that is presented to the user. This information was entered by participants in our user studies.**

### Co-Design with a Deaf-Blind Person

We designed the version of GoBraille for deaf-blind people with three sessions of working with a deaf-blind person who used the bus regularly. Each session lasted 1.5 hours.

We conducted iterative co-design with one person because we realized our knowledge of deaf-blind people was very limited. During our initial interviews, we encountered unexpected barriers, including low English and Braille proficiency and time delays and possible misunderstandings caused by interpretation. Furthermore, there was little prior work we could draw on.

Our participant had no functional vision or hearing, and used a DBC and a MiniGuide when on-the-go. He already used the OneBusAway SMS interface to get real-time arrival information for buses. This required knowing stop identification numbers, however, which are printed on stop shelters or schedules. Our participant had to find and bookmark these identification numbers in advance to use OneBusAway.

We now discuss the main issues that arose in each design session with our participant.

#### *Session 1*

Similar to our application for blind people, our initial design of the application for deaf-blind people provided the nearest intersection and address and bus arrival information for nearby stops. We also included a feature that displayed a message typed on the Braille notetaker on the screen of the Android to enable a deaf-blind person to convey information to a bus driver or passenger.

We conducted the first session indoors and provided a high-level explanation of the application. We then asked the participant to read a line of text from the application: “Enter 1 to get bus arrival information. Enter 2 to get location information. Enter 3 to print a message to the screen.”

The participant read the line of text with great difficulty. He read the first sentence for several minutes and asked for a translation from the interpreter. He was confused, frustrated, and did not know what to do. We realized that his lack of proficiency in English and Braille were both greater barriers than we anticipated.

#### *Session 2*

We simplified the application for the second session. We went to a bus stop and taught our participant exactly how to use it. Interaction with the second version of the application was as follows: when the participant reached a stop, he entered his bus route number and cardinal direction into his Braille notetaker. The application then displayed the number of minutes until the next bus of that route would arrive at the stop. For example, if the user entered “73s,” the Braille notetaker displayed “73 to Downtown: 3m.”

The participant said the system was “beautiful,” “so easy,” and fast. However, he had difficulty entering the cardinal direction in which his bus was headed. This information was necessary to disambiguate between stops located across the street from each other.

#### *Session 3*

During the final session, the application used the Android’s compass to disambiguate between stops. The participant pointed the phone to the street and pushed the “menu” button on a G1 phone.

The participant was once again pleased with the system, but found it difficult to know whether he properly pushed the button. One way to alleviate this would be to trigger a vibration when a button click was registered.

#### *Lessons Learned*

We distill some of the lessons learned from co-design as three general guidelines.

1. Use short output messages. Because of low English and Braille proficiency, deaf-blind people are often slow readers.
2. Use short input messages. Shorter input messages, even by a few characters, were much faster and easier for our participant to type, especially when waiting for a bus.
3. Be concise and provide training. Our initial design prioritized discoverability, but our participant preferred that we provide training, with interpreters, on how to use the interface and then rely on memory.

### Recommendations for Conducting Studies and Interviews with Deaf-Blind People

Since little research with deaf-blind people has been reported in the HCI literature, we offer the following recommendations (based in part on our own hard-learned lessons).

- Hire professional interpreters who have experience with deaf-blind people. Do not rely on written communication.
- Ensure the interpreters understand the goals of the study and the technology in advance.
- Speak slowly and clearly. Tactile sign language communication is slower than speech. Ensure the high-level goals of the study or interview are understood.
- When conducting a study, thoroughly train the deaf-blind person with an interpreter on how to use the technology.
- When conducting an interview, plan on asking only a small number of questions. (When planning the interviews, we greatly overestimated the number of questions we would be able to ask.) We were able to ask three to five questions in 30 minutes.

## FUTURE WORK

This project has opened a large set of possible directions for future work, including:

- Further enhancement of GoBraille for deaf-blind people, including a MoBraille application that facilitates communication with a bus driver and an application that alerts the user when his or her stop is near.
- Long-term field deployment of GoBraille. Usage logs, semi-structured interviews, occasional shadowing of participants, and participant diary entries can be used to see whether there is an increased sense of independence and safety and how this affects behavior. For example, how many more new bus routes did a user ride in a month with GoBraille? How many more spontaneous trips did he or she take?
- Development of a smartphone application that provides real-time bus arrival information and crowdsourced landmarks with speech output. Is the information provided by GoBraille as useful when conveyed with speech output and touch-screen input?
- Further exploration of crowdsourcing for relevant landmarks, including methods to elicit useful information and good coverage of stops and to increase user trust in the information presented.

- Integrate collaborative or social tools in GoBraille that facilitate blind people in meeting up with others (either blind or sighted) to take transit together. This would add a social element to the experience, and would probably also make people feel safer.

## CONCLUSION

Using the Value Sensitive Design methodology [5], we identified key values that are important to blind and deaf-blind people when using public transit. We also considered how other stakeholders were affected by conducting surveys with bus drivers and interviewing an O&M instructor for deaf-blind people. In terms of the use of Value Sensitive Design, this work has been fundamentally driven by value considerations; on the other, we didn't encounter the sorts of difficult value tensions that have arisen in other VSD projects. We developed technology to support the key values, focusing on increasing independence and safety, and providing blind and deaf-blind people information about bus arrival times and bus stop locations in Braille. Our GoBraille application used crowdsourcing and OneBusAway, and provides relevant, non-visual information. On the negative side, there were concerns regarding Braille output and the reliability of crowdsourced information. Unlike most currently available assistive technology, our applications also support the values of affordability and convenience using the novel MoBraille framework.

In sum, through user studies and co-design, we found that the technology we developed has high potential to increase independence and safety, enabling people who are blind to explore more unfamiliar places.

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