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Supporting People with Vision Impairments in Automated Vehicles: Challenge and Opportunities

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16. Abstract

Autonomous and automated vehicles (AVs) will provide many opportunities for mobility and independence for people with vision impairments (PwVI). This project provides insights on the challenges and potential barriers to their adoption of AVs. We examine adoption and use of ridesharing services. We study ridesharing as a proxy for AVs as they are a similar means of single-rider transportation for PwVI through observations and interviews. We also investigate perceptions towards autonomous vehicles and prototypes to address perceived barriers to AV use through design focus groups with blind and low vision people. From these studies, we provide recommendations to AV manufacturers and suppliers for how to best design vehicles and interactive systems that people with vision impairments trust.

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Introduction

Driverless vehicles have typically been studied in the context of military use or everyday use by people who currently own cars. Yet, driverless cars also have the potential to significantly impact the lives of people with disabilities, particularly people with vision impairments. Enabling access to driverless vehicles is a challenge for many reasons, but the largest concern is how to convey information to people who are unable to navigate such a dynamic and high-risk visual space. However, there is a lack of research on how people with vision impairments interact in an automotive environment since they are unable to operate vehicles or own driver's licenses. As such, we conducted a novel investigation on the challenges people with vision impairments face in vehicles, and opportunities for the design of autonomous vehicles to inclusively support people with disabilities.

We conducted a multi-phase project using contextual inquiry and user-centered design approaches, addressing the following objectives:

1. Examine the adoption and use of single-rider, direct transportation services by people with vision impairments
2. Understand social receptiveness of autonomous vehicles by people with vision impairments
3. Identify perceived barriers of autonomous vehicle use and potential design solutions to address these barriers

Adoption and Use of Transportation

Prior work focuses on how people with vision impairments use existing services, such as public transportation. Yet, the structure and design of public transportation services makes it vastly different from the experience in an autonomous vehicle. As such, we study ridesharing services (e.g. Uber, Lyft) as a proxy for an experience similar to an AV as it is a form of directed, single-rider transportation. To do so, we interviewed and observed ridesharing users with vision impairments, and interviewed ridesharing drivers with experiences with passengers with vision impairments.

Interviews

<u>Methods</u>
We conducted 16 interviews with people with vision impairments who were recent ridesharing users. Interviews were semi-structured and lasted between 60-70 minutes. Most of the interviews (n=12) were conducted in person while the rest were conducted

remotely over phone or Skype. Verbal consent was obtained at the start of the interview. During the interviews participants were asked about their overall experience with ridesharing services, challenges participants faced using ridesharing services, how they navigated these challenges, and perceptions of other forms of transportation (e.g. buses, autonomous vehicles). Additionally, we asked how they used these services to travel to unfamiliar locations due to work that suggests differences in navigating places based on familiarity (Banovic, Franz, Truong, Mankoff, & Dey, 2013; Guy & Truong, 2012). Interviews were audio recorded and participants were compensated $20.

We also conducted remote semi-structured interviews with ridesharing drivers about their experiences as a driver. The interviews focused on their interactions with people with vision impairments, but we also asked questions about their experiences with people that have other impairments (e.g. mobility) that may be similar to challenges blind and low vision people face. Some interview questions were informed by online forums where drivers discussed accessibility-related issues. These questions included what types of assistance they provided to riders with a vision impairment or other disability, how they felt about providing additional assistance, and what they did to ensure passengers felt comfortable during rides. Verbal consent was obtained from participants as interviews were conducted by phone. Interviews lasted 45-60 minutes, were audio recorded, and all participants were compensated for their time with a $20 gift card.

Participants

We recruited participants with vision impairments by contacting organizations catering to people with disabilities and vision impairments in the Detroit metropolitan area. Eligible participants were at least 18 years old, had a non-corrective vision impairment (blind or low vision) and had used ridesharing services at-least once in the month prior to when they were contacted. In total, we recruited 16 people (female = 6, average age = 41.5 years old) to participate in the interviews. Participants had varied vision levels including blind, blind with light perception, and low vision (visual acuity of < 20/70). Most participants (n=9) had used both Uber and Lyft while the rest had used only one of two services.

Drivers were recruited online in Facebook groups and forums (e.g., RideGuru, UberPeople.net) for ridesharing drivers to discuss their experiences, ask questions and share tips about working for ridesharing companies. The groups that we recruited from ranged in size from approximately 1,000 to over 8,000 members. Recruitment was done in both general and location-specific groups in the United States. Of the 67 individuals who indicated interest in the study by completing the online screening survey, 39 were eligible (inclusion criteria of at least one month of driving experience and indicated at least one interaction with a person with a vision impairment). After contacting those who were eligible, we conducted interviews with 18 participants who worked as drivers for at least one ridesharing service. Participants' ages ranged from 35 to 81 years old (median = 50), 6 participants identified as female, and 12 identified as male. A majority (17/18) had been working as a ridesharing driver for more than one year. They had a range of experiences with driving people with disabilities.

Results

In this section we focus on the roles that drivers and non-ridesharing technology plays in the transportation process. More details about our findings are in the two papers that we published on these topics (Brewer, Austin, & Ellison, 2019; Brewer & Kameswaran, 2019). Below, quotes from people with vision impairments use PXX and quotes from drivers use DXX.

THE ROLE OF THE DRIVER

Participants described many positive interactions with ridesharing drivers as they trusted drivers to help them when entering and exiting a vehicle (n = 15). They described how they asked drivers to drop them off at convenient locations that made it easier to find doors. For example, P16 asked his driver if he was "*familiar which way the sidewalks run. I want to make certain that they know I haven't been there before, 'could you please line me up with the door?'*" The lack of a driver, particularly for going to a new location, concerned one participant who said, "*if you go to a new place ...how are you going to...make sure that you're being dropped off in front of the door or how far away is the door or is it to the left or to the right?* (P9)" Some participants (n = 6) described how their drivers left their vehicles to assist them inside of buildings. For example, P11 described how "*I was going to work a couple weeks ago, and the Uber driver was really, really helpful, and there was a bunch of construction...he tried to walk me around the construction. You know, got out of the car, so that I could get through to go to work.*"

Two participants compared this interaction with other forms of transportation such as buses. One participant said, "*The con for me is that I don't think I could do it on my own without serious planning. I have to know on which side of the street the bus stops, when it stops, what are the routes in between. I need to tell the bus driver to make sure that he or she let me know when my stop is approaching. I need to know where it stops on what side of the street when I get off. It's a bit more planning than taking Uber*" (P3). This example illustrates how participants may need to trust drivers to help with vehicle entrance and exit work regardless of the form of transportation, but that this may take more effort when not using ridesharing services.

However, interacting with the ridesharing driver to enter a vehicle also presented challenges for participants. Popular services like Uber and Lyft provide the license plate, vehicle make and model, and sometimes image of the vehicle to help passengers locate the driver. However, this becomes a challenge for someone with low vision and almost impossible for a person who is blind to use as a resource. To help mitigate this challenge, some participants (n = 6) describe contacting the driver, disclosing their disability, and asking the driver to find them instead of vice versa. For example, P5 said: "*Well, sometimes they can't always see where you are. They think you can see them and you tell them you can't. You call the rider and you're waiting and they still can't see you. For example, I waited out by my garage before and a guy swore he was at my house. And I said, 'You're not at my house 'cause I'm at the garage.' He goes, 'I'm at the garage.' I said, 'No you're not, 'cause I'm right here.' And I even waved the cane around. So he drove around, and he finally saw me.*"

However, this is only available to passengers who know this is a feature as one participant wished ridesharing services had an option to contact the driver. Often, participants described this disability work of communicating with the driver and entering the vehicle as the most challenging part of using ridesharing services. While other work highlights this as a similar challenge in public bus systems for blind and blind-deaf people (Azenkot et al., 2011), this challenge was not as prevalent in our study when participants were asked about their use of buses, presumably since stops are fixed, and para-transit services where there is often door-to-door service to enter and exit a vehicle.

Upon entering a vehicle, participants (n = 12) enjoyed drivers who provided cues about the trip and destination environment. P8 describes a trip in which he was traveling to a new place and the driver provided him with information about nearby landmarks saying "*in route, she was noting different locations that we were passing, and what was in those locations, and you know, different tourist spots if we were interested and different restaurants that we might want to visit that was in our general area and the route...so I thought it was very accommodating*."

One participant mentioned how if not provided with these cues, he would ask questions to seek environmental awareness. P2 said, "*Well, he doesn't know that I'm unfamiliar with the location, so in that particular instance since I was leaving, it wouldn't be beneficial but let's say that I just arrived and I was taking Uber out, then it would be really useful to get information about the area just like you would in a taxi cab. If I were to take an Uber in that situation, I would probably strike up the conversation anyways. I'd be like, 'Oh, hey, what's around here?*'" Beyond local landmarks, people would also ask questions about nearby doors and obstacles at their target destination.

Participants also seemed to use conversation as a tool to establish trust with the drivers. Being in a vehicle with a friendly driver seemed to make participants comfortable enough to trust drivers to take them to the correct destination. For example, P1 said, "*I do go across some driver [sic] that I may have taken in the past. So, that happens like, 'Hey man, good to see you again.' I feel a bit comfortable because they know me.*" In his interview, P1 described an experience where he needed to take a 3-hour trip at 2:00 a.m. and felt more comfortable doing so with a driver he had encountered before. This trust that was built over multiple rides and conversations that put him at-ease to not only trust this one driver, but other ridesharing drivers.

While participants were concerned about using other forms of transportation, they seemed trusting of ridesharing services to take them to new places. For example, P2 said, "*I don't know anything about the taxi or bus routes. It's a completely new location, so I have no idea how it works, and it's not worth the effort for me to look all that up, and it's potentially unreliable, and I could potentially make a mistake*."
P4 agreed by saying, "*if it's somewhere new and it's, quite frankly, not in a congested area, I'll take Uber or Lyft*."

Prior work describes the amount of planning and coordination needed to go to a new destination (Guy & Truong, 2012). Based on this work, we asked participants specific questions as to how they use ridesharing services differently when going to an unfamiliar location. Surprisingly, no one reported differences other than searching for the address. This shows how much trust participants place in the drivers and ridesharing services.

Although positive experiences with drivers were described as reasons to continue using ridesharing services, negative experiences did not seem to deter participants from using them in the future. For example, P4 said, "*One of the drivers dropped me off five doors from my house and it was at night and he pulled off...and I didn't know if he dropped me off on the wrong street or if he had dropped me off on the wrong block. I really couldn't tell*." P1 had a similar experience where a driver wanted to drop him off on a highway. One strategy to help passenger know if the driver is navigating to the correct destination is to 'follow along' on their phones. Yet, P2 explicitly described not doing this because he trusted not just the driver, but the incentive systems for drivers, saying, "*I don't really do it because I usually don't have a real concern with that. Either the place I'm going to ... If I need to go to somewhere quick, it's usually to a place that I know. If I'm going to somewhere new, I usually am not necessarily under that same kind of time constraint. I usually have enough trust in the driver to not intentionally make any turns...I think the way Uber's payment system is set up, it's better to get more rides than to just drive* *someone around and get the extra cents per mile, but I'm not entirely sure*" (P2). Similarly, others like P6 placed trust in drivers because of the affordances inherent in the design of ridesharing services like background checks, saying "*I think there may be more security about the drivers because I know the drivers are screened*."

Despite the countless incidents where participants described being taken to the wrong destination, only P3 described not trusting drivers to take the most optimal route and using the GPS on his smartphone to confirm the route. However, P3 and other participants are active ridesharing users even after negative driver experiences. This suggests that the benefits of using these services outweigh the costs.

These findings show how drivers are critical in direct-route transportation services for people with vision impairments. Designers of AVs should consider how similar structures can support providing assistance with entering and exiting, environmental awareness cues, and facilitate trust.

THE DRIVER'S PERSPECTIVE OF LABOR

From the driver's perspective, they frequently discussed the advantages and disadvantages of different the physical and emotional labor involved with their jobs. Regarding physical labor, they described being asked or offering to physically assist passengers with vision and mobility impairments, such as helping them get in and out of the car, walking them to their destination, or loading a wheelchair or walker into their vehicle. For example, D10 described an interaction with a passenger with a vision impairment, saying, "*I got out and helped him with the door, he stepped out the car and he grabbed onto my arm and I lifted him up.*" Similarly, D17 walked a passenger with a vision impairment into a medical clinic saying, "*when we got there, I stopped, got out of the car, and I walked him in, and then walked him up to the desk, where he had to check in.*" Drivers indicated doing this physical work because they saw it as part of their jobs or noticed an environment was not accessible. This view has been echoed in prior work with passengers with a vision impairment, as they believed that receiving assistance from a driver was less burdensome than asking another individual who may not feel obligated to help (Kameswaran et al., 2018). For example, D1 said, "*The only one I had to assist was a gentleman [with a vision impairment] that I took to the airport early one morning. I did help him get to the doors of the airport, just because there's not a whole lot of clues for him to tap and there really wasn't a whole lot of clues close to him to get him where he needed to go*." Implicit in this statement is the invisible work performed by a driver who has to assess the destination environment and recognize that someone with a disability might need additional help.

Other examples of participants reporting doing physical labor include D13, who described a trip with a sighted passenger with a mobility impairment, saying, "*I usually have to fold up the wheelchair and put it in the trunk or the walker, but they're able to swing their bodies into the car. And then, when I end the ride, I get their wheelchair [or] walker out before I end the ride and get them started on their way to the door. So, that takes a little bit of time, but I'm paid for my time, so it doesn't bother me.*" Although many drivers echoed D13's sentiment and reported that they did not mind helping, sometimes it was described as a burden, depending on the nature of help needed. For example, D1 said, "*the passenger] could not stand on her own so I needed to help her get stood up from the chair and then turned into the seat. Then again reverse the process once we got her to her home. I actually had to assist her up the stairs to her front porch before I could get the chair and bring it to her. For somebody that's not trained to do that kind of stuff, that was very cumbersome.*" This quote describes the experience of a driver and a sighted person with a mobility impairment. While previous work describes how ridesharing drivers engage in emotional labor (Raval & Dourish, 2016), we find drivers supporting people with disabilities often engage in different forms of physical labor. Besides drivers stating how they are given specific instructions to not discriminate against riders with service animals, most described not being given explicit training on how to support various kinds of disabilities.

Drivers also implicitly discussed engaging in forms of emotional labor for passengers with and without vision impairments. Here we use the term "emotional labor" to refer to the concept that some kinds of work implicitly requires processing and managing customers' social and emotional needs, either by manufacturing emotions or concealing genuine feelings (Hoschild, 1979). Across our dataset, we see that the most common form of emotional labor was through conversation with passengers whereby drivers chatted with passengers and attempted to respond to their implicitly or explicitly articulated needs. For example, drivers provided information about their personal lives to help customers feel at ease or provided information about the surrounding environment. Prior work has described how establishing common ground through conversation can be used to decrease uncertainty in new or risky environments (Clark, Herbert & Brennan, Susan, 1991).

One driver described how they participated in attempts to find common ground: "*They might ask me something like, 'Are you married?' So I give 'em a little quick run down. It's like, yeah, 'In my 60s, I've been married for 32 years. I've got kids, grandkids, even have a great-granddaughter.' And, 'Oh, oh,' and then the conversations usually take off that way. But when they ask me, any passenger asks me something like that, I figure they're asking just because they [want to know], 'Okay, are you serial killer or a nice guy,' you know?* (D17)" Although in this case, disclosing one's family status did not seem particularly troubling, one can imagine this might not be the case for all drivers. For instance, a driver might not feel comfortable disclosing political views, sexual orientation, or nationality to passengers but may feel implicit pressure to do so. In this example, the driver talks about their experiences with people with and without disabilities, recognizing there may be some discomfort in getting in a car driven by someone else, and trying to minimize this discomfort by sharing personal information. While one could argue that passengers with vision impairments may rely on these verbal cues to determine whether to trust the driver, we also interpret the use of conversational grounding as an attempt to humanize the ridesharing experience while acknowledging that expectations of personal disclosures can function as a form of emotional labor for some drivers. Prior work with passengers has not explicitly mentioned personal disclosures from the driver as being important, but has found that conversation during the ride is both pleasant for the passenger and expected (Glöss, McGregor, & Brown, 2016).

Although disclosure can be a complex process, particularly for people with "invisible" disabilities (Faucett, Ringland, Cullen, & Hayes, 2017; Shinohara & Wobbrock, 2011), most participants said passengers would disclose if they were blind or had low vision before a trip and indicate that they needed additional assistance, if necessary. D16 recalled one such experience, saying, "*The first time I picked her up, I remember, she actually text me [sic] as I was on my way, saying that she was blind, and she told me exactly where she was at.*" Drivers appreciated this disclosure as it allowed them to better prepare for the ride. For example, D2 said, "*as a driver it would be nice to know ahead of time. However, I get the fact that they wouldn't want to tell us that ahead of time, also. ... There are predators out here and if somebody knew that that was a visually impaired person, they could plan it ... try to figure out some way to take advantage of them.*" Similarly, prior work shows how some people with vision impairments state that a form of identification would be useful in disclosing disability, with others believing that this may make them more vulnerable (Gallagher, Hart, O'Brien, Stevenson, & Jackson, 2011). When a passenger did not provide this information beforehand, drivers used "*the tools [passengers] had with them}*" (D18) or cues, such as dark sunglasses or a guide dog, to identify passengers who may have a vision impairment. Disclosure was most useful at the beginning and end of a trip as prior work has shown that people with vision impairments may need additional help locating the vehicle or getting from the vehicle to their target destination, a concept known as the "last mile problem". However, disclosure before a trip can also be risky for passengers of any protected class (e.g. disability, race) as drivers can discriminate by intentionally cancelling trips at their discretion. For example, D4 said, "*Well, like I mean with Lyft and Uber the driver is being paid by time and distance. I have a feeling, I personally wouldn't do it, but I have a feeling that there's people out there that would take a very circuitous route or drive wherever in order just to make more money...}*." This can be particularly problematic for people with vision impairments who have reported accessibility challenges with navigating ridesharing applications and could find it more difficult to report negative experiences.

We identified another example of this attempt to humanize the ridesharing experience when some drivers described sharing information about the environment with passengers, more broadly. For example, D10 said, "*And then I just try to be friendly and polite and answer questions about the city if I could. If the people from out of town would ask, 'Hey, what's the best barbecue place in town?' Since, you know, that's kind of our thing here, I would say, 'Well, here's where I would go if it were me. Tell your driver to take you to this particular place.' I mean, just nothing out of the ordinary than just trying to be a human being.*" This driver describes their role as a guide, regardless of passenger's abilities, providing recommendations and local knowledge to improve the passenger's visit to that location.

Emotional labor also included sometimes needing to serve as an impromptu social support provider. Similar to the 'stranger on a train' phenomenon (Rubin, 1975) wherein people engage in more honest self-disclosure with strangers whom they don't know and don't expect to meet again, passengers sometimes confided to drivers, such as: "*you just stop and sit and listen and talk them up for a while so they're not so depressed. Or, people who are abused by other people and in a bad situation and nobody's coming to bat for them, and so you sit and try to feed them other points of view and to boost them up so that they can [...] figure out options for themselves. It's like you bond with people, and you just get to be there for them sometimes}*" (D12). In these cases, when drivers noticed that a passenger (sighted or blind/low vision) might be upset about something, they tried to provide an emotional outlet for the person, allowing them to talk openly about what is bothering them, and sometimes offering advice. While prior work refers to how drivers perceive establishing this emotional bond as a burden (Raval & Dourish, 2016), drivers in our study did not seem to view it as such.

Drivers also engaged in less explicit, emotionally-tinged labor that fell outside the scope of their responsibility of getting passengers to their destination. Drivers often worked to assess the comfort of passengers using a variety of cues, regardless of ability. This was commonly done through interpreting body language and then adjusting behavior based on passengers' responses. For example, D18 said, " *you're talking to them, so I guess it's a matter of just reading people and understanding their non-verbal cues as well as the tone of their voice, and how they're speaking and how they're, I guess, sitting and answering any questions they have.*" Similarly D1 said, "*I guess it's just kind of instinctual. I've learned how to read people's body language and conversational stuff. If they're not comfortable, you can kind of hear it. Or you see them tense up, or whatever.*

Typically, if I see something or hear something like that, 'Is there something I can do? Do you want me to take a different route? Do you need more heat, are you cold?' You start asking some questions to see if there's an issue, or if it's just how they are." These two drivers, and others, described a continuous process of assessing expectations during a trip, evaluating patterns of their "backseat audience" over time, and modifying their own behavior to try to make their passengers more comfortable and to feel safer.

Lastly, some drivers discussed other forms of assistance that they provided, either labor outside of the ridesharing context or activities that could be categorized into multiple categories of labor. For example, D2 describes an experience with a passenger with a vision impairment who said, "*'I've just got a few things to move'. He goes, 'would you mind helping me?' I grab boxes. He's carrying boxes. We load them up, take him to his new apartment, and he goes, 'I've got a favor to ask you'. He goes, 'would you help me carry these up the steps?' No problem, I would've done it if he wouldn't have asked, I would've offered. But he asked, and you know, because I generally don't go inside anybody's apartment ever, you know? And he goes, but I've got one more favor. He goes, 'would you let me hold onto your arm, and you walk me around the room so that I can memorize where everything is at?'...We walked around and we got to the thermostat for the heating and cooling. And he goes, 'tell me what each button is for on this'. And then after we went over everything, he repeated it, and he goes, 'do I have it right?' I said, 'yeah, you do.' And he goes, 'okay, I'm all set'}.*" Helping someone carrying objects from the ridesharing vehicle to the target destination may not be considered too far outside of the range of requests a driver might get from a passenger. However, being asked to help the passenger carry boxes, rather than grocery bags, could be beyond a typical work request. Additionally, being asked to assist with object identification in a passenger's home represents a meaningful role transition, from a paid driver to a role more akin to that of an orientation and mobility specialist, for whose job it is to train people with disabilities to navigate their environments safely and independently.

Although these types of requests by people with vision impairments may result in additional emotional labor for drivers, participants like D2 did not express discomfort when describing these experiences. Similarly, D10 said, "*I get a lot of satisfaction in kinda giving back. I think for me, I kinda felt like, I'm helping this individual [with a vision impairment] do something that he wouldn't be able to do otherwise*." In this sense, assisting passengers with a vision impairment seems to move from being a form of labor, with its extrinsic incentives like ratings and payment, to more like an altruistic effort incorporating intrinsic incentives ("I get a lot of satisfaction"). Interestingly, most drivers reported not expecting passengers with a vision impairment to rate them or leave a tip due to accessibility issues in the app, saying that they did not consider either of these as a factor when assisting passengers. A majority of drivers did not see an issue with being asked to perform these additional tasks, and even described it as providing a service to their community.

More broadly, we find that one of the most salient aspects of driving those with vision impairments was the potential to engage in physical labor, which was much less often the case with sighted passengers. We also find that drivers are being asked to participate in forms of labor that may be outside the boundaries of what is expected for their jobs but see intrinsic incentives to engaging in such behavior.

THE ROLE OF TECHNOLOGY

Beyond drivers, some participants with vision impairments heavily relied on mobile applications and services for people with vision impairments to navigate to the correct location. With the advancement of GPS technologies, participants described using applications layered on top of common map services like BlindSquare and Around Me for navigation. Interestingly, few participants (n = 3) described using Aira[1], an augmented reality headset technology that connects people with vision impairments to live agents or "visual interpreters":
"*When I order Uber or Lyft, I can order it through my visual interpreter, and then the visual interpreter knows the name and the car, and they know what the car looks like. So now when the car pulls up, the Uber car, Lyft car, pulls up, because the visual interpreter can see what's in front of me, they can tell me, 'Yes, that's the car. Walk straight ahead, a little to your left is the back door.'...It limits the third party assistance that I would otherwise require.*" Here, P16 described using AIRA to resolve the ride initiation challenge described above.

Similarly, P7 used AIRA in place of asking a family member for assistance saying, "*I think I called my husband and told him that I was coming. But then it was my phone was tied up because I was using my phone with the Aira... I had her stay on till we got to the library so she could assist me from the car to the door...I'm not supposed to fall, so that's why I had her assist me. And it was good 'cause I just walked up the ramp and stuff.*" AIRA helped P7 with finding her target destination and with obstacle navigation. Technologies like AIRA are increasingly being adopted. Similar to systems like VizWiz (Bigham, J. et al., 2010), see observe how participants are receiving help virtually through a trusted strange, but this help is no longer visible while navigating.

These findings show the different forms of labor ridesharing drivers enact and that AVs must also be able to do in order to provide a positive transportation experience. Additionally, it suggests technologies could be used to connect people in vehicles to

[1] http://aira.io

other humans when additional assistance is needed.

Observations

Participants
The research team partnered with the Florida Center for the Blind and researchers at Clemson University to observe how people with vision impairments used Uber, a popular ridesharing service. People were eligible to participate if they were over the age of 18, had a non-corrective vision impairment (e.g. blindness, low vision), and did not have a motor or cognitive impairment that limited their use of a mobile device. We enlisted the Florida Center for the Blind to manage recruitment.
We recruited n=17 participants for the study (ages 20-88, mean = 55 years old). Three participants self-identified as blind and 17 self-identified as having low vision. Forty-one percent of the participants were retirees; 35.3% were unemployed, and 23.6% were employed. When asked about their usual mode of transportation, 41% indicated the use of public transportation (i.e., bus, taxi, shuttle) while the remaining 59% indicated using other forms of passenger vehicles (e.g. rides from family, friends). Many of the participants (41%) had a vision impairments for less than ten years, 35.3% had between 10 to 25 years of vision impairment, and 23.7% had been visually impaired since birth.

Methods
To increase ecological validity and minimize researcher interference, we remotely observed participant's Uber trips to a local park. To do so, a GoPro Hero 7 Black was strapped to each participant via a harness accessory to record the interaction between the participant and the ridesharing driver for data collection and safety purposes. We used a set of hand-held communication devices for communication between the research team and the participants. After participants completed a trip to a pre-defined destination, we interviewed them about their experience with Uber, any challenges they experienced, strategies for overcoming these challenges, positive aspects of their experience, their perception of risk, and how the experience compared to other modes of transportation (e.g., friends, family, public transportation). Interviews were video recorded within 15 minutes of each participant's use of the Uber service. Participants were paid $40 for their time.

Results
From transcribing interview recordings, we see similar themes from interviews with people with vision impairments discussed in the previous section. Namely, we find strategies people used to establish trust, verify their location, disclose their disability, and request assistance from the driver. Participants also report on risk and safety concerns and usability challenges in using the ridesharing application. We describe

these concerns and challenges below.

RISK AND SAFETY: We asked participants about the potential risks in using ridesharing services. The most common risks mentioned in the responses were tied to vehicle identification and the unknown intentions of the driver. For example, P3 said, "*There's people nowadays that uhm they like track the Uber app and they will pose as different cars and like a lot of people, even like people that nor visually impaired or anything, they'll get in the vehicle because they see it's like the same make or model, but it's not their Uber driver. And they will just think it's their car, so they get in and they drive off and then they don't know where they're going or who they go there with*."

The risks mentioned, combined with the participant's visual impairments, are barriers for them to fully trust ridesharing drivers. For example, P7 said, "*Yeah, exactly. You gotta / You know, I gotta get in their car, can't see anything, I don't know what they look like, hope they drive good, and, you know, hopefully take me to the right spot. And I've never had a problem so far, but, you know, could that be that day. Just gotta trust who you're going with.*" Similarly, P17 described location verification challenges saying, "*Well, because uh you don't know where you're going, you can't see where you're going, and you have to have the security of the Uber getting you there safely and to the right place.*"

When asked about their sense of safety being a ridesharing vehicle by themselves, 15 of the 17 passengers said that they felt safe. In their responses, most did not feel scared or have a sense of danger. The lack of fear could be attributed, in part, because of a member of the research team that follows the ridesharing vehicle on each trip; the participants were aware of this. Knowing there was following vehicle may have provided participants with additional assurance of their safety and assurance. Yet, P3 expressed concerns about going to a new place, saying "*I was a little concerned based on his driving, not knowing where he was going, even though he had the GPS. My anxiety was a little high.*" Participant P10 also expressed some initial concern about being in the ridesharing vehicle as it was their first time in one. P10 admitted that they felt more comfortable and safer knowing they had a walkie talkie to contact the research team, and they were being followed by a member of the research team.

Additionally, participants were asked how safe they felt during the ridesharing trip in comparison to their family members. Seven participants (P1, P6, P7, P8, P11, P12, P13) indicated they felt safer with the ridesharing drivers than with family or friends. Many of them alluded to how much safer the ridesharing drivers drove their vehicles compared to their family members. For example, P6 said, "*Actually, I think I felt in some ways a little bit more safe because I know how some of my friends and family drive. You* *know. And the other, like the driver today, he don't know me; I felt like he uhm, you know, he has that responsibility like 'your life is in my hands', so I felt like he's a good driver, he didn't I'd say like, you know, how some people might jerk wheel over here and there. He was a very good driver*."

Yet, five participants (P3, P4, P5, P10, P16) indicated that they would feel safer riding with family and friends than with the ridesharing service. For example, P4 said, "*Maybe I feel a little bit safer uhm with family and friends, but just because I know them. I don't know the Uber driver. But at the same time there wasn't any fear. If I had to pick one, it'd probably be family or friends, just because I know them compared to the Uber driver you don't know. Even though he's uhm doing a service, I mean, you don't really know who you get in the car with.*"

These findings align with prior work and suggest that people with vision impairments may feel more at risk when on a trip to a new or unfamiliar destination. As such, AVs may need to adjust the features that are provided on new routes with passengers with vision impairments.

APPLICATION USABILITY: Future visions of AV use describe similarities to ridesharing services to request a ride. However, we observe challenges to doing so for those who were novice ridesharing or mobile device users. For the four participants (P2, P3, P5, P8) who did not find the application to be accessible, they were either using the application for the very first time or have not used the mobile application in a significant amount of time.

We asked participants about possible areas of improvement for the mobile application; the responses were grouped into three central themes: situational awareness, ride and driver identification, and user experience. Participants indicated that they would like a feature in the application that provides constant updates, through speech or alerts, of where their current location on the route and nearby landmarks. They expressed concerns about not knowing where they are if the driver does not provide trip updates and how constant trip updates would make them feel more confident during the trip. For example, P3 said, "*Saying that like "I'm turning at left on this street" or "turn right on this street", if it was vocally announcing it. 'Cause the way I said, I have usable vision, but if somebody that didn't like they would definitely not. Based on the way he drove and like where he went, the path he took, would not have known where they were.*" Similarly, P4 thought "*periodic alerts from your app letting you know that you're still on the route or, you know, could be helpful*."

Participants also expressed a feature that vocally informs the passenger of the name of the driver and vehicle information such as the license plate number to help them find their ride when it arrives. For example, P11 questioned, "*how would a blind person identify or the tag number, you know, unless they had some type of way. It'd be nice if the app would ding whenever his phone got close to your phone. Kinda like the keyless entry on a car, so that you could identify this is the car that you're supposed to be getting into… so if there's some way that you could have your app ding whenever he got within, you know, ten feet of you or something like that, that way you would know that's the vehicle you're supposed to get into.*"

Generally, most of the suggestions focused on the importance of easier forms of location input. For example, P13 said, "I don't see how I can use it unless I can talk into it, talk to someone, and say I want to go to such-and-such and address. I had an Uber app put on my phone when I got it. I figured in an absolute dire emergency I could get a stranger to punch something in it for me. But I can't do it. And until it gets so you can talk to it, I will not be able to."

These findings show the importance of voice input and output, and suggest AVs for people with vision impairments need to have voice interaction as a default as opposed to visual (e.g. touchscreen) interaction.

Perceptions of Autonomous Vehicles

Design Focus Groups

Below we highlight some our findings, but additional detail can be found in the paper we published (Brewer & Kameswaran, 2018).

Methods

To investigate how to better design accessible voice and tactile systems for people with vision impairments in autonomous vehicles, we conducted design-based focus groups (Brewer, 2018). While interviews can help understand individual driving experiences, conducting focus groups allowed us to better understand consensus (or lack of) of opinions towards the use of autonomous vehicles. Prior work also used a focus group approach (Brinkley, Posadas, Woodward, & Gilbert, 2017), but we focus on differences in levels of autonomy, followed by design ideation sessions with people with vision impairments. Each focus group began with a definition of semi-autonomous and fully autonomous vehicles based on SAE's classification systems (SAE, 2016). Participants were then asked about any prior experiences with driving, perceptions towards these types of vehicles, to compare to other forms of transportation, and any perceived challenges to using the different levels of autonomous vehicles.

To understand how people would envision autonomous vehicles supporting varied levels of control for people with vision impairments, we then followed this traditional focus group discussion with design sessions where participants created artifacts to illustrate their ideas. In the design sessions, participants had access to popsicle sticks, cork stoppers, clay, rubber bands, cotton balls, and pipe cleaners. The session moderator identified each of these objects and explained their placement on the table. Prior work (Sahib, Stockman, Tombros, & Metatla, 2013; Williams, Buehler, Hurst, & Kane, 2015) suggests scenario-based approaches can work well for involving people with vision impairments in design and ideation sessions. Therefore, we presented participants with two scenario-based prompts for which to design solutions to challenges they described in the focus group discussion or challenges identified in previous research (e.g. (Brinkley et al., 2017)).

In the first activity, the researcher asked participants to design an audio or voice-based solution. However, conducting focus groups with sighted people can suffer from one person dominating the discussion (Kidd & Parshall, 2000), and design-based group activities with people vision impairments can be challenging to facilitate discussion in general (Bennett, Shinohara, Blaser, Davidson, & Steele, 2016; Sahib et al., 2013; Williams et al., 2015). Therefore, participants were asked to "act out" their solution with one group member acting as the driver and another acting as the vehicle. In the voice activity in the first focus group, participants were asked to work together and brainstorm how autonomous vehicles could address the safety concerns of a driver. In the second focus group was asked to design a voice solution to help a blind person navigate obstacles in a driver transition request. The groups had different prompts depending on what they focused on in their discussion prior to the design components.

Tactile interfaces for people with vision impairments have potential use cases in other contexts (Kane, Jayant, Wobbrock, & Ladner, 2009; Li, Baudisch, & Hinckley, 2008). Therefore, in the second activity, participants were asked to design a tactile solution to address the challenge in the scenario. All groups were asked to work together to design an artifact they could touch or feel to help a blind driver understand their car's location relative to other vehicles in the driving environment. This activity resulted in the creation of several artifacts participants envisioned as solutions to the design prompt.

Participants

We recruited 15 people (average age = 59 years old, female = 7) for two design focus groups sessions, which lasted between 60-90 minutes. Although many participants were older, there were differences in the level of vision loss (blind vs. low vision) and the age at which participants lost their vision, all signs of diverse experiences in the sample. Four people participated in the first focus group and 11 people participated in the second focus group.

Results

SPECTRUM OF CONTROL: Our findings begin to show nuances in the ways in which participants considered controlling autonomous vehicles based on prior experiences with driving. For example, participants described challenges being passengers in existing vehicles. P13 wanted "*to know the same thing about the locks – where are they, how to get to them*" P5 described "*more concerned about, how, you know some doors, you lock the door and just get out and driver has more control over there so I want to know how to unlock the doors just in case I want to get out*." Although participants also described wanted more control over the air conditioner system and radio, this concern of locks importantly connects concerns of safety to control. Similar to prior work on interpersonal safety of blind people with other sighted people (Branham et al., 2017), our research suggests interpersonal safety can also relate to perceived or desired safety from person to machine.

Lack of experience with driving also affected participant's desired levels of autonomy in an autonomous vehicle. For example, P4 said, "*I wouldn't want to be in a vehicle like that because I know nothing about operating a vehicle anyway so I would have to be in the fully autonomous.*" Similarly, P8, who had never driven before, said, "*I may get behind the wheel and get nervous so you know, the car will say 'you go over to the left' and you're getting ready to make a left-hand turn and turn your signal on. Okay I don't want to get in the position where I forgot my right and left, you know what I'm saying?*"

Unlike prior work, we defined different types of vehicle autonomy for focus group participants, semi- and fully-autonomous, recognizing that autonomy is a spectrum (SAE, 2016). Interestingly, participants agreed that semi-autonomous vehicles, which may require some driver intervention, would be best for people with previous driving experience. P3 said, "*if you've never drove, then a semi won't be for you because you have to know how to drive.*" Further, P14 said, "*if you were made aware that your vehicle was malfunctioning, you should still be able to stop it. You know, if the car starts making erratic motions and people are blowing their horn, you know everything needs a way out and you should at least be able to stop the thing and say 'I'm done.'*" Generally, participants who had driven before, like P14, wanted the option to intervene and control the vehicle. Yet, there were understandably concerns for how to be able to do this as a person with a vision impairment.

Participants in both focus groups struggled to envision themselves, as a person with a vision impairment, operating an autonomous vehicle. P1 said, "*I would think the semi-autonomous vehicle would be like safer than the autonomous vehicle because you know, you would have a person to take over should the system malfunction,*" distancing himself from the person who would be operating the vehicle. This was something the facilitator needed to clarify in both focus groups suggesting that an identity shift may need to happen for people with vision impairments to be envision themselves as not only users of autonomous vehicles, but also ones with agency over the vehicle's' actions.

In summary, findings show how AVs designed for people with vision impairments should account for the diversity of experiences driving, which is affected by the onset of vision loss. Providing a spectrum of control is crucial to designing for such experience.

ACCESSIBILITY METAPHORS FOR DESIGN: The design component of the focus groups confirmed common design approaches for voice-based and tactile systems in autonomous vehicles. Most interestingly, three participants described solutions that were directly inspired by existing assistive technologies and orientation and mobility (O&M) skills including refreshable Braille displays, probing canes, and screen readers. For example, P14 described a tactile solution in which, "*as you're driving with your hands at 10 and 2, you can use your thumbs ...[to] get some type of tactile feeling of what's going on there. So, it'll work kinda like a Refreshable Braille Display that can move up as vehicles are approaching on the left and right.*" Similarly, P2 described a tactile solution for navigating potholes by saying, "*you push this button, then it would go around those potholes, make adjustments. So, the button will be on the dashboard and this little stem will be on the outside tapping as you go along, just like my stick*."

Just as a probing cane or white cane helps people with vision impairments locate and avoid obstacles in their walking environment, a cane-like device for an autonomous vehicle may help people control obstacle avoidance by allowing people to recognize and avoid obstacles in the driving environment.
Sound is also an important sense for people with vision impairments. In response to

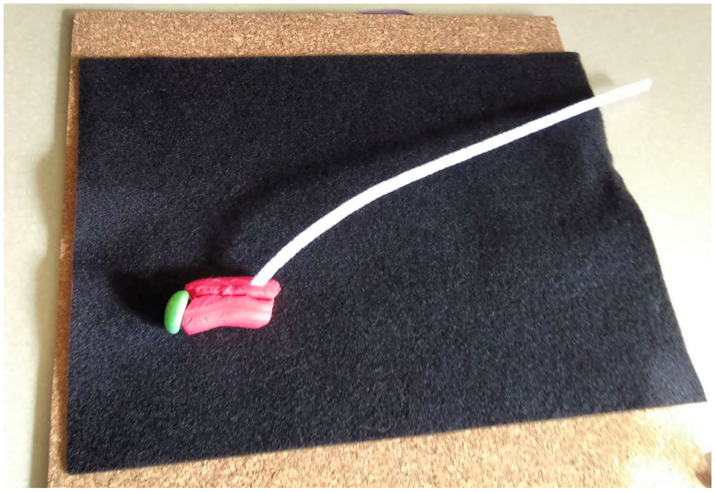


Fig 1 (on left) shows a white cane for a car allowing it to avoid obstacles similar to a white cane people with vision impairments use in their everyday environments. Fig 2 (on right) shows a tactile prototype that can vibrate when there are obstacles near the vehicle.

developing voice or audio-based solutions, participants described systems similar to screen readers and sonar. For example, P3 and P2 began a discussion about voice identification. P3 said, *"Everything in the car would have to talk. Whatever you push, it would need to tell you what you're pushing. It don't matter if it's the radio or cigarette lighter. It would have to tell you what you're pushing. If it don't tell you, you don't know what you're pushing.*"

In response, P2 commented that his solution was "*just like the screen reader*." Beyond voice, P14 considered audio response systems like, "*walking aids to go around with the visually impaired...You would hold [them] up as you walk and as objects came closer...once it became within range, it would beep as you got closer to it...It would beep and it would also let you know a certain direction, so if you held it up and someone walked across that beam, you knew that, at least something was moving there because it's no longer beeping*." Here, he describes a directional sonar-like system for obstacle detection based on a system for blind people.

Beyond assistive technology metaphors, participants also described preferring to interact like they do with other voice interfaces. The following describes how one group presented their voice solution:
P3/driver: "*…Put the key in the ignition. Turn it, now everything is starting to talk.*"
P2/vehicle: "*Ok. Where are we going?*"
P3/driver: "*Ok I'll punch in 1503 Drive Lane. That's a friend's address.*"
P2/vehicle: "*Ok Mr. [P3], we're going to that address you mentioned and we're on our*

way."
P3/driver: "*How is the traffic going to the house?*"
P2/vehicle: "*Ok P3, everything is clear. We're riding smooth.*"
P3/driver: "*Alright. Seatbelt is on. Everything is good. We're driving down the road.*"
P2/vehicle: "*Right. What's your destination? It's that address?*"
This script taken from participants in the first focus group shows how they envisioned being able to interact with an autonomous vehicle using a conversational tone and style, with "*the driver [being able to] tell the car where he's going*" (P6). Moreover, the vehicle would interact with the drivers/riders conversationally. Participants often compared this to how they speak to conversational agents like Siri. For example, P2 said, "*I can ask Siri on the iPhone where I'm at and what's my location and it tells you how to get there with the GPS.*" P2 describes how voice and being able to control the flow of conversation could help with context awareness. Others described how voice may help with driver transitions like P3 who said, "*the car, when you had to take over, it would tell you, you know just like a GPS*." Similarly, P2 mentioned how the voice system could help with context awareness saying, "*just like we have GPS right? You're riding along and it'll tell you what street you on*." Participants overwhelmingly described GPS and Siri as 'model' voice interfaces. And, although we did not gather information on the types of voice interfaces participants use daily, their comments suggest they are familiar with and enjoy the interaction styles of these systems.

These quotes describe participants' expectations for everything in the vehicle to be accessible and controllable by voice, not as a feature like voice assistants are for sighted people, but to be usable. Participants also agreed that voice would be necessary in emergencies. For example, people in the first focus group discussed a scenario where the car's tire comes off and P2 says, "*the car is gonna say 'we're riding on rims.*'" Although participants laughed, they did continue by describing how the car would, at times, need to initiate control over the voice interface, notify the driver of the malfunction, and take steps to resolve the problem by calling a roadside assistance service.

While tactile interactions were presumed to be a major interaction style since people with vision impairments may use Braille, a tactile writing system, it seemed that some participants preferred voice over touch. For example, P3 said, "*say you wanted to be headed east, but for some reason your car is not telling you you're not headed east, if you had …a compass that you can touch and it can tell you, 'We're going east. We're going south. We're going north.' If you could touch it, it can tell you which direction you're headed*." Here, P3 describes how a tactile context awareness tool, a compass, could serve as a backup to if the voice system were to malfunction. When referring touch, most participants described vibration-based solutions.

With clay, P7 built a vibration system in the tactile design activity that would help with obstacle awareness saying, "*the indicators are under your 10:00 and your 2:00 grip and under your left hand and right hands, you got a vehicle on the right, it would vibrate. You got a vehicle on the left, it would vibrate so vibration.*" Similarly, P13 created a vibration system shown in Figure 2 where a "*middle bar right in the middle would beep or do something when something's in your way and then these [other bars] will vibrate or beep and then you will know where the actual object is.*" This concept of 'feeling the obstacles' was present throughout both focus groups with P2 wanting "*a button that you start feeling potholes*". Similarly, P4 described how "*when this car starts, you know, leaning, the rubber [band] will pull it back in place*." In this example, P4 explains how she would be able to feel when the car has corrected itself by touching a rubber band representation of the car on the road. These solutions use direct manipulation for participants to socially construct a representation of their surrounding environment with cars and other obstacles.

These findings describe how participants prioritize voice, vibration, and touch for context awareness.

Findings and Recommendations

This project provides insights as to how people with vision impairments use transportation including their perceptions of autonomous vehicles. Findings from interview, observations, and focus groups suggest the following design recommendations should be followed:

- Connect people with vision impairments to other humans during an AV trip, as it can make the experience more trustworthy, particularly when traveling to a new location
- Design primarily voice-based features to provide environmental awareness cues and provide assistance with entering and exiting the value
- Leverage existing assistive technology metaphors (e.g. screenreaders) to mimic common and familiar interactions patterns within an AV
- Develop ethical approaches to disability disclosure processes in AVs such that people with disabilities are not disadvantaged, yet the information can be used to appropriately customize their transportation experience
- Design a spectrum of interaction patterns for people with vision impairments and other people with disabilities as their desire to use a semi- or fully-autonomous vehicle is largely dependent on the onset of their disability and prior experience driving

Outputs

The following outputs were generated during this project:

1. Brewer, R. N. (2018). Facilitating discussion and shared meaning: Rethinking co-design sessions with people with vision impairments. In *Proceedings of the 12th EAI International Conference on Pervasive Computing Technologies for Healthcare* (pp. 258–262). New York, NY, USA: ACM. https://doi.org/10.1145/3240925.3240981
2. Brewer, R. N., Austin, A. M., & Ellison, N. B. (2019). Stories from the Front Seat : Supporting Accessible Transportation in the Sharing Economy. *PACM HCI*, *3*(1), 1–17. https://doi.org/10.1145/3359197
3. Brewer, R. N., & Kameswaran, V. (2018). Understanding the Power of Control in Autonomous Vehicles for People with Vision Impairment. In *Proceedings of the 20th International ACM SIGACCESS Conference on Computers and Accessibility - ASSETS '18* (pp. 185–197). New York, New York, USA: ACM Press. https://doi.org/10.1145/3234695.3236347
4. Brewer, R. N., & Kameswaran, V. (2019). Understanding Trust, Transportation, and Accessibility through Ridesharing. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems - CHI '19* (pp. 1–11). New York, New York, USA: ACM Press. https://doi.org/10.1145/3290605.3300425

Outcomes

One of the main outcomes of this project was to increase the body of knowledge and safety of the transportation system in several ways, including:

- Increased the understanding of situational awareness challenges for people with vision impairments.
- Increased the understanding of safety concerns of people with vision impairments regarding in-vehicle experiences.
- Showed the ways in which transportation for people with vision impairments is challenging in ridesharing contexts (Brewer and Kameswaran, May 2019).
- Showed the nuances of transportation based on a spectrum of vision loss with perceptions of using an autonomous vehicle differing based on previous experience with driving. People who had prior experience preferred semi-autonomous vehicles and people who had never driven before preferred fully autonomous vehicles (Brewer and Kameswaran, October 2018).
- Novel use of ridesharing as a proxy for understanding autonomous vehicles for blind and low vision people and describe safety challenges in personal vehicles. Our findings show that there is an emphasis on driver, and we describe what makes the driver of ridesharing vehicles a crucial stakeholder in the transportation process.

Impacts

This project impacted our transportation industry by developing several guidelines that will improve the way people with vision impairments will interact and use ridesharing, including automated vehicles. Highlights of the guidelines include:

- Let drivers know, before picking up a passenger, whether they needed additional help due to a vision impairment.
- Implement changes to the ride app that penalizes drivers who use the above information in ethically suspect ways, such as taking a longer route.
- We provide suggestions for alternative forms of in-vehicle spatial awareness such as consider Incorporation of tactile displays with increased spatial awareness and trust.

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