Understanding and Designing for Deaf or Hard of Hearing Drivers on Uber

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ABSTRACT

We used content analysis of in-app driver survey responses, customer support tickets, and tweets, and face-to-face interviews of DHH Uber drivers to better understand the DHH driver experience. Here we describe challenges DHH drivers experience and how they address those difficulties via Uber's accessibility features and their own workarounds. We also identify and discuss design and product opportunities to improve the DHH driver experience on Uber.

CCS CONCEPTS

• **Human-centered computing → Empirical studies in accessibility**; *Accessibility technologies*;

KEYWORDS

Deaf or Hard of hearing drivers, Uber, Communication, Accessibility

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1 INTRODUCTION

Approximately 466 million people worldwide, or over 5% of the world's population, are identify as deaf or hard of hearing (DHH) [1]. In the United States in 2016 [4], roughly 11 million people (3.6% of the total population) reported being DHH. One of the biggest challenges for this population is finding work opportunities due to the limitations that their disabilities pose, and communication is the biggest barrier to work. The term "deaf" generally refers to an individual who has little or no functional hearing, and is formally defined [2] as "lacking the power of hearing or having impaired hearing." Based on the severity of the hearing impairment, four levels of hearing loss are commonly recognized: mild, moderate, severe, and profound. DHH individuals are generally grouped according to both their level of hearing loss and their preferred communication method, usually into one of three categories: (1) hard of hearing–using spoken language with a hearing loss level ranging from mild to severe; (2) deaf–using sign language with a hearing loss level ranging from severe to profound; or (3) deafened–using spoken and sign language. According to the U.S.Bureau of Labor Statistics [3], only about half of the DHH-identifying U.S. population was employed in 2017. While this issue of underemployment for people with hearing disabilities has long been recognized, it still persists today.

But recent years have seen changes in the labor market that could improve conditions for individuals with disabilities. The main change is the considerable expansion of the gig economy. The phrase "gig economy" refers to a current trend in the labor market where businesses contract with independent contractors for temporary work, in which the workers choose when and how much they work. The flexibility the gig economy provides workers is especially beneficial to people with disabilities in that they are able to set their own work schedules based on the conditions of their abilities and their availability. If the gig economy continues to grow, the number of work opportunities for this population may also grow. Uber, Lyft, Airbnb, and TaskRabbit are well-known examples of companies founded on the concept of the gig economy, and the number of individuals working in this sector has increased rapidly since their founding, and the number is still growing. According to a data analysis of Google Trends performed by Harris and Krueger [18], Uber constitutes the largest on-demand gig economy labor market, with 1.5 million active drivers using the platform globally as of 2017 [16].

As many Uber riders know, a number of drivers on Uber's platform are Deaf or Hard of Hearing (DHH). At one point,

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1.1% of drivers globally had activated the Driver app setting that allows them to indicate that they are deaf or hard of hearing. But because use of this setting is optional and because likely not all drivers who use the setting are actually DHH, the exact number of DHH drivers working on the platform is unknown. Interestingly, Uber's internal data suggest that DHH drivers' average number of driving hours is higher than that of similar drivers without disabilities. If we investigate and understand what it is like to be a DHH driver on Uber, how individuals with disabilities use the current accessibility-relevant features provided by the Uber Driver app, and what workarounds they have for challenging tasks, we may be able to improve working opportunities for DHH drivers, and DHH people in general.

In performing this investigation, we adopted a qualitative approach that incorporated two methods: content analysis and interviews. Here we present results from our research, describing the DHH Uber driver experience, accessibility-related challenges DHH drivers have had, how they cope with these challenges, how helpful the current Uber Driver app's accessibility features are, and what future opportunities we may have for improving the experience of DHH drivers.

Research questions:

(1) What is DHH drivers' experience with Uber? What accessibility-related challenges and difficulties do they face?
(2) How do drivers cope with these challenges using the Driver app's accessibility features, or their own workarounds?
(3) What design or feature opportunities exist to improve the DHH driver experience on Uber?

2 BACKGROUND AND RELATED WORKS

Communication and Driving

Depending on their condition and ability, DHH individuals utilize diverse communication methods including sign language, American Sign Language (ASL) interpreters, caption writers, instant messaging, pen-and-paper writing, emails, hand gestures, and hearing aids. Even though there are many methods of communication, it can still be challenging for DHH people to communicate with hearing individuals. This is because hearing people are not usually signers [11], and it is expensive to hire ASL interpreters and real-time caption writers. Additionally, arranging these supports in advance can be inconvenient. Therefore most DHH individuals frequently depend on visual representations of auditory speech, such as writing on paper or texting. In our study, we focused on these challenges as they relate to providing a transportation service using a ridesharing platform.

Communicating with a rider is necessary in the context of providing transportation, even though it is known that communicating while driving may cause distraction. In the case of an app-based ridesharing service, there are even more possible distractions since a driver may be interacting with the app to connect to and communicate with riders. Research indicates that the distraction caused by using a smartphone while driving can be threatening to the driver's and passenger's safety [19]. It may also be difficult and stressful for the driver. Technological interventions, such as more accessibility features for DHH driver, should be considered in order to help create a safe and low-stress driving experience.

Sound Awareness and Notification

DHH individuals' hearing impairment can make it difficult or impossible to use audio cues to understand their surroundings, especially if sound-driven events such as gunfire or a fireworks display are occurring. DHH people's methods of recognizing a sound that is intended to either inform or notify them of some action or event vary according to the level of hearing impairment. For those who have limited hearing ability, cochlear implants and various hearing aids are available to support the individual's hearing ability. However, Deaf people who have no hearing ability depend on other sensory channels such as vision and touch for sound awareness and notification. Much research has been done for the purpose of assisting Deaf people in developing sound awareness. Bragg et al. [9], for example, designed and studied a personalized mobile sound detection application that allows users to record the sounds that are important to them; the application then provides them with visual and tactile notifications. Polzehl et al. [21] also presented a mobile phone application that detects and analyzes audio events and gives users visual and vibration-based cues. Sauro et al. [17] studied the effectiveness of vibrotactile alerts in emergency situations and found that a longer length and temporal on-off pattern of vibration is more effective than a constant and shorter pattern of vibration. Another study considered individuals' ability to detect siren sounds coming from behind them on the road [24]. Mankoff et al. [23] studied and developed the application Scribe4Me, which can provide an audio transcription of the past thirty seconds of sound.

In addition to these research-based examples, there are numerous home-based commercial products that use flashing lights, vibration, pop-up messages, or other methods to notify DHH individuals of the door bell ringing, someone knocking on the door, the phone ringing, or other sounds. Moreover, some individuals carry devices that vibrate when a message arrives or the phone is ringing. According to a study done by Bragg et al. [9], Deaf people would rather receive many notifications than miss a notification. While all these studies and product examples focus on sound detection and notification, little research has been done related to the context of driving, and in particular, the use of a ridesharing platform through which notifications are frequently received

Table 1: Text/content analysis data sources

Data source	Description	Search keywords	Intent/goal
In-app driver satisfaction survey	Simple recurring survey of active drivers; collecting satisfaction and free-text feedback	"deaf", "hearing impairments", and "disability"	Drivers' feedback/suggestions on app features and functionalities
Customer support database	Complaints and support requests made by drivers to Uber	"deaf drivers"	App usage and rider interaction issues, as well as inquiries about application usage, support, and help
Twitter	Tweets made by Uber drivers, Uber riders, and general public	"Uber driver" and "deaf driver"	Communication challenges hearing riders experienced with DHH drivers

and the safety and reaction of the drivers in light of these notifications need to be considered.

Communication Technology

It is usually hard for DHH people to communicate with hearing people using spoken language since most of the time DHH individuals' speech is dysarthic, making it unclear and often incomprehensible to hearing people. Thus, hearing impairment and muteness pose communication barriers. To communicate with hearing people, DHH people use sign language, teletypewriter (TTY), text messaging [26], video relay services (VRS) [5], and facial expressions. However, these methods are often not enough to overcome the communication difficulties DHH individuals experience with hearing people. Many researchers have attempted to mitigate these difficulties by adopting different approaches.

Kanwal et al. [29] prototyped and evaluated a mobile phone application that utilizes speech-to-text and text-to-sign language to visualize the sign language using an avatar and convert the sign language to text. This enables DHH individuals and hearing people to communicate. In the case of group communication, Yi-Hao et al. [25] presented a prototype of a real-time speech recognition interface that features the visualization of speech bubbles via a head mounted - augmented reality display. Elliot et al. [11] conducted a survey-based study that showed that writing on paper, texting, emailing, and using Microsoft Word are technological practices that DHH people currently use in one-on-one or small-group conversation settings, even though these practices are not preferred. The researchers saw the need for a new strategy and suggested Automatic Speech Recognition (ASR) as an option. Yousaf et al [29] also investigated DHH individuals' perceptions of captioning imperfect ASR in one-on-one meetings. Elliot et al. [12] conducted a follow-up study in which they investigated a messaging application that incorporated ASR and assessed its effectiveness for communication between a DHH individual (typing) and a hearing individual (speech and ASR). Their study showed the merits of using ASR and indicated satisfaction with this method among study participants.

However, the specific contexts considered by the aforementioned researchers are the workplace and learning environments. Little research has been done on the communication challenges occurring in the transportation service-based driving context where communication between a driver and rider is sometimes necessary. This context merits the DHH research community's attention, since the number of DHH drivers participating in ridesharing platforms seems to be growing.

3 STUDY DESIGN

In the present study, we used two qualitative methods: text and content analysis and semi-structured open-ended interviews. We relied on several data sources including the in-house customer support database that houses data collected from DHH drivers and customers who rode with DHH drivers, in-app survey data about driver sentiment, and data harvested from online and social networking communities such as forums, articles, and Twitter. In addition to performing a text/content analysis, we conducted semi-structured in-lab interviews with five DHH drivers. Each interview was comprised of foundational research questions and applied research questions. Additionally, a journey map was used to guide the DHH driver interviewees in discussing each stage of a trip that they make with a rider.

Data Collection

Text/Content Analysis Study. The Uber Driver app regularly solicits both quantitative sentiment data and open-ended comment feedback from drivers through an automated in-app survey. To complement this data, we also extracted data from the customer support database in which incidents between customers (both a driver and a rider) are logged, tracked, and stored by the customer support team. Finally,

Table 2: Participant Demographics

ID	Gender	Age	Preferred communication method	ASL proficiency (self-report)	Trips completed on Uber	Average hrs/week driving on Uber
P1	M	40-49	ASL	Very good	501-1,000	21-30
P2	M	40-49	Writing/typing	Good	10,000+	41+
P3	M	20-29	ASL	Very good	3,001-4,000	21-30
P4	M	30-39	ASL	Very good	1,001-2,000	11-20
P5	M	30-39	ASL	N/A	10,000+	N/A

we also collected data on riders' experiences with DHH drivers, as expressed on Twitter. By examining data from both drivers and riders, we were able to understand the challenges of DHH drivers on Uber from multiple perspectives. After filtering the resulting tweets for relevancy, we analyzed 230 tweets from riders. Table 1 contains more details about our data sources and collection.

User Interview Study.

Participants. We recruited five male DHH drivers (Table 2) who drive in the San Francisco area for the interview portion of the study. Participants ranged in age from 25 to 44. The participants were identified by using the DHH driver notification feature in the driver's application, which a DHH driver can turn on or off. Those who indicated that they were DHH drivers were emailed a screening survey that inquired about whether they had been diagnosed as Deaf or Hard of Hearing and whether they were proficient with ASL. If an individual answered "yes" to both of these questions, we invited the driver to participate in the study's interview portion. We conducted an hour-long interview session with each participant, and compensated them for their time. We also hired a total of four ASL interpreters for the interviews, paying each by the hour.

Procedure. Each DHH driver participant and two ASL interpreters were guided to an office where the interview was conducted by two researchers. One researcher led the first phase of the interview during which the foundational research questions were asked. The other researcher led the second phase of the interview, which consisted of the applied research questions. This researcher also facilitated the overall interview process while asking additional questions and taking notes. There was also a third researcher present in the room taking notes. The seat arrangements were selected to facilitate the best visibility and communication between the DHH driver participant and the two ASL interpreters, and also between the participant and the researchers. Each interview session was audio- and video-recorded with the DHH participant's permission.

Journey Map. We utilized a journey map, an artifact that visualizes the entire process of a user's experience with a particular product or service [27], as a facilitator and stimulus for our interview study. During the interview session, we used a blank journey map representing the typical Uber drive to systematically investigate each stage of an Uber trip with the DHH driver participant. Our blank journey map was composed of a horizontal axis representing all phases of the trip, including the pre-trip, pick-up, on-trip, and end-trip phases, as well as a vertical axis indicating the empathetic elements and key components of doing, thinking, feeling, pain points, workarounds, and opportunities. This skeleton of the journey map was used to help the DHH driver easily think and reflect on his driving experience during each phase of the trip. The researcher recorded on a sticky note a short description of each phase of the journey, as related by the DHH driver, and placed each note in the corresponding location on the journey map. This approach allowed us to fill out the journey map with the participant and visualize the participant's emotional state throughout the interview process.

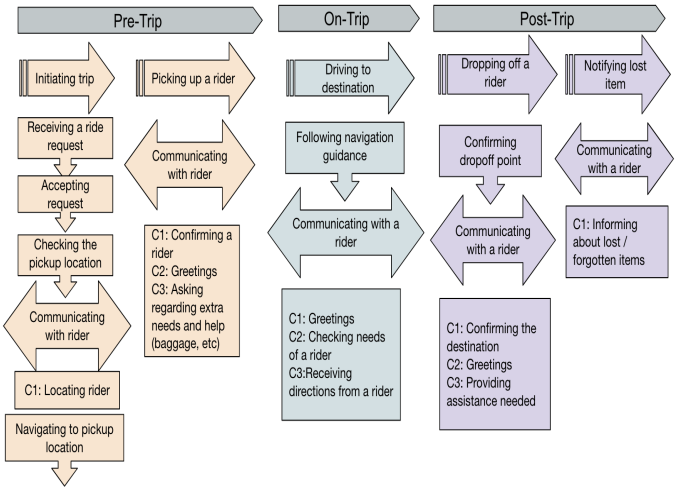


Figure 1: Picture of trip journey diagram

Data Analysis

Before performing the text data analysis, we developed and constructed a diagram (Figure 1) of the entire trip using a sequential temporal tasks segmentation approach. With this approach, we were able to visualize the overarching dynamic process of the trip, including the tasks required to be completed sequentially for each process. We were also able to visualize the communication phases involving either the application or a rider, as well as the phases' purposes. Finally, we were able to identify and locate stages during which the DHH drivers and riders talked the most and prioritize the issues to be addressed.

Content Analysis. The diagram allowed us to lay out a high level code and category that helped us to classify the text we looked at and identify what it is associated with. These high level categories were developed according to whether the text is related to communication with the app or with the rider, the location where the communication happens, and what specific tasks the communication required. We started with the DHH driver sentiment survey data, moved to the Twitter dataset next, and finished with the customer support dataset. From each data collection, we read the text and put it under the corresponding category. While we were sorting and grouping the data, we interpreted and developed themes by discussing amongst the researchers. During sorting and grouping, we identified new codes which were developed into a new theme and added to the collection. We reorganized and synthesized themes identified by priority in regard to the significance of each of the themes.

Interview Data Analysis. We used the thematic analysis approach [10] for the interview data analysis. First, we developed a deductive coding framework (e.g., difficulty in noticing ride request) from the themes identified from the secondary data content analysis. Then, additional codes (e.g., non-stop vision attention on the phone) were inductively extracted from an iterative coding process performed on the primary interview data. After collating codes from both data sources, we identified and developed the overarching themes presented in the findings section.

4 FINDINGS

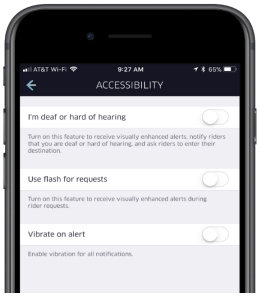
Based on our investigation, we identified the following three challenges facing DHH drivers: (1) concerns about missing ride requests on the app, (2) concerns about informing riders of their hearing disabilities, and (3) communication difficulties with riders throughout the various stages of the trip. Our triangulation approach using datasets collected via various methodologies validated and strengthened our findings. The key findings from the text content analysis and the interviews are consistent. We present these key findings by focusing on two types of interaction that a typical DHH driver has: one with the driver app and the other with the hearing rider and with following the trip stages. The details of the findings as well as the suggestions from the DHH drivers are reported in the rest of this section.

The findings we present here are the result of ranking all issues that came out of the analysis process described above based on prevalence and severity, then selecting the top ones. The basis for ranking included objective criteria (how many times each issue was mentioned) and subjective criteria (the judged overall impact to the Uber driving experience, the emotional expressions of participants reporting their experience, and the number and quality of workarounds available to address the issue). While desirable, more precise ranking would likely be misleading given the small number of interview participants and complexity of judging impact of single issues to the overall driver experience.

Concerns about Missing Dispatch Requests

The trip journey starts with receiving and accepting a dispatch request. Receiving all available dispatch requests is important since it directly affects the driver's earnings. It seems like noticing the request is not a difficult task and thus it should not be something to worry about. However, our DHH driver interviewees expressed that it was a major concern. The hearing drivers mostly notice dispatch requests via a sound notification. However, because of their hearing difficulty, DHH drivers cannot use the sound notification feature and need a different way to receive the notification. Targeting this problem, Uber implemented a visual cue-based notification feature that is a flashing light (Figure 2a). When a ride request appears in the app, the app flashes brightly in addition to emitting a sound, thereby aiming to attract the attention of DHH drivers easily and quickly. This is one of Uber's accessibility features that has enabled DHH people to

(a) In the Uber Driver app, the incoming ride request screen flashes brightly when the in-app DHH option is on



(b) DHH Driver can indicate their DHH status in the app, which triggers several accessibility-related features.

Figure 2: Accessibility features for DHH drivers

access the ridesharing platform, and our interviewees said that it undoubtedly helps them in receiving the ride requests.

Despite the presence of this feature, DHH drivers are worried about the possibility of missing dispatch requests and express continued difficulty with noticing the requests. We identified two problems during the interviews. One is that the flashing light feature is not noticeable enough to the DHH drivers. They described certain situations in which the feature is not as effective as usual. One of the situations is when the sunlight is too bright for the flashing to be visible to them. Another situation is when the DHH driver receives the notification while on a trip with a passenger in the car. One DHH driver said, *"Flash for next new rider request before drop off a rider. Why I got missing rider's request while I traveling for a rider? It's not easy for Deaf driver to get attention."*

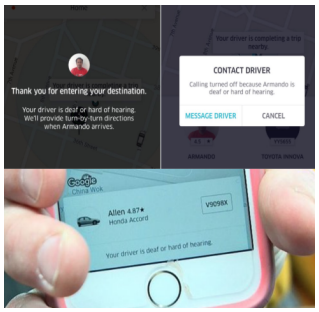
The other problem is that there is only one notification channel available for DHH drivers to use. Hearing drivers have the possibility of using both sound and visual notification channels. However, this is not the case for the DHH drivers; the visual cue is the only option given. Consequently, to avoid missing dispatch requests, the DHH drivers pay extra attention to the app notification. A lengthy period of sustained visual attention directed toward the phone easily causes unavoidable eye fatigue since vision is the only channel available for receiving the dispatch requests. DHH driver P5 said *"Feeling like my eyes glue to the phone, hearing driver hears the sound. I want to enjoy looking at surroundings."* In addition, we learned that this limited option creates more problems when receiving out-of-car dispatch requests that require the driver to help passengers outside of the car. To manage this kind of situation and still receive requests, the DHH drivers said they carried their phones with them. DHH driver P1 said *"I need to carry the phone with me and hold it one hand and help the passenger with the other hand."*

Some Drivers Anxious/Worried about Telling the Riders They are Deaf

Initiating communication with riders about one's hearing disability is not an easy task. It is even harder if a driver needs to do this every time he or she has a new rider. As a solution to this specific problem, Uber implemented the notification feature and added it to the accessibility page in the app for DHH drivers (Figure 2b). It can be turned on and off at the driver's discretion. With this feature turned on, the rider is notified on the app with the message, "Your driver is deaf or hard of hearing. " This feature helps the DHH drivers by relieving some of the stress of having to communicate this impairment to each new rider by themselves.

In spite of the feature's benefits, not all DHH drivers turn it on. The DHH driver interviewees expressed that they are anxious about letting hearing riders know ahead of time that they are deaf or hard of hearing. On one hand, they are well aware of the benefits of letting the riders know with regards to alleviating communication difficulties; on the other hand, notifying riders beforehand about a hearing impairment and acknowledging that texting is the main communication channel could cause a trip cancellation. The DHH drivers who were worried about this issue said that they choose to let riders know when they enter the car. DHH driver P1 said *"I rather them in the car and let them know. I am afraid that texting makes them cancel on me."* As a workaround for this notification issue, the DHH drivers write a note indicating their hearing difficulties and place it on the back of the seat or make a hard copy of it and ensure it is easily visible to hearing riders (Figure 3b).

However, we learned that this may introduce another problem–riders' low ratings. DHH drivers are concerned about this issue because it could affect their eligibility to drive for Uber, which is important to be mindful of. One DHH driver said, *"About the rating issue . . . it makes me disappointed that my ratings sometimes being dropped because sometimes the passengers want to call me which I can't and I'm deaf."* We found that this is a concern not only for those who do not use the feature, but also for those who turn it on and let hearing riders know through the app in advance. A rider tweeted, *"Though my Uber driver ignored me so I gave him no tip and when I got home I went to give him 0 stars and it said he was deaf"*. The complicated and uncertain consequences associated with notifying riders about a hearing impairment seem to cause anxiety among drivers when it comes to informing their riders. In addition, the drivers' need to deal with this issue and to tell riders repeatedly over a lengthy period time seems to frustrate them. P2 said *"Most time it is ok to let the rider know that I am deaf but it is still kind of annoying, I have to tell them I am deaf, I am deaf, and I am deaf."*



(a) Riders matched with drivers who have the DHH setting on see several notifications that their driver is DHH

(b) Many DHH drivers use in-car signs to indicate their status and their preferred workaround.

Figure 3: Notifications about DHH drivers to riders

Communication is By Far the Most Difficult Part of the DHH Driver Experience

The pre-trip to on-trip stages present the most communication-related challenges for DHH drivers. Communication is needed during the pre-trip and on-trip stages.

Pre-Trip Communication. During the pre-trip stage of any ridesharing service, communication between a DHH driver and rider is needed for the following tasks: finding a pick-up location and confirming a rider's request. This communication difficulty among the DHH community is well-acknowledged, as DHH drivers' communication methods are limited to non-verbal expressions such as ASL and written language. This communication barrier becomes more challenging when driving, a process during which people need to operate and control a vehicle and thus find it hard to have their hands free for engaging in such communication. It becomes even more problematic for DHH people who drive for a transportation service in which texting is the major communication method for drivers picking up mostly hearing passengers who do not know about ASL. However, texting while operating a vehicle is not just hard; it is also considered to be too dangerous to be allowed while driving.

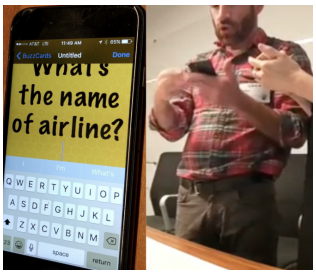
These are the issues facing Uber DHH drivers as well. Establishing a common ground for communication with hearing riders by conveying that texting should be the main method of the communication and communicating with the riders via texting while operating a car are the two main problems. Recognizing the former challenge, Uber provides an accessibility feature that serves as a solution. Turning on the DHH driver notification option presented in the previous section automatically disables the phone call functionality and sets texting as the main line of communication (Figure 3a). The DHH driver notification sent to a rider to inform him or her about the driver's hearing disability also lets the rider know that the communication method will not be spoken language; rather, texting will be the primary way to talk with the driver.

Our study shows that these accessibility features are helpful and effective in initiating texting as the main communication method. Only some drivers, however, use the feature. Drivers who do not use the notification feature due to its disadvantages handle these situations by themselves and use their own workarounds to communicate with hearing riders. Two of our interviewees indicated that they used the iPhone messaging app iMessage, which includes features such as preset messages, autocorrect, suggestions, and emojis. DHH driver P4 shared that he typically uses the preset message options provided in iMessage for responding to riders' phone calls. He said that he usually selects the message, "I'm on my way," whenever a rider calls him. Another driver, DHH driver P3, said that he just types "WHE" and then selects "WHERE" from the suggestions. *"I type a few word and then I picked the one that I want from the suggested ones."*

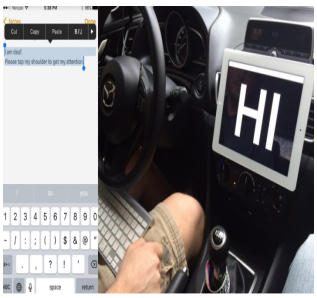
Despite the Uber feature and the drivers' workarounds, the interviewees said that some riders still make phone calls and do not respond to text messages. It seems that some riders do not realize that their drivers identify as Deaf or hard of hearing, even though they are notified of this ahead of time. Others do not immediately recognize that texting should be used for communicating with a DHH driver, even if they have learned ahead of time about their drivers' hearing impairment. Consequently, they keep calling the DHH drivers to coordinate their pick-up locations. DHH driver P2 said, *"Rider's calling, calling, and calling, and I was like "Hey, I am deaf, I am deaf, and I am deaf"*. DHH driver P1 similarly said, *"I hung up and text right back, "I am on my way" then the same rider called me again, and I texted him again. The third time the same rider called me again, and I finally needed to pull over the car, texted him again, saying, "I am on my way and I am deaf." Then they say Oh, OK."*

On top of conveying that texting is the main communication method, DHH drivers find it difficult to text while operating their vehicles. Talking on the phone while driving is not recommended for safety reasons. Texting is even more dangerous to do while driving. That texting is the only available method for the DHH drivers to converse with the riders makes the situation worse. This is especially the case when a driver is trying to find a legal pick-up location or confirm that he or she has picked up the correct rider in a very busy and crowded area. The interviewees described these particular scenarios as pain points in which efficient and timely communication is needed. Otherwise, they may result in a parking violation or a trip cancellation, both of which are costly. DHH driver P3 said, *"In city, this stage is more stressful for me than after or before, the fine and ticket is* 150*or*200*, that is challenging."* The driver P4 shared a similarly unhappy experience, recalling, *"I am sorry. I am not able to. It is intersection of Townsend and Fourth, I got tickets twice. I learned the lesson hard way. I make a decision to cancel if the rider is not willing to cancel the ride."* The driver P3 remembered that he had once picked up the wrong rider. When the correct rider called him, he needed to return to the original location.

This can lead to a stressful and frustrated experience for the drivers; however, there is not much they can do. They said they use the time that they are stopped at traffic lights to respond to riders. For more urgent situations, they find a place in which they can pull over their cars and communicate with riders via texting. This, though, could cause a delay in both responding and picking up a rider. This untimely communication could result in a rider's cancellation or a poor rating. DHH driver P2 said, *"The rider gets upset, but I can't do that while I am driving, my biggest concern is cancellation."*



(a) BuzzCard smartphone app used by one participant for in-car communication with riders



(b) Examples of device-based in-car communication methods used by DHH drivers

Figure 4: Various On-trip in-car communication methods

Another DHH driver said on Twitter, *"I am deaf. Have hard time to reach riders . . . hard time text messages during drive."*

Meanwhile, a rider tweeted, *"my deaf driver just drove past me as I shouted at him."*

To identify and confirm that they are meeting the correct riders, DHH drivers may employ a workaround such as calling the riders'phones.

On-Trip Communication: In-car Communication. We found that during the on-trip stage, as in the pre-trip stage, communicating with riders is the major challenge facing DHH drivers. The difference is that in the on-trip stage, these challenges are even more severe, since the driver and the rider are now in the same space and must interact directly. In the case of face-to-face communication, the more communication opportunities that are created, the more a particular form of conversation is expected, as are prompter and more timely responses and reactions. Facial expressions and hand gestures can help facilitate the communication. All of these seem to increase the challenge facing DHH drivers. We identified the following three typical situations in which specific in-car communication is needed: (1) coordinating directions to the destination if the rider has different directions than those provided by the app; 2) seeking to understand the needs and conditions of the riders and accommodate their needs; and (3) having casual conversation.

It is difficult for the DHH driver to communicate with a hearing rider in these cases, especially since texting is the primary method of communication. The driver needs to concentrate on the navigational guidance provided by the app and pay attention to the road for safe driving. DHH driver P2 said, *"I need to focus on driving, I ignore rider's talking and asking. Sometimes they get mad and I ignore and stay quiet."* Three threads by hearing riders on Twitter show how difficult it is to communicate with DHH drivers. One rider on Twitter said, *"My deaf driver dropped me off at the wrong house because he couldn't hear the directions I was giving him."* Another hearing rider on Twitter noted, *"my driver is deaf and this is by far the most difficult situation I ever had to give directions."* Still another driver expressed, *"Couldn't even tell my Uber driver not to go that way because he's deaf."* Our DHH driver interviewees said that because of the speed at which the car is moving, it is impossible and dangerous to text while driving, respond punctually to the rider's request, and take appropriate action to fulfill the request on time. DHH driver P4 said, *"If my rider wants to change the drop off location and asks me to stop at changed location, I pull over the car to communicate."*. It is hard and unsafe to make an abrupt lane change when one is unsure of the exact drop-off location or is responding to a sudden request made by a hearing rider. DHH driver P1 said, *"Wishes the app would be more specific about left side and right side. It would reduce communication burden."* The interviewees also described the following cases in which driving becomes harder and less safe: a rider handing over his or her phone with a typed message; a rider nudging or tapping the driver's shoulders, causing the driver to respond and turn around frequently; and a rider who wishes to exchange texts with the driver while in the car. One of our DHH driver interviewees indicated that the situation becomes more difficult in the case of UberPool, where communication occurs with multiple riders.

Currently there are no in-app features that support DHH drivers in these situations. However, some interviewees shared the workarounds they use to cope with these challenges. Driver P1 said he uses BuzzCards (Figure 4a) and a Bluetooth keyboard to communicate with passengers. He showed the researchers this application and said, *"I like it a lot because it is with yellow background with black text."* BuzzCard is an assistive technology developed specifically to aid DHH people in communicating with those who do not use sign language. DHH people type the words and show their conversation partners.

An assistive app that was introduced to the researchers by interviewee P4 was voice recognition app Ava. The interviewee expressed his feelings of isolation and his curiosity about what passengers are talking about while in the car. He said, *"If I use Ava app, I can hear what the passenger saying . . . it would be cool!"*

We found that notes, an iPad, and a Bluetooth keyboard are commonly used for in-car communication (Figure 4b). Interviewee P3 said using a keyboard and iPad makes complicated communication better and easier. P1 said that a Bluetooth keyboard makes typing easier.

5 DISCUSSION AND DESIGN IMPLICATIONS

Incoming Trip Requests

In the Findings section, we reported two problems connected to the Driver app's incoming trip request screen that caused DHH drivers to worry about missing trip requests. The interviewees stressed that DHH people mostly depend on their vision. However, during the daytime when the sunlight is bright, the flashing light on that screen is less noticeable to DHH drivers. Moreover, the visual workload of the DHH driver becomes heavier in driving situations, which require lots of visual attention. The need to pay attention to both the road and the navigation guidance takes up most of a driver's visual capacity, which makes concentrating on the dispatch request harder and may result in them missing a notification. To improve visibility, the interviewees suggested making the flashing light stronger and making the request screen font size bigger and bolder. Interviewees also suggested making the request last longer, and to include a text message along with the in-app notification.

The app notification is the only way for a DHH driver to receive a dispatch request. Since DHH drivers must use vision to notice incoming requests, they have to pay extra attention to the app. This leads to other problems, such as eye fatigue and the feeling that they need to carry their phone with them whenever they leave the car to help passengers with luggage or other issues, to make sure they don't miss a request. This may make for a cumbersome and stressful workload.

One suggestion that one interviewee made was to add a secondary notification to the visual notification. The driver showed the researchers Ditto, a Bluetooth notification system for smartphones that physically vibrates a worn or carried device whenever the smartphone would make an audible noise. He showed the app to the researchers on his phone and said, *"I stop by airport and I open up the door, you know go to back of my car for any reason If I have to leave for a moment . . . I don't want to carry my phone around with me when I leave the car . . . something like this would be huge benefit for deaf drivers."* This practical example of a driver using a vibration notification device to learn if the phone is ringing suggests a potential design solution. In theory, if the Driver app were able to provide both visual and haptic notifications in cases like the request screen, more DHH drivers would be able to notice incoming trip requests. This would not only help the driver to avoid missing trips, but it could also lessen the driver's cognitive load, reducing his or her stress. According to multiple resource theory proposed by Wickens [28], humans are able to process information from multiple sensory sources simultaneously. The benefits of using information from multiple sources have been well-studied [7, 13, 22]. The research showed that doing so facilitates perceptual information processing and enhances reaction time if actions are taken. These research findings, in addition to our driver's example, suggest the potential benefits of incorporating haptic output into a notification feature. We will investigate its effectiveness and requirements in future work.

Communicating Hearing Status to Riders

Our findings show that, for DHH drivers, communicating their hearing status to riders is not as simple as it seems. Many people do not like to reveal to others that they have a disability for fear of discrimination and stereotypes about their ability to perform certain tasks. It has been often debated whether DHH individuals can drive safely, but notable, many states allowed DHH people to obtain driver's licenses in 2013. Though DHH drivers on Uber are not obligated by law to disclose their hearing impairment to riders, many feel they must do so to communicate effectively with them. They often need to establish a communication method other than spoken language to be used during the trip, such as texting ahead of the pickup moment. This way, the riders are prepared for a different type of interaction and communication with their driver. It also prevents DHH drivers from dealing with all the difficulties caused by their riders' not knowing about their hearing difficulty in advance, making the trip smoother and more satisfying for both.

As we reported in the Findings section, some DDH drivers on Uber do not mind informing riders about their deafness, but others do. Several drivers chose to use the in-app DHH notification feature to let the app automatically notify the riders ahead of time about their hearing status, but they worried that riders would cancel over concerns about the DHH driver's ability, or in frustration at not being able to call the driver. However, these drivers seem to accept the possibility of the rider cancelling their trip, preferring that risk to having to repeatedly tell the riders themselves.

In contrast, drivers who chose not to use the feature and to instead let riders know themselves in order to minimize trip cancellations have to take extra steps to notify the rider manually. To some drivers, the need to take these steps on every ride can be annoying or feel like a hassle. Some who preferred telling riders once they get in the car worried that the rider might be uncomfortable at not being notified in advance, or at being put in an unexpected situation.

These findings imply that there is lack of genuine understanding among hearing people about the ability of DHH people [11], which may be one of the main reasons for trip cancellation. They also show that it is an emotional burden for DHH drivers to repeatedly identify themselves as having a disability. These issues suggest an opportunity for an in-app feature that helps riders learn about and better understand their drivers' hearing disability. Providing a rider with

details about a driver, such as his or her good reviews, ratings, and completed trips along with the DHH driver notification might be a good way to show the rider that the driver can be trusted. This could change riders' perceptions of DHH people's driving ability, and lessen the burden on drivers to inform riders about their hearing difficulty. Another opportunity to improve the already existing DHH notification would be to include more information on why the notification is being shown, or to show the notification closer to the moment of pickup or even when the rider gets into the DHH driver's car. Finally, another interviewee suggested not automatically dismissing the notification after some time, and instead leaving it until the rider manually dismisses it.

Pre-trip and On-trip Communication

During both the pre-trip and on-trip stages, our research shows that the biggest challenge DHH drivers face is communicating with riders using only texting. Communication in the two stages is meaningfully different, however, since pre-trip communication is remote and on-trip communication is co-located, which affords additional communication methods. To make pre-trip text-based communication easier and better, the interviewees suggested having pre-set messages available to send to the rider with just a tap, or using adding more autocomplete-like functionality so that complete suggestions could be provided by the app after the driver enters only a few initial words. Some drivers also suggested adding VRS functionality to the app. VRS functions as a communication assistant between a deaf VRS user and a voice telephone user through video-based human intermediary. One interviewee said, *"I would prefer using VRS over texting; it is much easier."* Despite the advantages of this method, it may not be a good option for DHH drivers on Uber since VRS typically includes a service fee, and also due to limitations on both the number of people who can use it at one time and network signal quality.

One way to improve pre-trip communication would be the in-app messaging feature we introduced and described to the DHH driver interviewees. This feature would bring native driver-rider texting into the Driver app instead of sending the driver to a third-party texting app to communicate with the rider pre-trip. The benefit of a native texting solution is that it can be customized and enhanced for the needs of users who are driving, whether they're DHH or hearing. For example, it could include frequently used or pre-set messages (or even simple emojis) that drivers could easily send with one tap. It could also be designed to be maximally usable for the in-car context, so that the text could be large and appear in the best possible screen location for the driving scenario instead of appearing via whatever method the phone's default texting app uses. One of the interviewees mentioned that a feature like the one we showed him would make him feel more connected to his riders. Deploying such a feature would tell us much about how to improve communication between DHH drivers and riders.

Another way to improve driver-rider communication would be to reduce the need for direct text-based conversation. This could be done by making the app handle more of the task so that less communication is needed. During the pre-trip stage, for example, the Rider app could guide the rider to an easy, legal pick-up location. Additionally, the Driver app could show more details about how to identify the rider via a photo or a text description of them, though of course such a feature would need to respect riders' privacy.

The communication occurring during the on-trip stage is different from that of the pre-trip stage in that more communication methods are available since the driver and rider are co-located. We found that the current way of communicating does not seem to accommodate situations in which the rider wishes to give the DHH driver navigational guidance that is different from the instruction provided via the Driver app. This is a difficult communication scenario in which the drivers said they often have no choice but to ignore the rider's requests. One interviewee said, *"How do we do that strategically to communicate with riders? It gets awkward really fast and I just want to resolve those types of situations."* Another interviewee expressed difficulty with carrying on a conversation and implied that he struggled with different conversation scenarios, saying, *"Complicated question, dumb question, smart question, the automated responses are not enough."* One suggestion made by the interviewee was to allow the rider to modify the exact navigation path in their Rider app during the trip so that the changes would reflect in the Driver app in real-time. In addition, providing more detailed navigational guidance, such as whether the drop-off location is on the left or right side of the street, would reduce the need (and stress) for DHH drivers and their riders to communicate in the car.

Notably, these communication challenges are exacerbated in the case of UberPool, which is an option that allows a rider to be matched and travel with other riders whose destinations are in the vicinity of the rider's own. This situation requires more complex communication with multiple participants, making for a more complicated and stressful experience. This is an issue that we will consider in future research.

Interestingly, we found that communication needs related to adjusting the car's temperature, turning on or off the music or the radio, and providing a phone charger are not as challenging as we anticipated. Interviewees told us that they use hand gestures most of the time in such cases and that doing so has been an effective way for them to communicate with the riders. One interviewee said, *"Most time, with hand gestures and face expression, I understand the riders and riders*

understand me." Body language is an information-dense and effective communication channel for human-to-human, face-to-face conversation [6], and it seems that it remains so in a ridesharing context.

Another opportunity to improve the driving experience for DHH drivers would be to help them feel more connected to riders in the car. One researcher commented that hearing impairment is a kind of disability that makes a person feel isolated from the world [20]. Overhearing others' conversations and other sounds in their environment helps people behave and communicate more effectively. One could imagine the Driver app including some automatic voice recognition and transcription feature similar to the Ava app mentioned above. Such a feature might help DHH drivers feel more connected to their riders, and also help them be more effective as drivers.

The new trend in human-computer interaction is speech-controlled interfaced interaction. Amazon Echo and Apple's Siri are well-known examples of voice input and output interaction, and ASR is the main technology enabling the interaction. We see the speech-controlled interaction of a DHH driver and the driver's app as having the potential to improve the driving experience as well as make a positive impact on driver safety. However, because the recognition of Deaf speech using ASR is difficult, since the data is trained based on hearing individuals' speech, this new way of interaction does not seem accessible to DHH people. However, researchers [14, 15] have begun analyzing the problem and have investigated the feasibility of improving the recognition of Deaf speech through ASR and iterative crowdsourcing workflows. Bigham et al. [8] proposed two possible technical approaches: human-powered crowd sourcing workflows and making mobile speak for the DHH individual. In the future, we will investigate the conversational interaction interface technology specifically for our DHH drivers with examining how it provides the interface that helps the DHH drivers to have proper conversation interaction for different situations and tasks.

Limitation

One limitation of our research is that it doesn't include in-context behavioral data, which could be gathered by accompanying and observing our participants as they complete real Uber rides. While this directly-gathered data would likely be valuable, we decided against this approach due to 1) concerns about the impact to driver/rider safety by having a third party in the car, which is already an attention-demanding environment for the driver, 2) logistical challenges with having a researcher and interpreter suitably positioned in sometimes small vehicles along with the driver and rider(s), and 3) concerns about rider privacy, consent, and perception since most Uber riders expect an empty car and may be concerned if unexpected passengers were present during their ride. Given that extensive internal research conducted with Uber drivers has shown their retrospectively-given data to be valid and insightful, we fell back on a more conservative approach: secondary content analysis to discover a broad set of perspectives and possible themes, which shaped subsequent deep interviews with a small number of DHH drivers to discover the nuance and complexity of their experience. Future research that avoids these concerns about driver and rider well-being can improve on the current work, though, since in-context research methods can often raise insights not gathered through retrospective methods.

6 CONCLUSION

The rise of the gig economy and its accompanying flexibility and autonomy create new work opportunities for people who live with disabilities. This research with DHH drivers on the Uber ridesharing platform reflects the potential for positive impact in this regard. To strengthen and improve upon this positive trend, we investigated DHH drivers' difficulties in communicating with riders and informing riders about their hearing impairment, as well as their concerns regarding missing ride dispatch requests or experiencing trip cancellations. The DHH drivers manage these challenges using several accessibility features built into the Driver app, as well as their own diverse set of independently-developed workarounds. But our findings also indicate many design and product opportunities to augment DHH drivers' abilities in the ridesharing context. Identifying these opportunities and acting on them could not only enhance the emotional and cognitive experience of driving for DHH people, but also could benefit riders and Uber alike.

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