Improving Accessibility of Fully Automated Driving Systems for Blind and Low Vision Riders

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Abstract

For people who are blind or have low vision (BLV), physical barriers and negative experiences related to using current transportation options can have negative impacts on quality of life. The emergence of levels 4 – 5 automated driving system-dedicated vehicles (L4+ ADS), which will not require human operators to provide any input into the dynamic driving task, could empower the BLV community by providing an independent means of transportation. Yet, the BLV community has concerns that their needs are not being adequately considered by those currently developing L4+ ADSs, which will result in this technology being inaccessible to populations that it would otherwise greatly benefit. The current study sought to address this gap in the literature by explicitly evaluating the information and interactions that BLV riders will require from L4+ ADS. Specifically, we collected focus group and empirical data across three studies on BLV riders' information and interaction requirements for L4+ ADSs across expected and unexpected driving scenarios as well as pick-up and drop-off tasks (PUDO).

Through focus groups with sighted (n = 11) and BLV participants (n = 11; Study 1), we identified similarities and differences between sighted and BLV participants in terms of their user needs for L4+ ADSs across five challenging driving scenarios. Next, we examined BLV participants' (n = 13; Study 2) information requests in real-world settings to better understand BLV riders' needs during a simulated L4+ ADS experience. Our findings show that BLV riders want information that helps with (a) orienting to important objects in the environment during PUDO, (b) determining their location while riding in the ADS, and (c) understanding the ADSs' actions. Finally, we developed an HMI prototype using BLV riders' feedback in Studies 1 & 2 and had BLV participants engage with it during a simulated L4+ ADS trip (n = 12; Study 3). Our results suggest that BLV riders value information about nearby landmarks in familiar and unfamiliar areas, as well as explanations for ADS's actions during ordinary and unexpected scenarios. Additionally, BLV riders need information about required walking distances and presence of tripping hazards in order to select a drop-off location.

Taken together, our studies show that BLV riders have specific requirements that L4+ ADS must meet in order for this to be an accessible means of transportation. In light of these findings, we generated 28 guidelines and 44 recommendations that could be used by designers to improve the accessibility of L4+ ADSs for BLV riders.

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General Audience Abstract

When using current transportation options, individuals who are blind or have low vision (BLV) often encounter physical barriers and negative experiences, which can limit their ability to travel independently and have negative impacts on their overall quality of life. However, future vehicles equipped with levels 4 – 5 automated driving systems (L4+ ADSs) will offer transportation that requires no input from human operators, and thus, could be used as an independent means of transportation for the BLV community. Unfortunately, the BLV community has concerns that their needs are not being adequately considered by those currently developing L4+ ADSs, which will result in this technology being inaccessible to populations that it would otherwise greatly benefit. The current work sought to address this gap in the literature by evaluating the information and interactions that BLV riders will require from L4+ ADS.

We conducted three studies to collected data on BLV riders' information and interaction requirements for L4+ ADSs across a variety of driving scenarios as well as tasks relating to being picked up and dropped-off by an L4+ ADS. First, through focus groups with sighted and BLV participants, we identified similarities and differences between sighted and BLV participants' user needs for L4+ ADSs across five challenging driving scenarios. Next, to better understand BLV riders' needs, we had BLV participants indicate when they would desire information during a simulated L4+ ADS ride-hailing experience in real-world settings. Our findings show that BLV riders want information that helps with (a) orienting to important objects in the environment during PUDO, (b) determining their location during their trip, and (c) understanding the reason for the ADS's actions. Finally, using BLV riders' feedback, we developed an HMI prototype and had BLV participants engage with it during a simulated L4+ ADS trip. Our results suggest that BLV riders value information about nearby landmarks in both familiar and unfamiliar areas, as well as explanations for ADS's actions during common (e.g., stopping at a stop sign) and unexpected driving scenarios (e.g., sudden swerve). Additionally, when being dropped off, BLV riders need information about required walking distances and presence of tripping hazards in order to select a desirable drop-off location.

Taken together, our studies show that BLV riders have specific requirements that L4+ ADS must meet in order for this to be an accessible means of transportation. In light of these findings, we generated a set of guidelines and recommendations that designers can use to improve the accessibility of L4+ ADSs for BLV riders.

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1 Introduction

1.1 Problem Statement

For people who are blind or have low vision (BLV), challenges related to accessing transportation can contribute to decreased participation in social interactions, employment opportunities, and even hinder receiving medical care, which in turn can have a negative impact on one's quality of life (Brinkley et al., 2020; Crudden et al., 2015). Current transportation methods often used by people that are BLV include public transit, relying on family or friends, and ride-hailing services (e.g., Uber). Unfortunately, feedback from the BLV community suggests that these common transportation options often result in negative experiences as they can be unreliable, inconvenient, discriminatory, and/or cause individuals to feel as if they are a burden to others (Bezyak et al., 2017; Brewer and Ellison, 2020; Brewer and Kameswaran, 2019; Crudden et al., 2015). Considering that the BLV community makes up an estimated 9.9% of the U.S. population that is 18 years or older (IPUMS NHIS Database, 2019), it is necessary to consider new solutions that can provide independent means of transportation that reduce, or even eliminate, the undesirable consequences that BLV individuals experience with current transportation methods.

Some new opportunities for BLV transportation solutions are likely to be empowered with the emergence of levels 4 – 5 automated driving system-dedicated vehicles (L4+ ADS), which will not require human operators to provide any input into the dynamic driving task (DDT) or act as a manual driving fallback for the system (SAE, 2021). Additionally, it is estimated that L4+ ADSs will be deployed on public roads in the 2030s, where this technology will initially be accessed through "driverless" ride-hailing services with the potential to be more affordable than current ride-hailing services such as Uber (Litman, 2020). However, members of the BLV community are concerned that their needs are not being adequately considered by those currently developing L4+ ADSs, which will result in this technology being inaccessible to populations that it would otherwise greatly benefit (Brewer and Ellison, 2020; Brinkley et al., 2020). Thus, to avoid this undesirable outcome, many challenges for designing an accessible L4+ ADS experience must be addressed. One challenge that is frequently acknowledged by industry, regulatory bodies, and academia, but is rarely the primary focus of research efforts, is determining how to design *human-machine interfaces* (HMIs) for L4+ ADSs to be accessible to BLV riders. **A goal of this proposed**

work is to specifically address the open question of how to design L4+ ADS HMIs for riders that are BLV.

To date, most research focusing on developing HMIs for L4+ ADSs is based on feedback provided by sighted participants, as opposed to representative BLV participants. For instance, previous work highlights the importance of using HMIs to provide visual and auditory explanations of what an ADS perceives and its future actions as a means to increase system transparency, which in turn increases sighted riders' trust in ADSs and their willingness to adopt ADS technology (Du et al., 2019; Koo et al., 2015; Oliveira et al., 2020). Furthermore, Wiegand et al. (2020) investigated how specific driving scenarios of Level 5 ADSs behaving unexpectedly (e.g., remaining stationary after a traffic light turns green) resulted in sighted participants requesting an explanation. However, as sighted and BLV riders may differ in the type and/or the use of information to evaluate their environment (in part, due to the inherent differences in their ability to perceive details in dynamic driving environments), it is unclear whether any resulting design insights that may be beneficial for sighted riders will be sufficient for BLV riders. **Thus, another goal of this work is to specifically engage the BLV community to elicit L4+ ADS needs**.

Other common trends in research efforts that investigate user's perceptions towards L4+ ADSs include the utilization of similar roadway environments (e.g., uninterrupted highway trips) and unpredictable events (e.g., an obstacle on the road) as well as the lack ecological context all together (e.g., surveys/interviews that only provide a definition of ADSs when gathering user feedback). While research utilizing common driving scenarios or surveys provide valuable contributions to this area of research, L4+ ADSs are expected to handle the entire DDT in most or all driving environments. Thus, making it likely that L4+ ADSs and their riders will encounter all kinds of *challenging driving scenarios* (CDSs), which will require intricate interactions with humans outside the vehicle (e.g., following directions from construction workers) and/or in highly dynamic environments (e.g., responding appropriately to law enforcement). To understand all information riders might require while using L4+ ADSs, research is needed to expand on common research trend relating to L4+ ADSs by exploring complex scenarios that reflect the dynamic environments of roadways that riders can expect to encounter in the real-world. **Thus, this research will explore common and challenging driving scenarios to expanded upon and fill gaps in the literature regarding ADS use cases and L4+ ADS HMI designs.**

To improve the likelihood that the BLV community can utilize L4+ ADSs as independent means of transportation in the future, it is essential to proactively create accessibility guidelines and recommendations that can be used by developers of L4+ ADSs. Similar to web content developers following Web Content Accessibility Guidelines (WCAG) to ensure their websites are inclusive and provide equal access, accessibility guidelines for L4+ ADSs would help developers address the diverse needs of the BLV community. In order to generate accessibility guidelines for L4+ ADSs, more research is required to identify and address potential issues related to BLV riders independently using this future means of transportation. Encouragingly, recent research efforts have taken the first steps towards ensuring L4+ ADSs are accessible for BLV riders by identifying high-level challenges and opportunities that need to be addressed (Bennett et al., 2020; Brewer and Ellison, 2020; Brinkley et al., 2020). However, little to no subsequent work has been done to: (1) understand BLV riders' specific needs when entering and exiting L4+ ADSs, (2) understand BLV riders' detailed information and interaction requirements when using L4+ ADS HMIs, and (3) explore whether these HMI requirements vary depending on L4+ ADSs encountering various driving scenarios. By proactively addressing these three challenges, we can inform guidelines and recommendations for designing L4+ ADSs prior to this technology becoming widely available, and ultimately, prevent the current concerns of the BLV community from becoming a reality. **Thus, the final goal of this work will be to use study findings to generate design guidelines and recommendations that can be utilized by developers to design L4+ ADSs to be accessible for BLV riders.**

1.2 Research Objectives

The overarching purpose of this work is to determine the information and interaction requirements of BLV riders using L4+ ADS ride-hailing services in order to distill design guidelines and recommendations for developing accessible L4+ ADSs. As challenges and barriers faced by BLV riders occur before, during, and after using current transportation methods, we believe it is important to explore various aspects of L4+ ADS ride-hailing experiences outside of just riding in the vehicle. Thus, to understand how to increase the accessibility of L4+ ADSs, we developed the following research objectives that address a range of different ADS driving scenarios (e.g., yielding to emergency vehicle) and tasks performed by riders (e.g., locating the ADS during rider pick-up).

Objective 1: Identify and classify information and user interaction requirements for L4+ ADS HMIs to be accessible for BLV and sighted users throughout various CDSs.

In Study 1, we conduct focus groups consisting of BLV and sighted participants. All focus groups follow a semi-structured interview process, which we designed to generate discussion regarding participants' opinions of what information should be presented by L4+ ADSs during various CDSs (i.e., identify *information* requirements). Additionally, we explore how participants would anticipate receiving, reviewing, and interacting with presented information (i.e., *user interaction* requirements). The research questions specific to Study 1 are as follows:

RQ1. What information do BLV and sighted riders require from L4+ ADS during CDSs?

RQ2. What user interactions do BLV and sighted riders expect to be available for L4+ ADSs?

RQ3. What are the commonalities and differences in L4+ ADS interaction and information requirements between BLV and sighted riders?

Objective 2: Investigate BLV riders' responses to real-road simulated L4+ ADS ride-hailing experiences.

In study 2, we simulate a L4+ ADS ride-hailing experience that requires BLV participants to perform a vehicle ingress task and experience two real-road trips as passengers in a simulated L4+ ADS. Findings from Study 1 suggest BLV riders are concerned about the impact L4+ ADSs will have on their ability to perform tasks that are fundamental to using ride-hailing services, such as locating and navigating to a requested vehicle without an on-board human operator to provide assistance. Therefore, Study 2 engages participants in semi-structured interviews prior to entering and prior to exiting the vehicle to better understand how to design accessible L4+ ADS experiences surrounding the trip itself. Study 2 additionally expands upon Study 1 by exploring BLV riders' information requirements during ordinary driving scenarios in L4+ ADSs that occur outside of CDSs explored in Study 1. Essentially, we investigate how various driving maneuvers (e.g., stopping for stop signs), L4+ ADS driving styles (e.g., smooth vs. quick decelerations), and driving environments (e.g., highway vs. rural roads) that can occur during ordinary driving scenarios result in BLV riders requesting information from an L4+ ADS. Our findings will provide insight for designers of L4+ ADSs to understand what information to provide to BLV riders during vehicle

ingress and egress. Furthermore, we expect our findings will help designers better predict what driving scenarios, and specific components comprising scenarios, will require information to be provided to BLV riders. The research questions specific to Study 2 are as follows:

RQ4. What information do BLV riders value when being picked-up and dropped-off by L4+ ADSs?

RQ5. What driving maneuvers during L4+ ADS trips warrant information from BLV riders?

RQ6. How do differences in L4+ ADS driving styles influence information requested by BLV riders?

RQ7. What driving environments during trips in L4+ ADS warrant information from BLV riders?

Objective 3: Identify benefits and challenges BLV riders encounter while using an HMI prototype during a simulated L4+ ADS trip.

In Study 3, we simulate a L4+ ADS ride-hailing trip on real roads that require BLV riders to experience ordinary and unexpected driving scenarios as well as perform a drop-off task at the conclusion of the trip. For each driving scenario, BLV riders receive information and perform user interactions using an HMI prototype informed by findings from Study 1 and Study 2. Using BLV riders' task performance and user feedback of the HMI prototype, we generate guidelines for designing L4+ ADS HMIs to be accessible to BLV riders, and more specifically, support their needs across several driving scenarios. The research questions specific to Study 3 are as follows:

RQ8. What information provided by the HMI prototype is valuable for BLV riders for different L4+ ADS driving scenarios?

RQ9. What are BLV riders' perceptions of interaction modalities offered by the HMI prototype?

RQ10. What challenges do BLV riders' encounter when using the HMI prototype during a negotiated drop-off scenario?

1.3   Contributions

The main outcome of this research will be a better understanding of what information and user interactions riders, primarily those that are BLV, will need when using L4+ ADS ride-hailing services. Specifically, findings resulting from all three studies will reveal riders' information and user interaction requirements when: 1) encountering CDSs during L4+ ADS trips, 2) experiencing different driving maneuvers, driving styles, and environments within driving scenarios, and, 3) independently navigating to and from L4+ ADS vehicles. Additionally, the design considerations we distill as a result of this research will be used to inform the development of guidelines and recommendations for designing L4+ ADS HMIs to be more inclusive for BLV riders. Additional contributions resulting from this research effort include:

- A list of information and interaction requirements for both BLV and sighted riders that can be used to identify any existing similarities and/or differences between these groups. Such information would increase designers' ability to design future L4+ ADSs to be inclusive of the needs of both sighted and BLV riders (and eventually all types of rider populations).

- Supplementary design considerations for the interior of L4+ ADSs, which could range from implementing other advanced assistive technologies (e.g., refreshable braille displays) to simple accessibility solutions (e.g., physical buttons with braille) to improve the riding experience for BLV riders.

- HMI prototype design(s), and/or distilled design considerations, that can assist BLV riders with the ingress process (e.g., verifying arrival of ADS, navigating to the ADS, identifying the correct ADS, entering the ADS) as well as egressing from L4+ ADSs (e.g., verifying drop-off location is correct, evaluating the environment before exiting vehicle, navigating to destination).

- Novel application of study methods that are accessible for specific populations often excluded from study samples and whose needs are seldomly accounted for when designing research studies. While the focus of this proposed research is on the BLV population, there are other disabilities that also cause people to face challenges when using current transportation methods that could be overcome if L4+ ADSs are designed to meet their accessibility needs.

- Lastly, an important contribution of this research is increasing awareness within academic and industrial domains on the significance of proactively designing novel technologies to

be accessible to allow more users to receive benefits of that technology and avoid exacerbating the current dilemma of environmentally imposed disabilities.

2   Definitions

2.1   Information and Interaction Requirements:

To design a product or system that users find useful (i.e., effective in accomplishing desired goals) as well as usable (i.e., easy to learn, use, and remember), designers must first understand the user requirements that the system must fulfill. Human factors research can utilize objective and subjective data collected from past, current, and future product users to derive user requirements to inform better product design. For example, Khanade et al. (2017) used feedback gathered during focus groups with nurses working in intensive care units to derive information requirements that influenced the design of a smartwatch to assist the nurses with completing daily tasks in high stress environments. For the proposed research, we will adopt Khanade et al.'s definition of *information requirements,* which is the information users require a system to provide as feedback or accept as an input (Khanade et al., 2017).

While Khanade et al.'s (2017) definition of information requirements covers the required information to be presented and accepted by systems, it does not directly address how the exchange of information occurs. Depending on individuals' sensory, mental, and physical abilities, people may require different methods for providing and receiving information (e.g., braille labels on buttons, auditory cues, voice commands). Thus, to design accessible products or systems, we must also understand the *user interaction requirements*, which we operationally define as the competency of a system to allow users to input, request, or review the required information.

Furthermore, we have developed two hierarchical levels of user interaction requirements, which we believe should allow designers to understand how to meet the needs of multiple user demographics. The first level of user interaction requirements, or the *system interactions*, identifies what tasks specific to a system will require interactions from users. For example, users will need to inform a L4+ ADS when to start the trip. The second level of user interaction requirements, or the *interaction modalities*, identifies the specific input and output modalities users will require to accomplish the system interaction. For instance, BLV riders using L4+ ADSs might require verbal

input and output methods to start their trip whereas sighted riders might only require interactions with visual information, such as pressing a button visually presented on a touchscreen.

We believe the proposed research detailed in this document will allow us to derive information and user interaction requirements to inform designs of HMIs for future L4+ ADSs. More specifically, by exploring various driving scenarios (e.g., unexpected construction zones) and tasks (e.g., identifying the correct vehicle) that riders using L4+ ADSs will encounter in the future, we hope to discover user requirements that will need to be address across the entire system (e.g., readily available accessible interaction methods) as well as requirements that are relevant to unique, but high stress instances (e.g., understanding what to do during ADS malfunction). As a result, we believe that determining all these requirements for multiple scenarios will be a foundational starting point towards ensuring riders will be able to access L4+ ADSs in the future as well as feel comfortable, safe, and confident in ADSs during challenging scenarios.

2.2   Automated Driving Systems

SAE International defines six levels of driving automation that range from systems that can provide warnings to drivers (Level 0) to full driving automation under all driving conditions (Level 5; SAE, 2021). As depicted in Figure 1, Levels 0-2 require drivers to be constantly engaged in the DDT, whereas Levels 3-5 allow drivers to fully disengage while an automated driving system (ADS) performs the DDT. Although Level 3 ADSs can perform the DDT, drivers are still required to act as a fallback and must be ready to control the vehicle upon the system's request. By contrast, Levels 4-5 ADSs will perform the entire DDT without any expectation that a driver will intervene, although the operation of Level 4 ADSs will be limited to pre-defined operational defined domains (ODDs). Because Levels 4-5 ADS eliminate the need for an on-board driver, they offer BLV individuals an independent means of transportation, and thus, the proposed research focuses only on Levels 4-5 ADSs.

Figure 1. Depicts the six levels of automated driving taken directly from J3016 (SAE, 2021).

2.3 Accessibility

Pursuits of a world that is accessible for all dated back as early as the 1950s (Persson et al., 2015), which have resulted in accessible designs that can be seen and heard when navigating through any city infrastructure (e.g., wheelchair ramps), when using public transportation (e.g., leaning buses), or when using modern consumer products (e.g., numerous accessibility settings provided on smartphones). While there seems to be a wide understanding of the need to consider accessibility when designing built environments, transportation, and consumer products/services, there is no standardized definition for the concept of accessibility (Persson et al., 2015). For instance, the International Organization for Standardization (ISO) guide for addressing accessibility in standards (ISO, 2014) provided two definitions of accessibility, which were selected because they best capture all definitions of accessibility used across numerous ISO standards. The two definitions of *accessibility* from ISO guide are:

1. "The extent to which products, systems, services, environments and facilities can be used by people from a population with the widest range of characteristics and capabilities to achieve a specified goal in a specified context of use" (page 3).
2. "The usability of a product, service, environment or facility by people with the widest ranges of capabilities" (page 4).

For the purposes of the proposed research, we are adopting the first definition of accessibility as it aligns best with our research objectives that focus on understanding how L4+ ADSs can be designed to be usable by individuals with varying degrees of vision across numerous driving scenarios. Additionally, as mentioned in Persson et al. (2015), the selected definition of accessibility provides a basis for how to measure accessibility (i.e., the "extent" that a design allows users to perform a specific goal as intended).

2.4   Blind and Low Vision

Although there is no universal definition for visual impairment (Center of Disease Control and Prevention, 2021), it is a term that is often applied to a wide range of vision functionality, from mild vision loss to total blindness. In the United States, individuals with a visual acuity of 20/40 to 20/70 in their better-seeing eye can still obtain driver's licenses (depending on the state) even though these levels of visual acuity classify as having a visual impairment (see Figure 2). Thus, to accurately represent the target population the proposed research intends to involve (i.e., individuals whose degree of vision loss prevents access to an independent means of transportation), we will instead use the terms: *blind* and *low vision*. Furthermore, the use of blind and low vision should help avoid any negative connotations someone might associate with terms, such as 'impairment'.

Category of visual impairment	Presenting visual acuity		Or central visual field*	Classified as
	Maximum less than	Minimum equal to or better than		
1	6/12 0.50 20/40	6/18 0.33 20/60		Mild visual impairment
2	6/18 0.33 20/60	6/60 0.10 20/200		Moderate visual impairment
3	6/60 0.10 20/200	3/60 0.05 20/400	20° or less but more than 10°	Blindness
4	3/60 0.05 20/400	1/60 (finger counting at 1 metre) 0.02 5/300 (20/1200)	10° or less but more than 5°	Severe blindness
5	1/60 (finger counting at 1 metre) 0.02 5/300	Light perception	5° or less	Very severe blindness
6	No light perception			Total blindness

Figure 2. Categories of visual impairments from Dandona and Dandona (2006).

Selecting appropriate definitions for blindness and low vision is important as these definitions influenced the development of our study eligibility criteria (i.e., definitions were presented to participants to be used for self-reporting their degree of vision). Because the presence and level of a visual impairment is typically determined by measuring visual acuity and degree of central vision in the better-seeing eye (Dandona and Dandona, 2006), we have opted to utilize the U.S. government's definition of legal blindness, which is a visual acuity score of 20/200 in the better seeing eye. However, for individuals that may be completely blind or unfamiliar with their personal vision acuity, we have adopted another widely used definition of blindness and low vision (American Federation for the Blind, n.d.), which is the complete loss of vision or vision that cannot be corrected by corrective lenses (e.g., contacts or glasses).

Finally, as seen in Figure 3, within a category of visual impairment, there are still differences in the characteristics of someone's remaining vision (e.g., blurred vision, tunnel vision, loss of central vision). Due to this, another method for classifying the degree of visual impairment is based on one's functionality with their remaining vision (e.g., how it impacts the ability to perform daily activities) (American Federation for the Blind, n.d.). This method of defining blindness and low vision was validated through consultations with subject matter experts (SMEs) from organizations that represent BLV communities (i.e., The Lighthouse for the Blind and Visually Impaired). Based on this recommendation, we developed two questions that will be incorporated into screening

interviews to understand BLV individuals' functionality as a result of their visual impairment (which were also approved by SMEs):

1) Do you use visual landmarks when navigating spaces?
2) When using your smartphone, computer, or tablet, which of the following tools do you use? (Selecting all that apply) Screen magnification, high contrast viewing mode, screen reader, or other (if other, please explain)

Figure 3. Image developed by Hu et al. (2019) to simulate different severities of visual impairments due the most common causes (i.e., uncorrected refractive errors, cataract, age macular degeneration (AMD), and glaucoma) to showcase the diversity in experiences amongst BLV individuals.

2.5   Driving Scenarios

For the proposed research, we intend to explore multiple driving scenarios that L4+ ADSs will encounter in the future as well as how the unique differences between these scenarios impact BLV riders' requirements. This section provides our operational definitions for a driving scenario as well as the three factors that we use to create unique driving scenarios. *Driving Scenarios* are moments along a trip that require a *driving maneuver(s)* to be performed (e.g., slowing, stopping, accelerating, turning, changing lanes) in order to advance and complete a trip. Additionally,

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driving scenarios can differ based on the *driving style*, which is the driving parameters that are used when performing driving maneuvers (e.g., quick vs. smooth deceleration). Because driving maneuvers and styles can be influenced by the type of road (e.g., highway, rural, urban), and the presence of traffic signals (e.g., stop sign) or on-road objects (e.g., vehicle or pedestrian traffic), *driving environments* are also a major component used to define driving scenarios. Thus, we will use differences in driving maneuvers, driving styles, and driving environments to define the driving scenarios explored in the presented studies.

To understand BLV riders' information and interaction requirements for L4+ ADSs, we will explore various driving scenarios that riders could be exposed to when using L4+ ADSs ride-hailing services. Driving scenarios will range from CDSs (see Section 1.1) to more common scenarios riders might expect during ordinary trips (e.g., smooth lane changes). Furthermore, we will examine how the driving maneuvers, driving style, and driving environments that comprise driving scenarios can influence BLV riders' information and interaction requirements. We provide details on the driving scenarios explored in this research in the methods sections for each study.

3   Related Work

3.1   Perceptions toward L4+ ADSs

In order for L4+ ADSs to become an accepted means of transportation in the future, it is crucial for designers to understand the public's perceptions toward this technology, such as their willingness to use L4+ ADSs. By understanding future users' perceptions, L4+ ADSs can be designed to counteract common concerns and/or to meet highly anticipated benefits. However, because L4+ ADSs have the potential for increasing BLV individuals' independence, it would be unreasonable to assume that the perceptions of the general public (i.e., populations often included in research efforts) is representative of BLV individuals' perceptions towards L4+ ADSs. Thus, in the following sections, we will discuss trends in the general public's perceptions and BLV individuals' perceptions in attempts to highlight any commonalities and differences between the two populations.

3.1.1   General Public's Perception

With limited access to L4+ ADSs, numerous studies have relied on surveys, interviews, and focus groups to examine the general public's perception towards L4+ ADSs and willingness to adopt this technology (Becker & Axhausen, 2017; Gkartzonikas & Gkritza, 2019). An early effort in gauging global perceptions towards the development and willingness to use future L4+ ADSs was conducted by Continental Mobility in 2013, which was repeated again in 2018 (Continental, 2013; Continental, 2018). Based on 4000 respondents from Germany, China, Japan, and the United State (U.S.), findings indicated more than half of all respondents (54%) believed this technology would be unreliable and were scared by the idea of using ADSs in 2013, with responses in 2018 suggesting an increase in the public's skepticism and fear around using ADSs. The negative perceptions towards L4+ ADSs held by the general public (especially by U.S. citizens) have been supported by findings from previous studies that suggest people are primarily concerned with cybersecurity, data privacy, safety consequences from equipment failure, relying too much on the technology to perform the driving task, learning to use the technology, amongst many other concerns (Kyriakidis et al., 2015; Schoettle & Sivak, 2014).

Although the public has various concerns with using future ADSs, previous work indicates that the general public anticipates L4+ADSs to provide numerous benefits. One major contribution the

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general public anticipates from L4+ ADSs is the increased safety to vehicle occupants and other road users (Howard & Dai, 2014; Panagiotopoulos & Dimitrakopoulos, 2018). This potential increased safety could also be the primary influence on peoples' likelihood to adopt L4+ ADSs (Jardim et al., 2013). The public also often anticipates that L4+ ADSs will reduce emissions and fuel consumption as well as increase travel convenience (e.g., not having to find parking, engaging in non-driving related tasks) (Howard & Dai, 2014; Kyriakidis et al., 2015; Schoettle & Sivak, 2014).

As detailed in Gkartzonikas and Gkritza (2019) and Becker and Axhausen (2017), numerous demographical differences, such as age, gender, education level, household income, current vehicle ownership, amongst others, have been examined in previous research to better understand factors influencing perceptions towards L4+ ADSs. While the included literature throughout this section is valuable resources that can help researchers and designers of L4+ ADSs discover challenges that need to be addressed, they also emphasize a lack in research focusing on other important user demographics, such as BLV individuals, who have previously expressed that their needs are frequently overlooked when it comes to designing novel transportation systems (Brinkley et al., 2017).

3.1.2   Perceptions of BLV individuals

Recent work has begun to address this gap in the literature by examining BLV individuals' perceptions towards using future L4+ ADSs through surveys and focus groups. Brinkley and Daily (2018) administered a survey to 516 respondents from the U.S. that were BLV and found that 50% of respondents held "extremely positive" impressions of autonomous vehicle technologies with fewer than 10% having negative impressions. Only 39% of respondents reported being "slightly concerned" by the idea of riding in a fully automated vehicle as the primary operator. With participants' greatest concerns including experiencing system failures, ADSs getting confused in unexpected situations, and ADSs' ability to interact with external road users (e.g., pedestrians, cyclists), in order of prevalence.

From focus groups with BLV individuals (n = 38), Brinkley et al. (2017) reported that 47% mentioned that access to L4+ ADSs could increase their independence by eliminating their need to rely on others or public transit for their transportation needs. As it relates to BLV individuals' concerns about L4+ ADSs, more than half of the focus group participants expressed skepticisms

in the capability of L4+ ADSs to operate safely alongside non-automated vehicles. Interestingly, some focus group participants mentioned that the potential for increased independence and mobility would overshadow the risks associated with using L4+ ADSs (Brinkley et al., 2017), which is belief that is supported by findings from another focus group study with BLV individuals (Bennett et al., 2020; Brewer & Kameswaran, 2018). By exploring 211 responses from BLV individuals to an open-ended question, Bennett et al. identified four determinants of BLV individuals' willingness to use ADSs in the future, which included: (1) hope for ADSs to provide increased travel independence, (2) skepticism that ADSs will not be feasible nor be accessible to BLV consumers, (3) safety concerns, and (4) affordability of this technology, in order most prevalent. Additionally, BLV respondents' willingness to travel in ADSs were significantly and positively influenced by the hope that L4+ ADSs will provide a future with better and more independent transportation (Bennett et al., 2020).

3.1.3   Comparing perceptions toward L4+ ADSs:

Although in its infancy, work focusing on BLV individuals has already suggested similarities and differences between BLV individuals' and the broader public's perceptions of L4+ ADSs. For instance, Bennett et al. (2020) reported that 37% of respondents have positive views about using ADSs while 45% are skeptical of this technology and have safety concerns related to using ADSs. Bennett et al. described how these percentages are similar to those reported in previous work that focused on the public's perceptions, which continues the narrative that public as well as BLV individuals' willingness to accept and use future L4+ ADSs is still unknown. Brinkley et al. (2020) compared survey and focus group responses from BLV individuals to findings from previous work that evaluated responses from the broader public. While their comparisons revealed shared concerns between BLV and (presumably) sighted individuals, they were often concerns that were held to different degrees of importance between groups. For instance, both groups shared concerns related to the absence of traditional vehicle controls, legal liability, and driving performance of ADSs. However, these were most concerning topics reported by the general public whereas they were some of the least concerning topics reported by BLV individuals. Furthermore, while both groups had concerns related to the performance of ADSs, BLV individuals were generally more trusting in ADSs and reported that ADSs would be as safe, if not safer, than human drivers (Brinkley et al., 2020).

Even when focusing on a single shared concern amongst groups (regardless of whether the level of concern differs between groups), the rationale for the concern differs. An excellent example of this difference can be seen in BLV individuals' explanation of their concerns regarding legal liability if their L4+ ADSs was involved in an accident. During focus group sessions, BLV participants associated legal liability concerns directly to being taken advantage of because of their visual impairments. BLV participants believed they would always have an increased likelihood of being held liable if an accident was to occur because their degree of vision would hinder their awareness of an incident, and thus, impede their ability to provide accurate testimony. Whereas most legal liability concerns from the broader public is related to policies for determining whether ADSs' occupants or the ADS developers will be declared responsible for an incident (Brinkley et al., 2017). Although at a high-level, concerns about L4+ ADS appear to be shared between BLV and sighted individuals, closer evaluation of these similarities reveal subtle yet important differences between each group. Thus, research in this area is early evidence that more investigation is required to understand the diversity of concerns and user needs for the BLV community towards L4+ ADSs.

While findings produced by the work described throughout this section and Section 3.1.2 might appear intuitive in nature, they were not substantiated empirically until work by Bennett et al. (2020), Brinkley et al., (2017), Brinkley et al. (2018), and Brewer and Kameswarn (2018), which is an additional indication of the infancy of research focusing on BLV individuals and L4+ ADS technologies. Additionally, findings from these early research efforts focusing on the needs of BLV individuals show that perceptions towards L4+ ADSs expressed by BLV individuals (perhaps do) align with sighted individuals at a high-level. However, when considering the severity of concern and the reason for a concern towards future L4+ ADSs held by a demographic group, it is easy to see how different degrees of vision between BLV and sighted individuals might impact concerns. Thus, due to the wide range of differences amongst the BLV community, it is necessary to continue exploring these differences (as well as discovering more) in order to ensure that future L4+ ADSs will be accessible to all individuals with visual impairments. The work we propose in this document will attempt to add to these findings, not by exploring solely perceptions towards the technology, but understanding how we can design information to alleviate concerns L4+ ADSs held by the BLV community, such as encountering unexpected situations and what needs this technology will need to account for in order to meet those expectations.

3.2 Understanding current transportation challenges

In order to design L4+ ADSs to function as an independent means of transportation for BLV individuals, it is important to understand the barriers and challenges BLV individuals encounter that make current transportation inconvenient or unsafe. Additionally, by understanding methods used to overcome these challenges and barriers, designers can explore opportunities to integrate such solutions into future L4+ ADSs to better support BLV individuals. Therefore, in this section, we provide a high-level overview of challenges as well as commonly adopted solutions for two aspects associated with using current transportation options, which are: (1) navigation, and (2) correctly identifying desired locations and vehicles. We also elaborate on how the difficulty to overcome these challenges can differ based on the transportation options to further highlight current unnecessary inconveniences that BLV individuals encounter that must be avoided, or better yet, eliminated through the design of L4+ ADSs.

3.2.1 Navigation

Navigating to a desired destination requires an understanding of one's current location and its relation to a desired destination, or *orientation*, while also safely and effectively navigating toward a destination, or *mobility* (Kuriakose et al., 2020). However, a lot of information that can assist with the orientation and mobility aspects of a navigation task are often presented visually, such as street signs for understanding one's current location, detecting raised curbs to avoid tripping, and assessing safety to enter a crosswalk. To overcome any inaccessibility to visual information, BLV individuals travelling independently can acquire compensatory perceptual information by using techniques from Orientation and Mobility (O&M) training (Azenkot et al., 2011) and/or assistive devices that range from traditional methods (e.g., white canes, guide dogs) to more technologically advanced devices, (e.g., smartphone apps or smart canes equipped with sensing technologies) (Hu et al., 2019).

When navigating, BLV individuals frequently report the importance of obtaining information related to landmarks in the area and/or cardinal directions, especially in new and unfamiliar environments (Gupta et al., 2020). When aware of landmarks along a route, whether they are physical, auditory, or olfactory, BLV individuals can build and follow a mental map during

navigation. As BLV individuals encounter these landmarks, they can orient themselves to their destination and monitor their progress and confirm arrival at the correct location (Kameswaran et al., 2020; Quiñones et al., 2011, Azenkot et al., 2011). However, any disruptions to this mental map, such as encountering an unexpected event (e.g., construction zones), can cause a breakdown in their ability to track their progress along routes, which can lead to confusion while navigating (Quiñones et al., 2011).

To assist with the process of building and following mental maps, BLV individuals (who have access to or experience using smartphones) may utilize information provided by GPS navigation apps (e.g., Google Maps, Microsoft Soundscape). For instance, BLV individuals will correspond turn-by-turn instructions provided by GPS navigation apps with information provided by the transit service (e.g., announcements of upcoming stops) or motion feedback from the vehicle (Brewer & Kameswaran, 2019). However, using a mobile app to track progress could be problematic due to limitations in GPS accuracy or a lack of information provided by human drivers/transit services for comparison. Additionally, for on-foot navigation, previous work suggests that information provided by commercially available navigation aids (i.e., current location and surrounding street names) may not be sufficient in making individuals feel comfortable navigating unfamiliar and complex environments, such as crossing intersections (Guy & Truong, 2012). Furthermore, the auditory feedback provided by more advanced assistive devices may compete with other auditory information in the environment BLV individuals are trying to attend to while navigating (Kuriakose et al., 2020, Azenkot et al., 2011).

Depending on the selected transportation method, difficulties associated with mobility and orientation can drastically differ. For instance, public bus or train services can require BLV individuals to traverse greater distances to reach fixed pick up and drop off (PUDO) locations. Comparatively, ride-hailing services will meet users at more convenient locations selected by the users, which will require much shorter navigation distances and/or allow people to navigate in more familiar environments (e.g., a private driveway). When transportation methods require BLV individuals to walk greater distances to and from PUDO locations, it can drastically increase the amount of effort required by BLV individuals due to planning, familiarizing, and memorizing walking routes in addition to the route used by the transit service (Azenkot et al., 2011; Quiñones et al., 2011; Kameswaran et al., 2020). Additionally, due to the nature of fixed-route transit systems, the ability to receive information directly from a vehicle operator may be challenging

(Azenkot et al., 2011; Bezyak et al., 2017; Flores & Manduchi, 2018), which can increase difficulty with tracking trip progress. Additionally, fixed-route options reduce riders' flexibility in route selection, which may prevent BLV individuals from selecting familiar routes that could help reduce efforts associated with building and monitoring mental maps.

3.2.2 Correctly identifying locations and vehicles

Another transportation challenge that can be cumbersome for BLV individuals is correctly identifying PUDO locations and/or vehicles (e.g., bus route, ride-hailing vehicle). When it comes to verifying a PUDO location or a correct vehicle, some BLV individuals may rely on similar techniques and resources detailed in the previous section (3.2.1). For instance, BLV individuals will often seek out landmarks such as bus shelters, benches, and signs to confirm they have arrived at the correct location (Azenkot et al., 2011). For fixed-route methods, BLV individuals can identify the correct vehicle or PUDO location by listening for announcements provided by the operator or automated announcement system as the vehicle arrives at the destination (Azenkot et al., 2011; Flores & Manduchi, 2018). However, upcoming stops may not always be announced if buses lack automatic announcement systems and drivers forget to notify riders. Furthermore, these announcements can be difficult to detect or distinguish in noisy environments (Bezyak et al., 2017; Flores & Manduchi, 2018). A potential solution for this challenge is through the use of frequently used services provided via smartphone apps (e.g., Be My Eyes and AIRA) that allow BLV individuals to receive assistance from remotely located sighted volunteers (Brewer & Kameswaran, 2019; Kameswaran et al., 2020). Sighted volunteers can view the environment via the camera on a user's smartphone in order to provide assistance with any tasks that rely heavily on visual information in the environment, such as identifying correct location or vehicles as well as with navigation challenges discussed in Section 3.2.1. When considering that L4+ ADSs will be equipped with advanced sensing technologies, it's not difficult to envision how current solutions, such as those provided through smartphone apps, could be incorporated into future L4+ ADSs.

Solutions to overcome the same location and vehicle verification challenges slightly differ for ride-hailing services due to the ability to communicate with drivers prior to their arrival at the pick-up location. For instance, to help identify the correct vehicle when using ride-hailing services, BLV individuals will often call or use a smartphone app to request assistance from the driver with

locating and identifying the correct vehicle (Brewer & Kameswaran, 2019). Additionally, Uber and Lyft have developed solutions that allow users to present a color on their smartphones to help drivers easily identify a rider (e.g., Uber's Spotlight feature). Verifying destination accuracy can often be supported by BLV individuals continuously building their confidence based on how drivers' navigation aligns with information provided by navigation apps (Brewer & Kameswaran, 2019). Considering that most solutions currently used for identifying the correct PUDO locations and vehicles often involve interacting with an in-vehicle human operator, it is crucial to explore new solutions for L4+ ADSs that will ensure BLV riders feel confident that they are at the correct PUDO location and/or approaching the correct vehicle without a human operator on-board.

3.3 Factors influencing perceptions of L4+ ADSs

3.3.1 Influence of driving scenarios on perception of L4+ ADS

To design L4+ ADSs to meet riders' information and interaction requirements, it is important to understand how different L4+ ADS driving scenarios, and the components that make-up driving scenarios (see Section 2.5), impact riders' responses and perceptions toward the technology. Previous research exploring L3-5 ADSs suggests that riders' perceptions towards ADS technology and need for information can be influenced by how ADSs handle different driving scenarios. Research simulating L3-5 ADS driving styles on highways using driving simulators (Bellem et al., 2018; Rossner & Bullinger, 2020) and real-road environments (Cramer et al., 2020) suggest that different driving styles for lane changing maneuvers can influence riders' trust, perceived safety, and acceptance of automated driving. Similar findings resulted from research exploring different ADS driving styles for non-highway environment on real-road and test track study environments (Dillen et al., 2020; Ekman et al., 2019; Yusof et al., 2016). Across the mentioned studies, findings generally suggest that riders preferred a more "defensive" ADS driving style (i.e., a comfortable/smooth driving style with minimal lateral and longitudinal accelerations and greater following distances) and that this the driving style results in more positive perceptions towards ADS technologies. Ekman et al. (2019) suggested that the defensive ADS driving style increased participants' trust because the ADS maneuvers were more predictable. However, what might cause ADSs to be more predictable for sighted riders could come from visual information in the driving environment (e.g., riders can anticipate a gradual slowing maneuver if they see a stop sign ahead), which may not be perceivable or as useful for BLV riders. For instance, consider findings from

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prior work investigating riders' responses to L4+ ADSs operating in different driving environments (e.g., rural, highway, urban) with different objects within an environment (e.g., traffic density, pedestrians). A majority of participant-based research studies exploring responses to ADSs are conducted on highway settings (Frison et al., 2019), with some research findings implying riders' negative perceptions towards ADSs can be influenced by dangers that are visually perceived by the rider, such as proximity to other vehicles (Rossner and Bullinger, 2019; Dillen et al., 2020). However, since visual proximity to other vehicles might not be information that is detectable by BLV riders, more research needs to be conducted to understand what other environmental factors would influence BLV riders' perceptions toward L4+ ADSs.

Another simulator study exploring participants' responses to riding in an L4+ ADS in various traffic densities and driving environments found that driving scenarios in urban environments elicited the greatest safety concerns and discomfort compared to riding on the highway and rural roads (Frison et al., 2019). To our knowledge, there is limited research comparing L4+ ADS riders' responses to different driving environments, which is further implied by the fact that previous research predominantly focuses on highway environments (Frison et al., 2020). With L4+ ADSs expected to traverse a wide array or driving environments, more research needs to be done to understand riders' responses and information needs as a result of the driving environment. Furthermore, when considering that different driving environments are often associated with different auditory and tactile stimuli perceived by vehicle passengers, more research is needed to explore informational needs, specifically of BLV riders, to understand if different environments might require explanations from L4+ ADSs.

With research suggesting ADS driving styles and driving environments influence riders' perceptions, what is less accounted for is the impact different driving maneuvers (e.g., turning, stopping, accelerating) has on L4+ ADS riders (when driving style is held constant). Based on our knowledge, Dillen et al. (2020) is the only research effort to incorporate ADS driving maneuvers independent of driving style. Although their evaluation of driving maneuvers was not a primary objective, their findings still indicate that stopping maneuvers resulted in the greatest increase in riders' physiological and self-reported levels of anxiety and discomfort (Dillen et al., 2020). Aside from this work, other research efforts have exposed participants to various driving maneuvers in simulated ADSs, such as going over speed bumps, accelerating and decelerating at intersections, using traffic circles, merging lanes to overtake traffic, lateral accelerations around a curve,

amongst others, (Yusof et al., 2016; Ekman et al., 2019), yet measures were more focused on participants' preferences for different ADSs driving styles rather than understanding what information riders desire for various driving maneuvers. As mentioned in Section 3.2, BLV individuals often track trip progress by corresponding a vehicle's motion with a mental map of their route or turn-by-turn information provided on GPS navigation apps. Thus, being able to monitor an ADSs' driving maneuvers could be important to BLV riders for orientation and navigation purposes. However, without the ability to obtain information from another human in the vehicle, BLV riders might not be able to differentiate the cause of a maneuver (e.g., stopping for pedestrian in a crosswalk rather than for an anticipated stop sign controlled intersection), which could lead to confusion when tracking their route mentally. Thus, in addition to needing to explore BLV riders' responses to different driving styles and environments, future work with BLV individuals should also consider exploring the importance of understanding driving maneuvers performed by L4+ ADSs.

3.3.2 ADS System Transparency

It has been suggested that people do not entirely comprehend the technological capabilities of an L4+ ADS that allow it to understand driving environments and perform the driving task (van Brummelen et al., 2018). Perhaps this lack of understanding is a reason as to why the general public has concerns relating to trusting ADSs to perform the driving task. A commonly proposed method for improving riders' perceptions of L4+ ADSs is to design in-vehicle HMIs to increase system transparency, which informs riders on ADSs' awareness of the driving environment and its future intentions (Haeuslschmid et al., 2017; Kyu Choi & Gu Ji, 2015).

Previous work focusing on how to design information to increase ADS system transparency explored when information should be provided to riders, information content, as well as different modalities for presenting information. Du et al. (2019) used a fixed-base driving simulator to evaluate how explanations provided by Level 4 ADSs impacted participants' trust, anxiety, mental workload, and preferences towards ADSs. By evaluating different timings of an ADS's explanations (i.e., 7s before maneuver, 1s after maneuver, or no explanation), they found that explanations should be provided prior to the ADS's actions to promote riders' trust. These findings support highly cited work related to the content and timing of explanations from Level 3 ADSs (Koo et al., 2015, 2016), which also suggest that explanations of for ADSs' actions should occur

prior to the maneuver and should include both 'why' (i.e., the cause of the maneuver) and 'how' information (i.e., the type of maneuver). Work focusing on what scenarios require information from ADSs found that without any explanations from the ADS during unexpected driving behaviors (e.g., abrupt stops, waiting for no apparent reason, unnecessary accelerations, driving too slowly, close following distances to leading vehicles) participants reported feelings of frustration and dissatisfaction (Wiegand et al., 2020). Furthermore, Wiegand et al. (2020) implies that riders' requests for explanations increase when the reason for an ADS's unexpected driving behavior is not visible (e.g., a pedestrian unobservable to the passenger).

Details related to what information riders want about upcoming maneuvers and hazards have also been suggested by previous work that simulated ADS driving scenarios using authentic automated shuttles and driving simulators. Diels and Thompson (2018) attempted to identify user requirements for future ADSs by exposing participants to various driving scenarios in urban and pre-urban environments. Findings suggest that HMIs for future L4+ ADSs should provide information relating to situation awareness (i.e., what the vehicle sees) and behavioral awareness (i.e., what the vehicle is going to do) as it may improve the system transparency, comprehensibility, and predictability of the automated system. A majority of participants reported wanting both categories of information to be presented visually. Diels and Thompson's findings are reflected in other prior work, such as Oliveira et al. (2020), which reports that participants wanted to see the upcoming maneuvers and hazards identified by a Level 4 ADS. Similarly, Miglani et al. (2016) found that participants wanted to use the HMI to see objects recognized by the ADS so they could match it to what they could see in the environment. The collective work detailed thus far highlights a trend that (presumably sighted) participants wanted L4+ ADS HMIs to present visual information relating to upcoming maneuvers and/or detected objects in the environment. While it is easy to understand how the use of visual information on HMIs would offer little utility for most BLV individuals, future work should examine whether BLV and sighted individuals have similarities or differences in the content of information desired by L4+ ADSs regardless of presentation modality.

Although limited, previous research has taken initial steps in identifying information and user interaction requirements for BLV individuals that yield early insight on how to design HMIs to increase the accessibility of L4+ ADSs. Brinkley et al. (2017) reported that a majority of BLV focus group participants anticipate using speech interactions with the ADS (e.g., similar to using Siri or Alexa). A finding supported by Brewer and Kameswaran (2018), which also identified

specific tasks that may require speech interactions and auditory feedback, which include: planning routes, receiving route updates, and understanding outcomes of using certain in-vehicle controls/buttons prior to activation. Brinkley et al. (2017) also reports that BLV individuals desire the ability to request information to increase their situation awareness (e.g., proximity to other vehicles, pedestrians, important landmarks, and the destination) at any time. Furthermore, BLV individuals reported the need to verify they have arrived at the correct destination, which is a challenge BLV individuals experience with current transportation methods (see Section 3.2.2). Finally, many focus group participants raised questions about being able to request help during unforeseen events (e.g., vehicle breakdown) as well as understand who would be providing that help (Brinkley et al., 2017). Currently, Brinkley et al. (2019) is the only work that has built and evaluated an L4+ ADS HMI prototype designed for BLV riders. The HMI prototype addressed BLV individuals' feedback by providing auditory information that was designed to support BLV riders' situation awareness and location verification needs. Twenty BLV participants interacted with this HMI while riding in a simulated L4+ ADS on public roads. Results indicated that the HMI increased participants' ratings of trust in ADS technologies, usability of ADSs, as well as reduced ratings of fear of system malfunctions. Lastly, BLV participants reported that the information provided by the HMI helped them understand their surroundings during the ride and verify the destination (Brinkley et al., 2019).

While previous research focusing on BLV individuals' needs for ADSs are excellent initial strides, more work is still required to expand our understanding on how to develop accessible L4+ ADSs for BLV riders. To build upon the solid foundation set by previous work, future work should continue to identify BLV individuals' user requirements for L4+ ADSs to validate and expand upon findings from previous exploratory studies. Additionally, future studies should explore how HMIs can support BLV riders' needs across additional driving scenarios that L4+ ADSs will encounter on real roads (e.g., construction zones). We believe that outcomes of our proposed work will provide meaningful contributions to the growing literature on L4+ ADSs as well as the limited work focusing on the accessible design of L4+ ADSs.

4 Study 1

4.1 Objective

Identify and classify information and user interaction requirements for L4+ ADS HMIs to be accessible for BLV and sighted users throughout various CDSs.

Study 1 was designed to reveal riders' information and interaction requirements for various CDSs that L4+ ADSs will encounter when eventually operating in the real-world. We designed this study to generate discussions amongst groups of sighted and BLV participants regarding what information and interactions they would desire from L4+ ADSs while encountering CDSs. The data gathered from this study allowed us to understand how to increase the accessibility of L4+ ADSs as well as understand the information and interaction requirements specifically as they relate to CDSs.

RQ1. What information do BLV and sighted riders require from L4+ ADSs during CDSs?

RQ2. What user interactions do BLV and sighted riders expect to be available for L4+ ADSs?

RQ3. What are the commonalities and differences in L4+ ADS interaction and information requirements between BLV and sighted riders?

4.2 Method

4.2.1 Participants

We recruited and screened 26 participants (13 females) to take part in our focus group sessions, however, four participants decided to drop-out the day of their session. Thus, only 22 participants (13 females) actually participated in focus group sessions. All participants were required to be at least 18 years old and have experience independently using ride-hailing services in the Washington, D.C. and/or surrounding areas that shared similar urban infrastructure (i.e., Northern Virginia and Maryland). Eleven participants self-reported being blind (n = 7, avg. age = 57.57, *SD* = 13.26) or having low vision (n = 4, avg. age = 50.75, *SD* = 15.95) based on the following definition provided during the screening process: "blindness or limited vision not correctable by glasses or contact lenses." Eleven participants (6 females) self-reported have normal or corrected

to normal vision with an average age of 38 years old ($SD = 10.30$). Eleven sighted and four BLV participants reported having experience with vehicles equipped with Advanced Driver Assistance Systems (ADAS), such as Adaptive Cruise Control or Lane Keeping Assist.

We recruited participants through sending out recruitment materials via university email listservs and newsletters with an effort to target individuals living near the Washington, D.C. area. For recruiting BLV participants, we found the most successful strategy to be through collaborations with the LightHouse for the Blind and Visually Impaired and the National Federation of the Blind, which resulted in our recruitment advertisements being disseminated via their email listservs.

Table 1. A breakdown of blind and low vision participants demographics.

Self-reported degree of vision	Count	Perc.
Blind	7	63.6%
Low Vision	4	36.4%
Length of time with vision loss		
Since birth	5	45.4%
≤ 20 years	2	18.2%
21 – 50 years	2	18.2%
50+ years	2	18.2%
Gender		
Female	7	63.6%
Male	4	36.4%
Age Range		
18 – 24	0	0.0%
25 – 34	1	9.1%
35 – 44	1	9.1%
45 – 54	3	27.3%
54 – 64	2	18.2%
65+	4	36.4%
Race		
White	9	81.8%
Black	2	18.2%

Table 2. A breakdown of sighted participants demographics.

Gender		
Female	6	54.5%
Male	5	45.5%

Age Range			
	18 – 24	1	9.1%
	25 – 34	4	36.4%
	35 – 44	4	36.4%
	45 – 54	1	9.1%
	54 – 64	1	9.1%
	65+	0	0.0%
Race			
	White	6	54.5%
	Black	3	27.3%
	Asian	1	9.1%
	Other	1	9.1%

4.2.2 Focus Groups

We conducted six focus groups with three to four participants per group. Three focus groups included only BLV participants, and three focus groups included only sighted participants. Focus groups lasted 90 minutes each and covered the same five CDSs in the same order. Focus groups sessions were conducted virtually using the Zoom audio-video conferencing platform. Zoom was selected due to the accessibility of the software (compliant with WCAG guidelines and Section 508 Standards). Additionally, Zoom allowed us to capture audio and video recordings of sessions as well as Zoom automatically generates text transcripts of the group's dialogue, which drastically reduced time required for cleaning and preparing transcripts for analysis.

4.2.2.1 Organization of Focus Groups

When organizing participants into focus groups, we wanted to increase the likelihood of generating discussion within groups. Thus, we organized participants into groups based on similarities in their characteristics or experiences, while still maintaining enough variation to allow for different opinions and ideas (Krueger, 2014). To ensure all participants would feel comfortable contributing to a conversation related to future ride-hailing experiences, we felt it necessary that all participants shared a similar experience of independently using ride-hailing services. Furthermore, we wanted participants to have similar experiences with accessing and using ride-hailing services, which is why we recruited participants that have used ride-hailing services in similar urban environments. Group organization primarily resulted from participants' degree of vision. As Krueger (2014)

suggests, willingness to engage in group discussion can be hindered if participants have drastically different lifestyles. Thus, we organized groups such that three groups consisted of only participants that are blind or low vision and three groups of only sighted participants. For groups with three participants, we made sure there would be at least two females to avoid the likelihood of men dominating the conversation and receiving little to no input from female participants (Krueger, 2014). For BLV groups, we also tried to include a balance of participants that were blind and had low vision per group as well as a diversity in how long participants have lived with their degree of vision. Factors such as education and income were not taken into consideration when constructing focus groups. Finally, while it is recommended to conduct focus groups consisting of at least 10 participants (Krueger, 2014), our practice focus group sessions revealed that groups of six people were difficult to manage on Zoom. Eventually, we determined that groups consisting of four participants allowed for everyone to contribute equally to the discussion within the allotted time.

4.2.2.2   Focus Group Script

Prior to presenting any CDSs, we provided a definition of L4+ ADSs along with a description of the vehicle's interior we wanted them to imagine throughout the session. Within the description of the interior, we explained that there would be touchscreen displays located in front of them as well as speakers throughout the car that could be used for presenting information from the ADS during CDSs. However, we also encouraged participants to present other options for receiving and interacting with information provided by the ADS.

We developed five CDSs that encompass unique situations that L4+ ADSs may encounter in the future. Additionally, these scenarios were selected based on their similarities with a project funding this research, which is supported by the Federal Highway Administration (details included in the Acknowledgement section). All focus group instructions and CDSs were presented verbally by the moderator without any visual images or text for participants to refer too (see Appendix A for full focus group script). Below are summarized descriptions for the five CDSs presented during focus group sessions and our rationale for including each CDS:

- *Construction Zone* (Scenario 1): An unexpected construction zone that requires the L4+ ADS to follow instructions provided by a construction worker using a sign to direct traffic through an alternative path along the shoulder of the road. We developed this scenario to explore participants' information and interaction requirements relating to 1) unexpected

trip interruptions, 2) L4+ ADSs detecting and maneuvering through construction zones, 3) L4+ ADSs interacting with outside personnel, and 4) L4+ ADSs following temporary signage/markings to drive along unplanned paths that go outside the normal lane lines.

Figure 4. Depicts the multiple stages of the construction zone scenario as it was described to focus group participants: (a) L4+ ADS passes temporary signage indicating an upcoming construction zone, (b) the construction zone becomes detectable in the distance and the L4+ ADS will have to being slowing soon, (c) L4+ ADS is waiting for the worker's instruction to take the alternative path around the construction.

- *Move-Over* (Scenario 2): While traveling on the highway in the far-right lane, there is a law enforcement vehicle (LEV) about 100 yards ahead that has pulled over another vehicle in the right shoulder. The L4+ ADS should abide by the move-over law and merge one lane to the left, or slow down if unable to merge, prior to passing the LEV. We developed this scenario to explore participants' information and interaction requirements relating to L4+ ADSs identifying and reacting to a common situation involving the presence of LEVs on the highway.

- *Uncertain Traffic Stop* (Scenario 3): While traveling on the highway, an LEV with its lights and sirens engaged approaches from behind and in the same lane as the L4+ ADS. It is unclear whether the LEV is intending to pull over the L4+ ADS for a traffic stop or pass by. We developed this scenario to further explore participants' information and interaction requirements relating to L4+ ADSs identifying and reacting to LEVs, specifically when the intentions of LEVs are unclear.

- *LEV at Busy Intersection* (Scenario 4): While stopped for a red light at a crowded four-way intersection in a city environment, an emergency response vehicle approaches from behind the L4+ ADS. To clear a path for the emergency vehicle to turn at the intersection,

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the L4+ ADS moves out into the intersection even though the light is still red. We developed this scenario to continue exploring participants' information and interaction requirements relating to L4+ ADSs identifying and reacting to emergency vehicles in the vicinity. Additionally, we wanted to understand requirements related to L4+ ADSs

Figure 5. Representations of the three CDSs involving emergency vehicles, which include the Move-Over (top-left), Uncertain Traffic Stop (top-right), and LEV at Busy Intersection (bottom).

disregarding traffic signals as well as performing a risky maneuver.

- *Degraded State* (Scenario 5): The L4+ ADS detects an issue with the vehicle that requires it to pull over and stop in the right shoulder of a highway. Due to the issue, a new L4+ ADS is dispatched to pick up the rider and complete the trip. Additionally, a tow truck is dispatched to retrieve the malfunctioning L4+ ADS and arrives before the new L4+ ADS. We developed this scenario to understand participants' information and interaction requirements relating to 1) experiencing L4+ ADS malfunctions or failures, 2) seeking out solutions or alternatives for finishing their trip, 3) communicating with outside personnel, and 4) determining when a new L4+ ADS arrives and navigating to it.

As our CDSs captured very dynamic and complex driving scenarios, we found it challenging to develop verbal descriptions that were not overly detailed and lengthy, which could result in losing participants attention or interest. Thus, to efficiently provided all necessary details without

overwhelming participants, we decided to break up some CDS descriptions into multiple segments (see Figure 4). The segments would be presented to participants with group discussions occurring between each. We also found that presenting CDSs in this manner would allow us to pinpoint information and user interaction requirements as they related to specific instances within CDSs. Questions we administered to focus groups for each scenario were: "What information would you require at this moment, if any?" and "How would you want this information provided to you?" Occasionally, the moderator would administer improvised questions to obtain additional feedback about topics that were generated during a group's discussion. Finally, by conducting practice sessions with staff of organizations representing BLV communities and receiving their feedback on our script, we were able to confirm that our CDS descriptions were easily comprehendible by those that may never have observed driving behaviors and roadway features before.

4.2.3   Procedure

Prior to recruiting participants, we worked with organizations representing the BLV community to ensure that our study methods and materials were accessible for BLV participants. Specifically, the main reasons for working with BLV organizations were 1) to preemptively detect and avoid any difficulties participants might experience with methods used for remote participation (e.g., filling out online paperwork, downloading Zoom software, joining Zoom meetings) as a means to reduce the likelihood of participant attrition, and 2) to continue improving our general understanding about accessibility design.

Participants we deemed eligible after completing the screening process were required to complete a 30-minute intake session via Zoom prior to attending the focus group session. During the intake session, we reviewed the IRB approved information sheet provided to participants ahead of time and addressed any questions participants had about the study. Lastly, we used the intake sessions to determine if participants could maintain a stable connection to the Zoom meeting, and if so, were eligible to take part in the focus group session.

Focus group sessions lasted about 90-minutes and were audio and video recorded via Zoom. For privacy reasons, we adjusted settings to disable participants' cameras and only show participants' first name. During the focus group, we asked participants to imagine themselves riding in an L4+ ADS that they ordered through a ride-hailing service. We then described five CDSs that they would encounter when riding in L4+ ADSs. For each CDS description, participants engaged in

discussions and provided their opinions about the information they would want provided by L4+ ADSs, how that information should be presented, and how they would want to interact with that information and the ADS. At the end of the session, the participants were thanked for their time and the Zoom meeting was concluded. Within a week of session completion, we placed the participants' compensation in the mail to be delivered to an address provided by each participant.

4.2.4 Content Analysis

To prepare transcripts generated by Zoom for analysis, two researchers went through and removed any personal identifiable information and re-formatted the transcripts to be better-suited for later analysis processes. Because Zoom's automatic transcript is not perfect, one researcher reviewed the transcript while listening to the audio recording and corrected mistakes. A separate researcher reviewed the cleaned transcripts while also listening to the audio recording to verify that all mistakes were corrected. This process allowed both researchers to begin familiarizing themselves with all focus group transcripts.

To analyze the qualitative data gathered from our focus groups, we performed an *Inductive Content Analysi*s, which is the process of deriving codes, categories, and themes based on the content within participants' responses and is appropriate for areas with limited previous research (Elo and Kyngäs, 2008, Hsieh and Shannon, 2005). To start this process, we identified *meaning units*, which are "sentences or paragraphs containing aspects related to each other through their content and context" (Graneheim and Lundman, 2003, p. 106), for one randomly selected CDS across all six focus group transcripts. We used the meaning units from this CDS to develop an affinity tree diagram, which organized our meaning units into categories and sub-categories (see Figure 6). An initial codebook was generated using the results of the affinity tree diagram. Two researchers proceeded to use the initial codebook to individually code meaning units resulting from discussions from another randomly selected CDS. Afterwards, researchers compared their attempts and made any necessary additions and adjustments to the codebook. All agreements between researchers were entered into an excel spreadsheet that documented all meaning units and their representative code. To settle situation where different codes were applied for identical meaning units, both researchers would each present their reasoning for code applications and discuss these perspectives until an agreement was reached. These discussions were often used to adjust existing codes as well as develop new codes for the codebook. When these discussions resulted in the addition of new

codes, researchers would work together to review previously coded meaning units and apply the new codes where appropriate. This collaborative process of applying new codes to previously coded meaning units allowed both researchers to practice applying new codes before attempting to do so independently. This process was repeated until no more adjustments were made to the codebook and both researchers had an agreed understanding of the codebook. The resulting codebook (see Section 4.3.1) was then used to independently code all remaining meaning units.

Figure 6. Depicts the affinity tree diagram process we used to organize meaning units and develop our initial codebook.

It should be noted, that due to limited resources, one of the researchers assisting with the content analysis process had to withdraw their assistance before completing the entire coding task. Thus, a single researcher was responsible for applying the finalized codebook to all remaining meaning units and producing the results we discuss in the following sections.

4.3 Results

Through the content analysis process, we applied a total of 995 codes to meaning units. It should be noted that for one of the BLV focus groups, the moderator made the decision to skip the discussion for the Move-Over scenario to avoid exceeding the session's time limit. However, BLV

focus group discussions still produced 527 coded meaning units, which accounts for about 53% of all coded meaning units. See Table 3 for an overview of the number of coded meaning units for each CDS across all focus groups.

Table 3. A breakdown of coding instances for all CDSs per focus group

	FG 1 (S)	FG 2 (BLV)	FG 3 (S)	FG 4 (S)	FG 5 (BLV)	FG 6 (BLV)
Construction zone (Sc. 1)	46	48	45	61	25	49
Move-over (Sc. 2)	12	n/a	11	19	10	8
Uncertain Traffic Stop (Sc. 3)	25	30	13	19	14	17
LEV at Intersection (Sc. 4)	11	13	14	10	12	9
Degraded State (Sc. 5)	57	65	45	55	71	73
Non-scenario specific	3	18	0	25	36	26

4.3.1   Generated Codes and Code Categories

In Table 4, we provide the entire codebook and breakdown the number of times a code was applied (i.e., *frequency*), the percentage of participants that mentioned the same codes (i.e., *extensiveness*), and code descriptions (Krueger, 2014). We developed 19 codes that were then organized into the following five code categories: (1) Information Requirements, (2) System Interactions, (3) Interaction Modalities, (4) Vehicle Entry and Exit, and (5) Perceived Comfort and Safety. Of the five categories, the last two do not directly address RQ1 or RQ2, yet we thought both were beneficial to include for different reasons. We developed the Vehicle Entry and Exit code category based on noticeable trends of meaning units revealing information and interaction requirements relating to challenges with independently entering and exiting vehicles. The Perceived Comfort and Safety category was developed based on participants describing (1) how their level of comfort could be influenced by information or actions performed by ADSs, and, (2) concerns related to the safety of themselves or other road users during CDSs. Throughout the following sections, we highlight instances where participants mentioned how their sense of comfort or safety concerns would be influenced by the ADS and/or CDSs. Additionally, it should be understood that we will only present codes that occurred the most frequently and extensively, and thus, not all codes presented in our codebook will be discussed in the following sections.

Table 4. Codebook with the extensiveness and frequency of codes.

Code	Extensiveness (Frequency)			Code Description
	Total	**BLV**	**Sighted**	
Category – Information Requirements				
Object Detection & Recognition	95% (108)	91% (49)	100% (59)	Information about object(s) that the ADS has identified an important object(s) in the surrounding environment (e.g., temporary road signs, person, vehicle)
Trip Information	100% (86)	100% (41)	100% (45)	Information relating to the rider's trip (e.g., route overview, ETA, delays, cause of delay)
Environmental Awareness	86% (76)	91% (52)	82% (24)	Detailed descriptions of the driving environment that can include information, such as the location of objects, the topography, weather, and nearby landmarks.
ADS's Actions	91% (75)	91% (36)	91% (39)	Information about the ADS's current or upcoming driving maneuvers
Vehicle-to-Everything (V2X) Communication	77% (24)	73% (11)	82% (13)	Information that the ADS is communicating with other sources of information (e.g., infrastructure, vehicles, or people outside the vehicle)
Intentions of Others	64% (24)	55% (13)	73% (11)	Information of actions that will be taken by other road users (e.g., vehicles, pedestrians)
Lack of Information	64% (21)	64% (11)	64% (10)	A lack of information that could otherwise inform riders on how they should respond during scenarios or how the ADS will respond.
System & Vehicle Status	45% (13)	36% (7)	55% (6)	An awareness of the condition of the vehicle and ADS, including detection of system malfunctions, physical damage, or lack thereof. (*Note: code is exclusive to scenario 5*)
Category – Interaction Modality				
Output Modality	100% (166)	100% (79)	100% (87)	Methods for receiving information from the system.
Device	86% (70)	91% (32)	82% (38)	Devices used for information input and output.
Input Modality	82% (46)	100% (28)	64% (18)	Methods for inputting information into the system.

Category – System Interactions				
Personalization	86% (45)	100% (24)	73% (21)	Ability to adjust user settings and/or preferences for the riding experience (e.g., avoid toll roads, text size, desired feedback).
Control the ADS	73% (45)	64% (19)	82% (26)	Ability to adjust the ADS's course of action or adjust the trip itself while riding in the ADS (e.g., stopping the vehicle, adjusting the route during the trip).
Request Assistance	64% (30)	82% (24)	45% (6)	Ability to request assistance from a human that is remote (e.g., customer support) or in-person (e.g., a nearby pedestrian).
Category – Vehicle Entry and Exit				
Preparation for PUDO	82% (34)	91% (22)	73% (12)	Information that prepares riders for the pick-up or drop-off phases of their ride-hailing trip, such as understanding when an ADS will/has arrived for pick-up, when a destination has been reached for drop-off, and conditions to be aware of prior to approaching/exiting the vehicle.
Entering the Correct ADS	77% (29)	64% (14)	91% (15)	Information and interactions riders require to identify the correct vehicle as well as for entering the vehicle and starting their trip.
Orientation & Mobility	50% (26)	100% (26)	0% (0)	Information that allows riders to understand their current positioning and its relation to a desired destination while safely navigating toward that destination.
Category – Perceived Comfort and Safety				
Comfort & Peace of Mind	82% (41)	82% (16)	82% (25)	Information or interactions that will increase riders' level of comfort when using the ADS and/or their peace of mind during driving scenarios.
Safety	82% (36)	73% (21)	91% (15)	Concerns related to the safety of the ADS rider and other road users (e.g., pedestrians, drivers, cyclists).

4.4   Discussion

Below, we discuss BLV and sighted participants' information requirements (RQ1) and user interaction requirements (RQ2) (Sections 4.4.1 and Section 4.4.2), and highlight any similarities

and differences amongst the two groups (RQ3). Additionally, we discuss findings related to information and interaction requirements for entering and exiting an L4+ ADS (see Section 4.4.3). Additionally, Study 1 findings were used to generate design guidelines and recommendations for developing accessible L4+ ADSs (see Section 0).

4.4.1 RQ1: What information do BLV and Sighted riders require during different scenario?

Scenario 1: Construction Zone

When discussing information participants would want when encountering an unexpected construction zone in an L4+ ADS, four topics were similarly prevalent across both BLV and sighted focus groups, which were trip information, object detection and recognition, ADS's actions, and environmental awareness.

Trip Information – When encountering an unexpected construction zone in an L4+ ADS, every participant stated that they would want information related to their trip. Across both focus group demographics, participants frequently described information relating to the detection of an upcoming construction zone, anticipated delays to their estimated time of arrival (ETA), and possible alternative routes to avoid the construction zone entirely. It is no surprise that participants would expect this trip related information from L4+ ADSs as this information is similar to details often provided by current GPS navigation apps (e.g., Waze, Google Maps). Another potential reason for focus group participants wanting trip related information could be related to the general public's concerns towards future ADSs' ability to perform trips as scheduled and in a timely manner (Naujoks et al., 2016).

While the need to provide real-time trip updates may seem obvious, a comment by P06 emphasizes how critical this information could be for a BLV rider:

> P06 (low vision): "I would absolutely want the ADS to say, 'we are stopping due to a construction issue.' Because sometimes you might have a stop on that road, and you might be counting stops in the back of your head, and this would be an extra one that you normally wouldn't have."

The ability to receive updated trip information could prevent BLV riders from experiencing confusion when disruptions occur while navigating and following a mental map of their trip (Quiñones et al., 2011). In addition to riders wanting this information to understand dynamic

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adjustments to their trip, some BLV and sighted participants also suggest that access to this trip information could increase feelings of comfort and safety while riding in L4+ ADSs:

> P05 (sighted): "I think it'd be really helpful for [the ADS] to say, 'construction ahead,' or 'recognized,' or something like that. I'm just thinking of being in this scenario that it can be really scary that you're not sure if [the ADS] sees that [construction zone] and if it's going to try to like speed through this [construction zone] or something."

We find it interesting how trip information, which is often provided through current GPS navigation services, could also be useful in establishing confidence in L4+ ADSs by providing riders with an early indication of an ADSs' awareness of the upcoming scenario. Furthermore, participants' comments about using trip information to build their confidence in the ADS is reminiscent of how BLV individuals currently build their confidence in human operated transit services by aligning a vehicle's maneuvers with information provided via a GPS navigation app (Brewer and Kameswaran, 2019). Perhaps during certain driving scenarios, trip information provided by an L4+ ADS could serve a subsidiary purpose of establishing rider's confidence or peace of mind while achieving the primary goal of keeping riders updated about their trip.

ADS Actions – In total, 73% of participants mentioned that they would desire information relating to the current and upcoming behavior of their L4+ ADS when approaching and navigating through a construction zone. Specifically, participants would want to know that the L4+ ADS will slow down and stop at the construction zone as well as understand how the ADS intends to navigate around the construction zone using the temporary, alternative path:

> P04 (sighted): "I think that on the screen, it would have to be like the speed that the car is going on, and then you can see that this car is slowing down by the decrease in the miles per hour and maybe they also have words, 'slowing, approaching construction zone' appears on the screen too."

> P24 (blind): "say something like, 'veering right to go around the construction zone' [...] some small piece of information so that I would understand we're not getting off the track really, but you know, there's a reason for this."

Interestingly, only BLV participants mentioned the need for information that indicates a return to the original route:

P19 (low vision): "…and then once [the alternative path] concludes, 'we're back on our regular speed and our regular route.' I think I'd feel uncomfortable if all of the sudden, I saw that the vehicle sped up, and it was going at 45 or 55 as opposed to 20."

As suggested by P19, without proper awareness of a shift in driving environments, BLV riders may feel unprepared for any changes in driving behavior (e.g., sudden acceleration) or possibly concerned if they think they are still in a risky environment (e.g., construction zone). Alternatively, because sighted riders would be able to independently detect changes in the driving environment, they could predict shifts in driving behavior as well as quickly verify that an ADS's driving performance is suitable for a driving environment, which potential explains why this design detail (i.e., notifying the end of the construction zone) was not mentioned by any sighted participants. While this difference between groups is minor, it is representative of how subtle differences in otherwise similar information requirements could yield design insights that may allow BLV riders to feel more comfortable in L4+ ADSs when experiencing CDSs.

Object Detection and Recognition – Across all participants, a majority (77%) stated that they would want to know that an L4+ ADS has detected and recognized important objects related to the construction zone. However, information relating to object detection and recognition was more extensive across sighted groups (82%) compared to BLV groups (55%). Even with the difference in extensiveness, both participant groups reported wanting similar information, which was information about an ADS's detection of a construction worker and construction signage. A few BLV participants mentioned a noteworthy reason for wanting to know about the presence of the construction worker:

P26 (low vision): "Another reason why I would want to know that there's a human object is in case for some reason, I may have a question. It will be nice to be able to communicate questions that I may have if I so choose to do so. I may have a question about what, something about the construction, or… it just leaves room for interaction I guess, human interaction. […] in a perfect world, I would just like to have like a just a low down and quick description of like what the person looks like. Like, male with construction clothing holding a stop sign…"

P08 (low vision): "knowing there's a warm body there and that if I need further clarification, I can get it from him."

These comments suggest that BLV riders may want to understand when other humans are in their vicinity during CDSs as they may serve as additional sources of information. Knowing specific

details of the nearby person, as described by P26, could help riders determine the credibility of information that person could provide. For instance, understanding the nearby person is the construction worker (as opposed to a standard pedestrian), a BLV rider may seek them out to obtain additional insight about the construction zone.

A majority of BLV and sighted participants also stated they want to know that the L4+ ADS is aware and understands the meaning of nearby construction signage. Specifically, 82% of sighted and 45% of BLV participants were interested in an ADSs' detection and recognition of signage operated by construction workers to control and direct traffic flow around the construction zone (see Figure 7):

> P13 (sighted): "that [the ADS] can be reactive enough so, you know, if it flips from the 'stop' to 'slow' […] Like will it be able to detect when it switches over."

> P09 (blind): "let me know that this person holding the sign and they're going to lower the sign and if they lower the sign; they put up the 'you can go sign.' I would like that information some kind of way relayed to me."

Figure 7. Example of signage used by construction workers to direct traffic.

Lastly, one major difference between BLV and sighted participants was that 45% of sighted participants mentioned that they would want to know the ADS detected signage leading up to the construction zone, whereas this was mentioned by none of the BLV participants. This finding

supports Miglani et al. (2016) finding that (presumably sighted) participants wanted to use the HMI to match objects recognized by the ADS to what they could see in the environment.

Environmental awareness – Lastly, participants from both groups (64% in total) mentioned wanting information that could provide an increased understanding of the construction zone environment and where objects were located throughout that environment. As represented in the comments below, a few sighted participants (36%) wanted to know the layout of the construction zone:

> P04 (sighted): "I think I'd want some confirmation on the screen that the path of the cones is visualized by the car."

> P12 (sighted): "I'd like to know if, you know, is it that a lane is blocked?"

Similar to sighted participants, 45% of BLV participants stated wanting more information relating to distances relative to events or objects in the environment, which included primarily the distance to the construction site as well as the construction worker. Additionally, some BLV participants wanted information beyond objects relating to the construction site, but rather information that helps them understand where the construction site is along their route:

> P19 (low vision): "where are we? […] a road or intersection. The closest marking that [the ADS] can identify to where the construction worker has the STOP sign."

Scenarios 2 – 4: Emergency vehicles in the vicinity

For scenarios 2, 3, and 4, all of which included the presence of an emergency response vehicle, we noticed three codes (within the information requirement category) were consistently the most frequent across all three scenarios, which were (1) object detection and recognition, (2) ADS's actions, and (3) environmental awareness. Upon further examination of comments that were assigned these codes, we determined participants desired similar information from L4+ ADSs across all three scenarios. Thus, we have condensed the findings from scenarios 2 - 4 into a single section to succinctly present participants' information requirements during scenarios where emergency vehicles are in the vicinity.

Object detection and recognition – Across all three emergency vehicle scenarios, 91% of BLV participants and 91% of sighted participants mentioned wanting to simply know that their ADS detected the presence of an emergency response vehicle:

P03 (sighted): "I would want to make sure that [the ADS] was able to recognize the emergency vehicle […] I want to feel comfortable and know that [the ADS] recognized that."

Furthermore, 73% of BLV participants mentioned that they would want the L4+ ADS to specify the type of the emergency vehicle, whereas only 36% of sighted participants desired this information. One reason for wanting this information from an L4+ ADS is that it could provide information that may otherwise be unperceivable by BLV riders, which could influence riders' behavior:

P06 (low vision): "I'd like to know if it's 'statie', or a local, if it's a college police […] I would like to know roughly who I'm speaking to because obviously the guy will have a name on a badge, you know like 'Jay Shmidt' (note: this is a fabricated name), but I won't be able to see that. So, I'd like to know where this person is coming from, because I might be able to be more clear if he has a question for me."

ADS's Actions – Seventy-three percent of all participants (64% of BLV and 82% of sighted participants) stated they want to know how their L4+ ADS intends to respond to an emergency vehicle for all three scenarios:

P20 (blind): "All I would need is really, 'emergency vehicle ahead. Moving to center lane to avoid.'"

P11 (sighted): "something acknowledging that something was detected ahead and then either like 'slowing down' or 'moving lanes' […] something that's like either 'police detected ahead, changing lanes' or 'police detected ahead. Can't change lanes. Slowing down.'"

P08 (low vision): "I want to make sure I understand what's going on in the moment. 'We're slowing down, this officer wants a word.' […] 'I'll be slowing down now.' Or at least 'pulling off to the shoulder.'"

Specifically for Scenario 4 (i.e., the L4+ ADS moves into a four-way intersection on a red light to allow space for the emergency vehicle approaching from behind to pass), 45% of sighted participants and 35% of BLV participants mentioned they would want to be aware that the ADS was performing an unusual action, or an "evasive maneuver", to yield to the emergency vehicle:

P14 (sighted): "I'd want to know that it's initiating some sort of evasive maneuvers. It's initiating a maneuver to allow passage of an emergency vehicle, I just want some sort of prompt like that."

P25 (blind): "'Moving forward to clear the way for emergency vehicle.' That is what I would want to say. Maybe, 'Running a red light.'"

Environmental awareness – Eighty-two percent of BLV participants and 64% of sighted participants want to know information about the location of other vehicles relative to their position:

P25 (blind): "[The ADS] announcing, saying, 'vehicle ahead on the shoulder.' And then it just moving one lane over and that's it"

P07 (blind): "…identify the vehicle approaching and where it is approaching from…"

A few sighted and BLV participants want to know the location of other non-emergency vehicles in the vicinity. This would help support riders' understanding of whether their ADS was about to perform a safe maneuver.

P12 (sighted): "I would like to know it doesn't see any traffic coming towards it, like we're not pulling out too far from the intersection into oncoming traffic."

By examining the comments that were assigned the three codes detailed above, we were able to find many similarities between both BLV and sighted participant groups. These similarities suggest that when L4+ ADSs are reacting to an emergency vehicle in the vicinity, both BLV and sighted participants desire simple explanations that include three components: (1) the detection of the emergency vehicle, (2) ADS's intended actions in response to the emergency vehicle, and (3) the location of the emergency vehicle.

Scenario 5: Degraded State

When discussing information participants would want during the degraded state scenario, four codes were similarly present across both BLV and sighted focus groups, which were (1) trip information, (2) object detection and recognition, (3) environmental awareness, and, (4) system and vehicle status.

Trip information – A majority of all participants (86% in total) stated they would want information about how the scenario impacts their overall trip. We discovered similarities and differences in the details that each group wanted related to the timing of steps being taken to solve the situation. The most desired piece of information relating to the trip by both participant groups (64% of sighted and 64% of BLV participants) was knowing how long until the new ADS arrives. One difference found between groups was that a majority of sighted participants (73%) desired information

relating to how the scenario impacts the overall ETA for their trip, whereas only two BLV participants, which were in the same focus group, made a similar comment. Alternatively, several BLV participants mentioned needing to know additional information (e.g., ETA of the tow truck driver) as well as knowledge of their current location. Interestingly, no sighted participants mentioned wanting to know the ETA of the tow truck driver. One possible explanation for this dissimilarity in the need for this information could be related to differences in participants' capability to independently detect the arrival of the tow truck driver. For instance, BLV riders might need to have a general sense of when a tow truck driver would arrive in order to prepare for any possible interaction that might occur with that driver:

> P08 (low vision): "if that worker is approaching, now I need to know […] So, I know that there's a person, a live body, who's deliberately coming up, probably to talk to me, so I wouldn't jump if I didn't see them when they're suddenly a knock on the window."

Object detection and recognition – The majority of all focus group participants (82% of sighted and 64% of BLV participants) stated they want information indicating that the ADS has detected and recognized two specific objects: the new ADS and the tow truck/tow truck driver. However, the need for information about the detection of the incoming ADS was more extensive throughout sighted participants (73%) compared to BLV participants (36%). On the contrary, information about the ADS detecting the arrival of the tow truck as well as verification of the tow truck was slightly more extensive throughout BLV participants (55%) compared to sighted participants (36%). Similar to the construction zone scenario, it appears that the detection and verification of the tow truck and truck driver could inform BLV riders of possibilities for communicating with another source of information:

> P24 (blind): "realistically, if I knew somebody was coming near the car, I might roll down my window. If I knew the tow truck arrived, I would just speak to the human being. Just to verify that I needed to stay in the car."

Another reason why information about the tow truck driver could be important is related to safety concerns. Both BLV and sighted participants expressed concerns about strangers or non-verified companies:

> P09 (blind): "…you don't know whose around to just wait for the opportunity to have an ADS stop and then you know somebody to say 'Okay, this is usually, what happens, so now we can take advantage of these people' […] "I will want [the ADS] to be telling me

who the tow truck driver is, what's their name, and you know, the company and identify that. I would like that information."

P02 (sighted): "for the tow truck, if it's being driven by human, knowing who is going to come pick you up will be safe […] having that information: the license plate, the person driving the tow truck; I think that would probably put me at ease."

P14 (sighted): "I would want to know that is their [the ride-hail service's] tow truck, not just some random tow truck."

By knowing that the ADS is aware of the tow truck company and has access to identifying information about the driver, L4+ ADS riders might feel more comfortable during scenarios where they are more vulnerable.

Environmental awareness – Seventy-three percent of BLV participants stated that they would want detailed descriptions of their current location and the surrounding environment once the ADS pulled over. Opposingly, no sighted participants mentioned wanting information that could provide them with an increased understanding of their surroundings. Examining BLV participants' responses indicated that they would desire information about landmarks (e.g., nearby shops, mile markers, guardrails), the topography of the area, and safe areas that they could wait outside the vehicle:

P09 (blind): "tell you what's around you. I mean 'there's a major shopping center,' […] I would definitely want to immediately know where I am, my location and what's around my location."

Later in this scenario, after the new ADS arrived, 45% of BLV participants stated they wanted detailed description of where exactly the new ADS was positioned. However, as this relates more to exiting the ADS, we discuss information requirements relating to locating the new ADS in Section 4.4.3.

System and Vehicle Status – Finally, there was one noteworthy topic that was exclusive to the degraded state scenario, which was understanding the status of the ADS. Interestingly, just under half of all participants (55% of sighted and 36% of BLV participants) mentioned wanting to know details about the issue that caused the ADS to stop the trip. We found this lower percentage to be surprising as previous work on Level 3 ADSs suggest the importance of providing information about ADS status or sensor failures to riders (Naujoks et al., 2019). Perhaps, because L4+ ADSs remove occupants entirely from the driving task, even during system failures (e.g., L4+ ADSs

perform minimal risk condition maneuvers), the need to understand details related to the system failure is less important compared to Level 3 ADSs. Regardless, as mentioned by BLV and sighted participants, information about the status of the ADS could still serve the purpose of informing riders of the safest actions to take following system or vehicle malfunctions. More specifically, information about the detected issue could influence whether the rider should exit the vehicle or not:

> P06 (low vision): "I would want to know if it is dangerous for me to stay in this vehicle […] is there something that really would be unsafe for me to stay there and should I get out?"

> P12 (sighted): "I'd like to know why it's pulling me over. Did it detect a flat tire or is smoke pouring from the engine? Are we out of gas? What [the ADS] knows, why it's pulling over, what it detected?"

4.4.2 RQ2: What user interactions do BLV and sighted riders expect?

Focus group discussions revealed system interactions as well as interaction modalities that both BLV and sighted participants would want while riding in L4+ ADSs. Regarding system interactions, there was a shared interest between BLV and sighted participants in wanting the ability to (1) control aspects of their ride in an L4+ ADS, (2) personalize their riding experience based on their preferences, and (3) request additional assistance or information.

System Interactions:

Controlling the ADS – Eighty-two percent of sighted participants and 64% of BLV participant mentioned wanting the ability to control certain aspects of L4+ ADSs. This finding is common across related work that suggests people generally want to keep some control over the ADS rather than relieve complete control to the system (Golbabaei et al., 2020). Discussions from both BLV and sighted groups suggest that participants primarily want the ability to (1) re-route the ADS during the trip and (2) request the ADS to pullover and stop.

Both participant groups mentioned wanting a feature for re-routing the ADS in response to situations where their trip might be delayed (e.g., unexpected construction zone). Furthermore, participants expect the ADS to automatically provide an overview of route options and let riders select the best route.

P02 (sighted): "[the ADS] provides options as to, would you want to continue in your current path? Would you want an alternate route? And if you choose route A or B or C, it is going to tack on this additional amount of minutes to your trip."

BLV and sighted participants also stated wanting an ability to control when the L4+ ADS should pull over or quickly stop. However, the reasoning for using this type of interaction seemed to differ depending on the scenario. For instance, some BLV focus group participants mentioned wanting to instruct the ADS to pullover if it was not responding properly to the approaching emergency vehicle or if the ADS stated it was unaware of the emergency vehicle's intentions.

P08 (low vision): "…so [the ADS] can tell me the cop is there but not coming for us because it's far enough back and it's about the move to another lane […] Or if that's unclear, then, 'should we pull over?' should be an option [presented by the ADS] before we're at the point where we know that we have to [pull over]."

P20 (blind): "Think, you might need to have multiple options [to stop/pullover the ADS], maybe either speak it, or have it in the app, or have it if there's a button you can press in the vehicle, I mean, you know, if it was an emergency."

This was a similar rationale expressed by a few sighted participants:

P16 (sighted): "I think that if it was a police car, I think you would directly go to the 'pullover button' and just, if the car doesn't automatically recognize it to pull over, then you can press the physical button in the car so that tells it a go over to the shoulder and wait."

P02 (sighted): "Give me the option: 'what would you want to do? Would you want to change lanes? Do you want to slow down or pull over?' I think I would love that option, both visually and auditory."

Participants' responses relating to instructing the ADS on the correct action support findings from previous literature, which reported that riders want the ability to inform the ADS on appropriate actions or to assist the ADS in interpreting the scenario (Wiegand et al., 2020). Another trend in controlling the ADS came from sighted participants, who stated they would want an "emergency stop" button in case an L4+ ADS started driving irrationally:

P11 (sighted): "I was gonna suggest just an emergency button that's there in case something like this [construction zone] scenario where it isn't stopping when it needs to or just anything else."

P16 (sighted): "Maybe have a physical button, or a digital button that just says, "pull over" and basically end the trip at that point. Just pull over if it's not too safe."

P13 (sighted): "Yeah, I would definitely like some sort of a stop button if it goes really crazy on me…"

Commanding the ADS to perform an emergency stop was not an interaction stated by BLV participants. Lastly, for situations where an ADS stops at a location other than the destination (due to a requested pull over or system malfunction) some sighted and BLV participants mentioned having the option to end the trip early:

P14 (sighted): "I'd want some sort of notification that it's making unplanned stop and then I would like to be able to talk to an agent to relay if they had any questions [and possibly inform them that] 'I'm close enough. I can walk from here.'"

P22 (blind): "The system should designed like, okay wherever I say, 'drop me off.' If I want to get out immediately, for whatever reason, I could be sick or I just need to get out, for whatever reason, the vehicle needs to let me off at a safe place. If I can't give them an address, I'll say, 'okay, let me off safely at the next corner.'"

Personalization – All BLV participants and 73% of sighted participants provided comments about wanting to personalize their L4+ ADS riding experience. A majority of comments about personalization from both participant groups were focused on being able to adjust the amount of information and the context of the information provided by L4+ ADSs:

P04 (sighted): "the option of how [information] is presented to be defined by the rider maybe at the beginning of the ride. Whether you like auditory or just reading alerts or a combination of both. Maybe you set your preferences and maybe there's a different setting for emergency vehicles versus other traffic that the car may encounter. But that may be a good feature when you get in the car; that you can set the options of what you want to experience; how you want the message conveyed."

P26 (low vision): "I'm wondering if there is a feature that we could switch on and off where it would like, one track will give us key information that we need to know about the route itself and then maybe another one to give more scenic information if we want it. Because maybe I want to learn what's around me, or if I see a restaurant or something that I want to go, I'm like 'Okay, I want to make note of that.'"

As P26 points out, some BLV riders might want to learn more about the surrounding environment, and with the sensing technologies that will be implemented on L4+ ADSs, this technology may have the potential to provide more detailed information about the environment that BLV riders may otherwise be unaware of. Participants' comments also suggest the amount of information

should be adjustable on a trip-to-trip basis due to differences in their levels of comfort, which could vary due to factors such as experience using L4+ ADSs or familiarity with driving environments:

> P11 (sighted): "if it's my first time, then yes, I'm going to say, "Yes please. I want to have the verbal [information] so I know what's going on," but if it's like my 50th time, I don't necessarily need you to tell me verbally every time something's happening, especially if I'm trying to do something else that I don't want to be interrupted.""

Similar to current GPS navigation apps and ride-hailing mobile apps, BLV and sighted participants stated that they would want to customize their trip using their knowledge of the area (e.g., awareness of a construction zone that will cause a delay). Additionally, some BLV participants mentioned the need to select more unique trip preferences, such as avoiding large vehicle types that require large step-in heights to enter the vehicle (e.g., SUVs and trucks). Another difference between participant groups was that BLV participants mentioned wanting the ability to personalize common accessibility settings (e.g., activating and adjusting a screen reader feature on the HMI, increasing text size). Finally, many BLV participants expressed the need to have their personalized settings linked to a user profile that can apply their selected preferences automatically and effortlessly for all future trips.

Request a service – Comments about wanting a system interaction to request remote or in-person human assistance were noticeably more frequent and extensive for BLV participants (82%) compared to sighted participants (45%). The most common reason for needing to be able to request a service for BLV participants was to receive more information about the surrounding environment:

> P19 (low vision): "…for purposes of safety and reassurance, there are a couple of apps that are out there now, Be My Eyes and Aira, and the person comes on and can see the whole situation, can see where you are in traffic, can see the inside and outside of the vehicle and whatnot [...] there may need to be some people back in a call center that can come on and virtually see the lay of the land."

BLV participants mentioned that they would want this interaction across several CDSs, whereas sighted participants only mentioned that they would want the ability to request assistance during the degraded state scenario. This finding aligns with findings from a previous focus group study involving BLV individuals, which also reported that many participants raised questions about being able to request help during unforeseen events (e.g., vehicle breakdown) as well as understand

who would be providing that help (Brinkley et al., 2017). More specifically, sighted participants typically wanted to speak with a human operator to understand what steps are being taken to resolve the situation and receive information related to the new ADS coming to pick them up.

Interaction Modalities*:*

Regarding comments that describe how participants want to receive information (i.e., output modality), 100% of BLV participants mentioned instances where they would want information to be presented only auditorily. While this finding may have been predictable, some of BLV participants' comments still provide a deeper context as to why only auditory information would be beneficial during highly dynamic driving scenarios:

> P07 (blind): "I would want to know what [the ADS] is doing, even if it were doing it in real time. […] I'd want to know what the [LEV] that's approaching, what it's about to do. Where I'm located intersection wise. All that I expect to be audible because we don't have time for screens."

As the above comment suggests, due to the nature of highly dynamic scenarios, automatically presenting desired information auditorily would be more beneficial to BLV riders compared to interacting with the screen to review visually presented information (e.g., adjusting zoom or text size, guiding a screen reader to find desired information). While 65% of BLV participants mention instances where multi-modal could be beneficial or was desired, all comments were related to the use of accessibly designed visual information:

> P25 (blind): "And the information is given to us in whatever format that we set up for ourselves, so that it could be popping up in large print, it could be popping up in audio format, it's whatever settings that we set it up as."

> P19 (low vision): "[the touch screen] would give you directions. It would have large print for those that are low vision. It would have the speaking for either those that are low vision or totally blind."

Comparatively, 91% of sighted participants mentioned instances where they would want information to be presented visually, 91% mentioned instances of wanting auditory information, and 84% mentioned instances of wanting multi-modal information to be presented. Generally, sighted participants mentioned they would want audio information for attention grabbing purposes:

P16 (sighted): "I think that when we're using in AV, you're not particularly paying attention at all times to some display in front of you or like this heads-up display that I mentioning. You're probably on your phone or something, and I think that it's important to have like some verbal feedback coming from the car too."

P13 (sighted): "I prefer that [the ADS] announces it, just in case I was distracted looking at my phone or something like that and not staring at the screen on the back of the seat."

Sighted participants often described wanting information from L4+ ADSs to be presented visually, with some even saying that this modality should be a baseline design characteristic of in-vehicle HMIs:

P16 (sighted): "the visual feedback on heads up display will always be there, no matter what, you can't like change that it just built into the car basically."

One example of the differences between participant groups' desired output modalities used by the ADS can be seen in responses for the construction zone scenario. Sighted participants often want to observe visual indicators of objects in the environment and the ADS's plan of attack, which is similar to previous work (see Section 3.3.2), whereas as BLV participants want similar information requirements to be provided auditorily:

P13 (sighted): "…it can draw out what the car's plan of attack is on a situation like that, so we could see if we're okay with it […] you know that it's not gonna drive right into the construction zone."

P24 (blind): "say something like, "veering right to go around the construction zone" [...] some small piece of information so that I would understand we're not getting off the track really, but you know, there's a reason for this."

Interestingly, BLV participants mentioned a variety of modalities for providing inputs to interact with the ADS, which primarily included wanting to use physical buttons and voice commands:

P07 (blind): "A button I can push, maybe on my end, that forces it out to an interactive person somewhere in the control center."

P22 (blind): "they need to have a feature where you can pick up a phone or say 'help,' so that a live person can come on and say, 'hi, what do you need help with? What's going on?'"

One important detail we found in the limited comments BLV participants made about using touchscreen interfaces was that they always described using the touchscreen in relation to standard screen reader gestures:

> P07 (blind): "I would want the ability to potentially touch the screen and use standard screen reader gestures, which I'm going to call 'standard gestures' to make the adjustment, as if I were using my phone."

When looking at sighted participants' comments, only one mentioned the idea of using voice commands as an input. A majority of sighted participants described using touchscreen interfaces or physical buttons to perform inputs. Finally, one last interesting difference between BLV and sighted groups was found in their explanations of wanting to use an external device, such as a personal smartphone, to perform interactions with the L4+ ADSs during trips. Sixty-four percent of sighted participants stated wanting information to be redundantly available on their smartphones and the HMI touchscreen to ensure they do not miss important information, especially during stressful situations, such as the degraded state scenario:

> P11 (sighted): "as much communication I think if you can give at that point in time is better, so a text message and the audio through the car and the visual on the screen, I think would all be good."

Whereas 73% of BLV participants stated the reason for wanting to use their personal smartphone during the trip was primarily due to their familiarity with their device:

> P24 (blind): "interacting with our iPhone instead of the touch screen [...] because I'm so familiar with it [using their iPhone / personal smartphone]. I'm not familiar with your touch screen."

> P22 (blind): "I think there should be a corresponding phone apps to what would be on the touch screens, because like if this is coming out for the first time and you're in a vehicle and maybe having to learn right then how you would operate on the touch screen, it's kind of unnerving when you feel under the gun. Whereas with your iPhone you're more or less familiar."

4.4.3   User requirements for entering and exiting L4+ ADSs

For the degraded state scenario, discussions about having to wait for the new ADS to arrive revealed information and interaction requirements for entering and exiting L4+ ADSs. Specifically, we identified two codes that were prevalent across both sighted and BLV focus

groups discussions, which were (1) preparation and (2) identifying the correct ADS. With another code that only occurred in BLV focus group discussions, which was (3) orientation and mobility. Interestingly, meaning units derived from BLV group discussions that were assigned one of these three codes also occurred during discussions outside of the degraded state scenario, which we think further emphasizes the concerns related to these topics.

Preparation – For the degraded state scenario, discussions about waiting for the new ADS to arrive revealed that 73% of sighted participants would want information that would help prepare for entering the new vehicle. This desired information would primarily include information about the ETA of the incoming ADS and notifications of its arrival. To monitor the progress of the incoming ADS, sighted participants often mentioned the idea of having access to a map in order to view the ADS's location in real-time.

Ninety-one percent of BLV participants mentioned they would want information that would help prepare for entering and exiting an ADS. Similar to sighted participants, a majority of BLV participants stated that they would like to receive information relating to how far away the new ADS was and understand when it has arrived. However, 55% of BLV participants wanted a description of the surrounding environment to learn of any hazards to be aware of when exiting and/or areas that are safe for vehicle exit (e.g., away from moving traffic):

> P09 (low vision): "I have gotten out on the sides of roads that have a very steep decline, after two feet or one foot after you get out of a vehicle. So, I would want to know that. I would want to know the topography of the site. Especially if you're on a two-lane highway with trees, foliage, all that kind of stuff, it can be a little rough."

Unlike sighted participants, a few BLV participants described information that they would find useful for preparing to exit L4+ ADSs when nearing a destination. One piece of information would be announcements of street names they pass when approaching their destination:

> P19 (low vision): "There'd have to be announcements within the car, 'we are now at 22nd and Main' or… how would you know where you want to get off unless there were announcements within the vehicle?"

Additionally, if an ADS had to stop (e.g., for a traffic light) when near a rider's destination, information clarifying that they are not at their destination could prove useful in preventing participants from trying to exit the vehicle prematurely:

P20 (blind): "they could have [the ADS] programmed to speak, you know, 'the car is stopping. You're not at your destination, yet.'"

Orientation and Mobility – Even though all focus groups were provided similar discussion prompts related to navigating to the new ADS, the mobility and orientation code only applied to discussions generated from BLV focus groups. When sighted participants were asked if they would require any information to be provided when navigating to the new ADS, 73% stated they do not need any information:

P05 (sighted): "I don't think you need anything on the way to the new ADS."

P16 (sighted): "the previous ADS showed you all the information, showed you the license number and everything, so I don't really know what else you would need between the short distance from one AV to the other."

Opposingly, 100% of BLV participants mentioned wanting information for orientation and mobility purposes. Details BLV participants frequently provided in their responses included exact distances, directions relative to themselves, as well as landmarks and objects in the environment:

P20 (blind): "if you're travelling with a cane, you might get out of that vehicle and you're gonna have to know, do I turn left or right? Am I on the shoulder of the road? Where do I go to get to that new vehicle? That's what you've got to know, and you've got to know is there grass along, you can trail with your cane? You've got to know more than just get out of the vehicle."

P26 (low vision): "Identifying a place on the side that's safe would be important to know […] if it said, like, 'a sidewalk 5 feet to your right,' or something."

While the previous quotes show information that could be useful prior to exiting the vehicle, 73% of BLV participants also described a system interaction that would allow riders to receive orienting information while navigating outside the vehicle. Specifically, they would want the ability to request on-demand audio chimes from the nearby ADS or verbal instructions from their smartphones to locate their requested L4+ ADS:

P25 (blind): "Having our phones say, 'hey, your arrived ADS is 10 feet behind you,' from our personal devices, or '10 feet behind you, 20 feet to the left.' Kind of describing exactly where it is from where we are. And then have like a little remote inside of our settings, and that we don't mind the car announcing something to us, we could press that little remote button and it could beep at us or like some kind of unique sound saying, 'Hey, ADS!' And then we can follow the sound of where the ADS is. And I'm just talking for someone who's

totally blind with no functional vision. And then we would be able to find it with those two things."

Finally, to assist with orientation and mobility, 36% of BLV participants mentioned receiving assistance from another person in the area (e.g., tow truck driver) or remote volunteers accessed through mobile apps (e.g., Be My Eyes).

Identifying and entering the correct AV – Ninety-one percent of sighted participants mentioned that they would want visual information about the incoming ADS's vehicle description, such as a license plate number, make and model, and color to ensure they can identify the correct ADS. Also, a majority of sighted participants would want all of their settings and trip information from the last ADS to be automatically transferred to the new ADS. Participants stated this would increase convenience as well as be useful in confirming they are in the correct vehicle:

> P04 (sighted): "it would be nice maybe if the second AV was able to get the same settings that you're using and the other AV […] you had selected certain options for how you want messages […] maybe it picks up the same route that you were on, so you get in and see that the route is already there and it knows that it's taking you still to the same destination and see the new ETA on the screen."

Sixty-four percent of BLV participants mentioned they would require information that could be used to identify the correct vehicle as well as improve the process of entering vehicles. Similar to sighted participants, 45% of BLV participants mentioned the importance of having vehicle description information to assist with correctly identifying the desired ADS. Vehicle descriptions could be beneficial for low vision individuals who are capable of perceiving noticeable vehicle features, such as type (e.g., SUV vs. sedan) and color. Additionally, knowledge of vehicle descriptions can still be beneficial for individuals who are completely blind when able to ask for assistance from nearby pedestrians or a remote, sighted guided via mobile app:

> P20 (blind): "I mean, sometimes when I'm waiting for Lyft and there are multiple cars, I asked someone. I mean I know what cars coming, so I might say, 'I'm looking for a Ford Fusion, do you see such and such?'"

As it relates to entering the ADS, 36% of BLV participants wanted information on the vehicle's step-in height and presence of other occupants or available seats:

P08 (low vision): "So when you arrive and the doors open, it could say something like 'this is an SUV there will be a step up,' 'this is a Sedan just slide on in.' I think that that would be a really big help with the vehicle, with you just in entering and exiting."

Interestingly, no BLV participants mentioned wanting the trip information to be provided to them again upon entering the new ADS for the degraded state scenario. One possible reason for this could be due to the majority of discussions focusing on describing orientation and mobility information leading up to the entering the new ADS.

5 Study 2

5.1 Objective

Investigate BLV riders' responses to real-road simulated L4+ ADS ride-hailing experiences.

In Study 2, we simulated a L4+ ADS ride-hailing experience that required BLV participants to perform a vehicle ingress task and experience two real-road trips. To better understand how to improve accessibility for BLV riders prior to entering and after exiting L4+ ADSs, we had participants engage in semi-structured interviews while walking up to and entering the test vehicle (i.e., pick-up) and just prior to exiting the vehicle to head to their destination (i.e., drop-off). Additionally, we examined participants' reactions to different driving scenarios (e.g., stopping for stop signs), L4+ ADS driving styles (e.g., smooth vs. quick decelerations), and driving environments (e.g., highways vs. rural roads) during two on-road trips in a simulated L4+ ADS. Essentially, we wish to understand whether specific driving maneuvers, driving styles, and/or driving environments result in BLV riders requesting information from L4+ ADSs. Thus, Study 2 addresses the following research questions:

RQ4.   What information do BLV riders value when being picked-up and dropped-off by L4+ ADSs?

RQ5.   What driving maneuvers during L4+ ADS trips warrant information from BLV riders?

RQ6.   How do differences in L4+ ADS driving styles influence information requested by BLV riders?

RQ7.   What driving environments during trips in L4+ ADS warrant information from BLV riders?

5.2 Method

5.2.1 Participants

We recruited 13 participants (female = 6, avg. age = 68.50, *SD* = 4.09; male = 7, avg. age = 49.86, *SD* = 13.36) from the New River Valley (VA) area that self-identified as blind or low vision and are 18 years of age or older. Seven participants self-reported being blind (avg. age = 64.71, *SD* =

12.01) and six reported having low vision (avg. age = 51.17, *SD* = 12.80). Additionally, because we wanted to investigate requirements for assisting BLV individuals with independently locating, navigating to, and entering vehicles, we recruited participants that required no physical mobility assistance (e.g., crutches, wheelchair, another individual) when walking and getting in/out of vehicles.

Table 5. A breakdown of participants demographics.

Self-reported degree of vision	Count	Perc.
Blind	7	53.8%
Low Vision	6	46.2%
Length of time with vision loss		
Since birth	7	53.8%
≤ 20 years	4	30.8%
$21 - 50$ years	1	7.7%
50+ years	1	7.7%
Gender		
Female	6	46.2%
Male	7	53.8%
Age Range		
$18 - 24$	0	0%
$25 - 34$	0	0%
$35 - 44$	3	23.1%
$45 - 54$	2	15.4%
$54 - 64$	2	15.4%
65+	6	46.2%
Race		
White	13	100%
Familiarity with area		
Not familiar	6	46.2%
Familiar	7	53.8%

During the recruitment process, we also evaluated participants' level of familiarity with the study location (i.e., Blacksburg) by having them rate their familiarity with roads included in our designed routes and other nearby roads using a 4-point Likert scale, with 1 being "not at all familiar" and 4 being "definitely familiar." We believed that individuals who are more familiar may request less information during study tasks compared individuals who are less familiar. That is, individuals who recognize their location or aspects of the driving environment may not require additional

information (from the L4+ ADS) during trips. Thus, through the screening process, we initially attempted to only recruit individuals that were unfamiliar with local roads. However, due to difficulties with recruiting enough participants with this specific background, we eventually broadened our eligibility criteria to include individuals familiar with local roads. As a result, we ended up with six participants who were not familiar and seven participants who were familiar (avg. familiarity rating = 2.67, *SD* = .91).

Participants were recruited via advertisement emails sent out to the Graduate Student and Industrial and Systems Engineering listservs. We also contacted BLV individuals that participated in previous research efforts. Most notably, we received assistance with disseminating our recruitment materials from local and national organizations serving the BLV community.

5.2.2 Design of real-road trips and driving scenarios

To understand how differences in L4+ ADS riding experiences influence BLV riders' need to request information, we used a within-subject study design to examine participants' responses to two trips in a simulated L4+ ADS on real roadways. Before highlighting the unique details of each trip, we first address how we attempted to overcome challenges associated with conducting studies on public roads.

Due to the unpredictable nature of real roadways, we were aware that the frequency and type of driving scenarios could be inconsistent across participant sessions. For instance, uncontrollable factors such as timing of traffic lights, presence of pedestrians in crosswalks, and actions of other drivers could result in different types of driving scenarios occurring across participants. Inconsistencies across study sessions could reduce our ability to detect common trends in the information BLV riders desire for driving scenarios. Therefore, we designed each trip such that specific driving scenarios would be more likely to occur consistently across all participants without impacting the ecological validity provided by on-road studies. Both trips included roads with specific traffic signals (i.e., stop signs) and road structures (i.e., traffic circles) that require specific driving maneuvers to be performed (i.e., stopping for stop signs, turning in a traffic circle). To examine driving maneuvers that could not always be enforced by traffic signals or road structures, we included long segments of road to allow ample opportunities for maneuvers to be performed (i.e., multiple lane changes over 3-miles on a highway). As a result of our trip designs, participants were able to experience a variety of planned driving maneuvers that were repeated across both

trips. However, as detailed in following paragraphs, each trip provided participants with different simulated ADS driving styles for the planned driving maneuvers (e.g., quick vs. smooth decelerations at a stop sign). Furthermore, to explore if driving environments influenced riders' information needs, we incorporated a variety of road types (i.e., highway, business park/urban roads, and local rural roads) that ranged in speed limits (i.e., 65, 35, and 25 mph). The deliberate design of both trips should allow us to explore the unpredictability of real roads while still maintaining sufficient experimental control to explore BLV riders' needs to specific driving maneuvers, styles, and environments (see Table 6).

Table 6. Lists the three independent variables we explored using two simulated L4+ ADS trips.

Independent Variables	Variable Levels
Planned Driving Maneuvers	3: stopping for stop sign, using a traffic circle, and changing lanes
Simulated ADS Driving Style	2: expected (smooth and comfortable) and unexpected (quick and jarring)
Driving Environments	3: highway, business park/urban roads, and rural roads

The *Expected Trip* (ET) represented a L4+ ADS riding experience that riders would anticipate when using ride-hailing services. The ET was designed such that we can investigate what information BLV riders want when L4+ ADSs are operating perfectly and without any unexpected or jarring driving scenarios. During the ET, participants experienced a comfortable ADS driving style across all driving scenarios (e.g., smoothly decelerating to a stop). Additionally, the ET only consisted of environments with well-maintained surfaces (e.g., smooth pavement). See Figure 8 for an overview of the ET.

Figure 8. Overview of the ET (left) and UT (right). Both trips start and end in a parking lot indicated with the red pin icon and travel in a counterclockwise pattern with the final portion of both trips taking place on the highway.

Alternatively, the *Unexpected Trip* (UT) represented a L4+ ADS riding experience that riders would not anticipate encountering when using ride-hailing services. We designed the UT to evaluate whether unexpected driving scenarios that introduce different driving style and environments (compared to the ET) influences information desired by BLV riders. The UT was comprised of five unexpected driving scenarios (see Figure 8). Two driving scenarios were exclusive to the UT (i.e., unexpected stop in a parking lot, using a poorly maintained rural road). At the midway point of the UT, the ADS unexpectedly stops in a parking lot for 30 to 60 seconds. We designed this driving scenario to explore what information BLV riders would seek when experiencing a trip interruption due to an unknown reason. The other driving scenario exclusive to the UT involved the ADS driving along a rural driving environment with rough terrain that could be physically and auditorily detected by vehicle occupants. The other three unexpected driving scenarios for the UT were similar to three ET scenarios with the only difference being the simulated driving style used to perform the maneuvers (i.e., quick decelerating at a stop sign, full lap of traffic circle, and quick lane changes) (see Figure 9). To understand the differences in the vehicle parameters for the ET and UT driving styles please refer to Table 7. All remaining driving

scenarios during the UT provided riders with the same comfortable ADS driving style that was used in the ET.

Figure 9. Both the ET (left) and UT (right) included three driving scenarios located at identical locations and required the same driving maneuver. However, the ADS driving style differed depending on the trip (see Table 7). Scenario A required the ADS to deceleration from 25 mph to a stop for a stop sign located at a 3-way intersection. Scenario B required the ADS to use a traffic circle to exit onto the next street. Scenario C required the ADS to perform up to four lane changes while traveling on the highway at 65 mph.

Lastly, one concern with performing real-road studies is the potential for inconsistencies between participant trials due to a safety driver's ability to consistently reproduce simulated driving behaviors (Bengler et al., 2019; Scheiter et al., 2020). To account for this concern, we performed two tasks in preparation for participant trials. First, we referred to the university's course schedule to determine times to conduct all participant trials such that pedestrian and vehicle traffic density along both trips are greatly reduced. Second, we required up to ten hours of practice to ensure the safety driver is familiar with both trips and all study protocols. During practice sessions, we monitored the safety driver's speed as well as longitudinal and lateral forces rates to ensure they consistently produced the various L4+ ADS driving styles for all participant trials (see Table 7). To prevent distracting the safety driving while navigating public roads, we decided against installing any device(s) that provides real-time feedback on driving performance. Once the safety driver was able to consistently produce the desired results and completed a minimum of ten hours of practice, we started participant trails.

Table 7. Lists the target vehicle parameters for the driving styles produced during the ET and UT. The table specifically highlights the three driving scenarios detailed in Figure 9. We determined the driving style parameters based on research examining the average longitudinal acceleration and decelerations performed by human drivers (Hugemann and Nickel, 2003) as well as research that defined a "comfortable" or "everyday" ADS driving styles with longitudinal and lateral acceleration forces (Ekman et al., 2019; Yusof et al., 2016; Rossner and Bullinger, 2019; Festner et al., 2017). Additionally, the maximum parameters for the UT driving styles were influenced by VTTI safety committee review.

Location	Driving scenario	ET driving styles	UT driving styles
A	Deceleration to stop (Longitudinal accel.)	$\leq$ -0.3 g	-0.4 to -0.5 g
B	Traffic Circle (Lateral accel.)	Exit on first pass through	Exit on second pass through
C	Lane Changes (Lateral accel.)	$\leq$ 0.1 g (over 6-8 sec)	0.2 to 0.3 g (over 3-4 sec)

5.2.3   Equipment and Test Vehicle

We used a 2018 Chevrolet Malibu 4-door sedan to simulate L4+ ADS ride-hailing experiences. The exterior of the test vehicle was equipped with a forward, rear, and two side facing cameras to capture the surrounding driving environment. The interior of the test vehicle was outfitted with a camera and microphone to record participants' behaviors during trips. Additionally, we installed a physical button that participants were instructed to press when they wanted information relating to the ADS's driving behaviors or general riding experience (e.g., trip progress, current street location, environment description). Although we never provided participants with any sought-after information, we considered the action of pressing the button to be an indication of wanting information, which is why we refer to this action as an *information request*. We also mounted a smartphone directly in front of participants on the back of the front passenger's seat headrest. As we detail later in this section, we used this smartphone to communicate with participants via an audio-visual conference call during trips. Finally, the test vehicle was equipped with a Data Acquisition System (DAS), which collected and stored data from the vehicle's sensors (i.e., longitudinal and lateral accelerations, speed) and other installed equipment (i.e., cameras, microphone, handheld button). The DAS also tracked the vehicle's GPS location throughout trips.

As a COVID-19 safety precaution, we installed a clear, plexiglass barrier between the safety driver and participants sitting in the second row of seats. Although we did not occlude the participants' view of the safety driver, we attempted to provide participants with a more authentic experience of independently L4+ ADS ride-hailing experience by removing all other research personnel from the test vehicle. We accomplished this independent riding experience by using the Remote Experimenter (REX) system, which allows data to be shared between the test vehicle and a remotely located laptop. Thus, instead of having to ride along with participants, a researcher, herein referred to as the *remote researcher*, was able observe and interact with participants using the remote laptop. As a result, participants were seated by themselves in the second row of the test vehicle during both trips.

Through the use of the REX system, the remote researcher was able to view all data collected via the DAS in real-time during trips via a specialized interface (see Figure 10). Amongst the data provided on this interface, the remote researcher could determine when participants performed information requests as well as communicate with participants following any requests. Upon detection, the remote researcher unmuted themselves on the conference call to communicate with participants. Access to live audio-video feeds of participants riding in the test vehicle as well as to the test vehicle's GPS location, speed, lateral and longitudinal accelerations in real time, provided the remote researcher with a better understanding of driving scenarios (or lack thereof) that prompted information requests. By understanding the context surrounding request to a higher degree, the remote researcher was able to record more thorough field notes as well as use the additional information during post-trip interviews. Lastly, it should be noted that all internal and external vehicle audio-video feeds, button pressing occurrences throughout trips, and vehicle kinematic data (that was recorded via the DAS) were also used in post-hoc data analyses to explore BLV participants' responses to L4+ ADS riding experiences (as well as to evaluate internal consistency in the safety driver's driving performance across all participant trials).

Figure 10. During trips, the remote researcher used the depicted interface to monitor (a) the audio-video feed of participants riding in the test vehicle, (b) the GPS location of the test vehicle, (c) the test vehicle's driving parameters, (d) status of the remote call, and (e) when participants press the button (text flashes red for button presses), in real-time.

5.2.4 Measures

Information for Vehicle Pick-up and Drop-off

To understand BLV riders' information needs for independently performing L4+ ADS pick-up and drop-off (PUDO), we administered semi-structured interviews in realistic situations. For instance, participants responded to interview prompts targeting information requirements for ADS ingress tasks while walking through a parking lot to reach the simulated L4+ ADS. Below are the semi-structured interview prompts we used to identify information requirements for ingress tasks:

1) Prior to the arrival of your requested automated vehicle, what information would you want? How would you want that information to be presented to you?
2) Now imagine that the automated vehicle has arrived and parked somewhere in this parking lot, what information would you require to locate it?
3) What is the most important information for you to know before you start moving through the parking lot?
4) What information would make you feel confident that you are at the correct vehicle?
5) Once in the vehicle, what information would you like to receive before starting your trip?

6) Reflecting on the environment you just experienced, can you think of a different scenario and/or environment that would be more challenging to find your requested automated vehicle?

We also designed interview prompts that targeted egress related information requirements, which were administered prior to exiting the test vehicle after completing the second trip. Interview prompts addressed the following topics:

1) When imagining using driverless AVs in the future, how would you expect to verify that the AV is taking you to the correct destination? At what point during your trip would you try to access this information?

2) If you were to exit the AV independently and navigate to your final destination (like a door of a store), what information would be beneficial to know prior to exiting the vehicle?

3) What information would be beneficial for you after you have exited the AV and are navigating to your destination?

Information Requests During Trips

To determine if BLV riders' information requirements differ for L4+ ADS driving scenarios, we allowed participants to freely perform information requests whenever they desired information about the ADS's driving performance, their trip, or other topics they deemed relevant. We believe that having participants voluntarily and deliberately perform information requests during trips provides a better understanding of the driving scenarios that BLV riders genuinely require information about, which would otherwise be less detectable if participants were required to provide feedback after every driving scenario.

To determine the context prompting participants' information requests, we collected qualitative and quantitative data during simulated L4+ ADS trips. Qualitative data was gathered from conversations with participants following information requests to determine whether participants' information requests resulted from specific driving scenarios or because participants desired information relating to their general riding experience. For information requests that are determined to be caused by driving scenarios, we examined quantitative data collected via the DAS to understand the characteristics of driving maneuvers, styles, and/or environments that influenced participants' information requests.

To further examine participants' information requests across driving scenarios, we used data collected via the DAS to calculate the *time to information request (TIR)*, which is the latency between the start of a driving scenario (T_0) and when the information request occurred (T_1; $T_1 - T_0 = TIR$).

Determining T_0 can differ depending on the maneuvers and/or environments that make up a driving scenario. For instance, for information requests resulting from decelerating maneuvers, T_0 is when the test vehicle's longitudinal acceleration initially exceeds -0.1 g. Whereas for lane changes, we did not rely solely on changes in lateral acceleration because smoother lane changes may not produce a noticeable enough difference in acceleration to identify the beginning of the maneuver. Instead, we reviewed external video recordings to determine when the test vehicle's front tire first touches the lane line to determine when the lane change has been initiated. It should be noted that because ADS driving styles are a characteristic of driving maneuvers, determining T_0 will not differ based on driving style. For instance, T_0 for quick and smooth decelerations will be determined once the vehicle's longitudinal acceleration reaches -0.1 g. For information requests resulting from participants experiencing driving environments, we attempted to identify T_0 using GPS coordinates and external camera footage to determine when the test vehicle changes driving environments. The criteria we used to calculate T_0 for each driving scenario for both the ET and UT are presented in Table 8.

Table 8. Because driving style does not impact when T_0 is identified, driving scenarios for both ET and UT are presented in the left column. A note is included in the left column for instances where driving scenarios are unique to one trip type.

Driving Scenarios	T_0
Smooth and quick decelerations	When longitudinal -0.1 g is reached
Smooth acceleration	When longitudinal 0.1 g is reached
Traffic circle	When lateral ±0.1 g is reached
Turning left and right	When lateral ±0.1 g is reached
Unexpected stop in parking lot (UC only)	When the ADS has come to a complete stop
Smooth and quick lane changes	When the vehicle's tires first touch lane line
Changing driving environments	When test vehicle enters a new environment (e.g., using on-ramp to enter highway)

It is possible that information requests result from unplanned driving scenarios (e.g., slowing for nearby emergency vehicles). If such cases are detected during analysis, we will apply similar methods detailed above for determining T_0 using the vehicle's dynamics and/or video data. Additionally, we anticipate instances along trips where participants perform information requests regardless of driving scenarios. For instance, requesting information about a building they are passing, the weather forecast, or the remaining time until they reach their destination. As we mentioned at the beginning of this section, qualitative data collected from conversations following information requests (in addition to qualitative data from measures detailed in the following section) was used to explore and understand the context of any information requests about the general riding experience. By using a combination of qualitative and quantitative data, we were able to understand what driving scenarios elicit information requests, the urgency BLV riders require information for driving scenarios, as well as the context of information BLV riders desire about their general riding experiences.

Post-trip and Post-Study Interviews

After each trip, participants took part in a semi-structured interview that we designed to further explore their behaviors during trips as well as to understand their perceptions towards the L4+ ADS based on the trip they just experienced. Interviews started with the following open-ended question: "what were you primarily thinking about during the trip you just experienced?" We believe this initial prompt will allow participants to address any topics or events that they deem most relevant without bias from the researcher. Responses may reveal participants' concern around how the ADS handled driving scenario(s) or their interest in topics outside of the ADS itself, such as wanting to be aware of objects in their surroundings. We will use responses to this question to discover similarities or differences between BLV participants' information requirements (similar to methods used in analyzing focus groups responses in Study 1).

Next, participants listened to statements about the necessity to receive information for driving scenarios they experienced during the previous trip. Participants then rated how much they agreed or disagreed with each statement using a five-point Likert scale (with 1 being "strongly disagree") and provide a reason for their rating. Responses to these statements will be compared to participants' information requesting behaviors during trips. Due to the UT consisting of similar driving scenarios used in the ET in addition to scenarios unique to the UT, there will be more

statements presented during the UT post-trip interview. All possible statements that were present in post-trip semi-structured interviews are presented below:

- It is necessary to receive information every time the ADS…
    o …turns onto another road.
    o …smoothly decelerates to a stop.
    o …quickly decelerations to a stop (UC only).
    o …makes a full loop of a traffic circle (UC only).
    o …uses a traffic circle.
    o …smoothly accelerates from a stop.
    o …pulls over and stops (UC only).
    o …drives on a rural road that is poorly maintained.
    o …enters and exits the highway.
    o …performs a quick lane change (UC only).
    o …performs a smooth lane change.

Additionally, we asked participants to rate their level of agreement with statements about their perceived level of satisfaction, enjoyment, and safety for the previous trip. (i.e., "I enjoyed my ride in the ADS", "I was satisfied with my ride in the ADS", and "I felt safe riding in the ADS."). Responses to these statements will provide a quick understanding of how each trip influenced participants' perceptions towards the ADS. Lastly, we gave participants the opportunity to make any final comments about the trip they just experienced before concluding the post-trip interview.

After participants completed their second trip, and the subsequent post-trip questionnaires and interviews, we conducted one final semi-structured interview before concluding the study session. As mentioned previously, a majority of the interview was focused on deriving information requirements for vehicle egress related tasks; however, we also used prompts to understand participants final thoughts about using future L4+ ADS ride-hailing services. These final interview prompts asked about participants' willingness to use ADS ride-hailing services to travel to familiar and unfamiliar locations. Additionally, participants were asked whether or not they would want the ability to stop the ADS during a trip, which was a common interaction requirement mentioned in Study 1's focus groups.

Acceptance of L4+ ADSs and Trust in Automation

While examining participants' trust in automation and their acceptance of L4+ ADSs was not a primary objective of our research effort, we argue that evaluating these factors provide further insight into how we can design L4+ ADS HMIs to meet BLV riders' needs. Thus, prior to entering the vehicle, we administered questionnaires to assess participants' initial levels of acceptance of L4+ ADSs ride-hailing services as well as their initial levels of trust in automation. Additionally, to examine whether participants' trust and acceptance of L4+ ADSs change as a result of experiencing both trips, we administered both acceptance and trust measures after each trip.

One of the questionnaires was an adapted version of the Self-Driving Car Assessment Scale (SDCAS; Nees, 2016), which originally includes 24 Likert-scale items that capture participants ratings across eight dimensions: perceived reliability, cost, appropriateness, enjoyment, perceived usefulness, perceived ease of use, user experience, and intention to use. For the purpose of this study, we adjusted the SDCAS items to reflect using L4+ ADS specifically as a ride-hailing service rather than a personally owned vehicle. For instance:

> *Original item* – "I would be willing to pay more for a self-driving car compared to what I would pay for a traditional car"

> *Adjusted item* – "I would be willing to pay more for an automated vehicle ride-hailing service compared to what I would pay for a traditional ride-hailing service"

We also removed items capturing "perceived enjoyment" for manually driving a vehicle due to concerns that some of the recruited participants might have no previous manual driving experience. As a result, our adjusted SDCAS only included 21 items and can be seen in Appendix C.

Finally, we administered the Trust in Automation (TiA; Körber, 2019) scale, which originally included 19 Likert-scale items that measure trust in automation across six subscales: competence/reliability, understandability/predictability, familiarity, intention of developers, propensity to trust, and trust in automation. Based on Körber's recommendations for using this scale in the domain of automated driving, we have removed the subscale for *intentions of developers* based on the assumption that the development of ADS technologies is "motivated by the increase in safety and comfort" and that developers of these systems "would not act in a benevolent manner" (Körber, 2019, p. 20). As a result, our adjusted TiA included 17 items and

can be seen in Appendix B. Similar to the SDCAS, we have adjusted the TiA to change some of the verbiage to make more sense as it relates to L4+ ADSs.

5.2.5 Procedure

Participants we deem eligible after completing the screening process were required to visit the Virginia Tech Transportation Institute (VTTI) campus in-person for a study session that lasted approximately two hours. Due to challenges BLV individuals can encounter when independently using transportation, we offered participants the option to have a member of our researchers transport them to and from the study location. Upon arrival at the study location, we greeted participants and guided them to a conference room to conduct the intake session. During the intake session, we read the IRB approved informed consent form out loud to participants and answered any questions. We informed participants that the study involved riding on public roads in vehicle that is configured to simulate a L4+ ADS ride-hailing vehicle that is actually operated by a driver at all times. If interested in continuing, participants completed the SDCAS questionnaire to provide their initial levels of acceptance of L4+ ADSs.

After completing the intake session, participants completed two tasks that simulated using L4+ ADS ride-hailing services, which were the vehicle ingress task and the riding task. For the vehicle ingress task, we escorted participants to the starting location and asked participants to walk through a controlled parking lot while imagining they are independently performing tasks relating to locating and entering a L4+ ADS vehicle they requested using a ride-hailing service (see Figure 11). At various instances throughout task, we administered semi-structured interview questions that focused on information participants might desire while performing various phases of a vehicle ingress task. To represent a more naturalistic use case, participants were allowed to use low-tech navigation aids (e.g., white canes, guide dogs) that they regularly use during navigation tasks. Upon completion of the ingress task, participants would be seated in the second row on the right side of the simulated L4+ ADS vehicle. For safety precautions, we ensured the participants are seated properly with their seat belt fastened before closing the door.

Figure 11. Depicts the path participants followed during the vehicle ingress task. The test vehicle (not seen in the figure) that we used to represent the requested L4+ ADS was always located at the end of the loading area (i.e., the blue rectangle in between accessible parking spots).

For the riding task, participants were driven on two trips along public roads that simulated different L4+ ADS riding experiences (see Section 5.2.2 for trip details). The order in which the trips occurred was counterbalanced across participants. Prior to starting the first trip, we informed participants that they would not be receiving any information from us or the ADS during trips but instead that they would need to indicate when they would expect or want information by performing an information request. We then provided participants instructions on how to perform information requests as well as what to expect when communicating with the remote researcher following any requests (see Appendix E for script). We then asked participants to practice performing an information request to verify their instruction comprehension and to walkthrough how the proceeding conversation with the remote researcher will transpire. Participants then

experienced both trips as well as responded to two questionnaires (i.e., SDCAS and TIA) and a brief semi-structured interview administered by the remote researcher after each trip.

After completing both trips and subsequent questionnaires/interviews, participants remained in the vehicle to complete the post-study interview with the remote researcher. The study session concluded with the completion of the post-study interview. We then provided participants with compensation and thanked them for their time. Participants that required transportation were provided a ride.

5.2.6   Content Analysis

We performed an inductive content analysis to derive requirements of BLV riders from participants' responses (Elo and Kyngäs, 2008, Hsieh and Shannon, 2005). To start this process, we transcribed audio recordings of interviews and then read through the generated transcripts to familiarize ourselves with the material. Next, we re-read the transcripts with a focus on identifying text related to our research questions (i.e., information and interactions required for ingress, egress, and specific driving scenarios).

During this initial phase, we determined that participants' responses to our targeted interview questions were more direct compared to responses to more open-ended questions used during Study 1's focus groups. Consequently, we felt that the process of identifying common topics within and across participants' responses could be managed by one researcher. The individual researcher identified meaning units (see Section 4.2.4) and then organized them into two major areas of interest, which were (1) ingress and egress, and (2) riding in L4+ ADS. The area for ingress/egress consisted of meaning units from pre-trip interviews and post-trip interviews while the area for riding in L4+ ADSs consisted of meaning units from interviews following IRs, post-trip interviews, and post-study interviews. Within each area, meaning units were condensed and organized into information categories, which were based on common types of information or interactions mentioned by participants (e.g., vehicle descriptions, trip-related information, understanding ADS's actions). Meaning units within categories were assigned codes, which were based on the specific text within the meaning unit (e.g., vehicle size, tripping hazards, reasons for stop) to provide additional details related to meaning units that made up each category.

5.3   Results

We first examined descriptive statistics to evaluate the normality and sphericity of the data as well as to detect potential outliers. If data was not normally distributed or the nature of the data was categorial (i.e., binary, or ordinal data), we used appropriate non-parametric methods, such as the Friedman's ANOVA and Mann-Whitney U test. Additionally, for each outcome variable, we conducted t-tests (or Mann-Whitney U tests) as well as examined correlations coefficients to determine if potential differences in outcome variables were associated with key demographics (e.g., age, gender, degree of vision loss), familiarity with the study location, and order effects (i.e., order of trip exposure). If any significant differences were detected, those variables were enter entered in subsequent analyses as a covariate. We used SPSS version 25 to conduct all statistical tests.

Among the data used for quantitative analysis, two data points were missing. Due to the uncontrollable nature of traffic on real-roads, two participants did not receive all of the planned driving scenarios. One participant did not receive the quick lane change while another participant did not receive the normal traffic circle. Due to the relatively small sample size of our study, we decided to not perform any data imputation nor remove their data entirely from our sample. Any instances of participants not receiving interview questions or surveys will be detailed in their respective sections.

We examined the safety driver's performance to determine their ability to consistently produce the same driving styles and maneuvers consistently for all participants. Specifically, we examined the peak accelerations (i.e., absolute values of g force along the x-axis and y-axis) produced for the three driving maneuvers that were replicated at the same locations between trip types, but with different driving styles. Unfortunately, due to the noisy nature of data collected by the DAS, and because of how smoothly the safety driver performed normal lane changes, we were unable to detect any deviations in g forces along the y-axis for the normal lane changes. However, we viewed our inability to detect instances of normal lane changes across participants sessions as an indication of the safety driver's ability to consistently performed that driving scenario. Based on our examination of the descriptive statistics for the other driving scenarios (see Table 9 and Figure 12), we felt that all participants received similar riding experiences.

Figure 12. Vehicle telemetry for the three driving scenarios repeated across ET and UT, which were: (a) smooth and quick decelerations, (b) normal and full lap of traffic circle, and (c) quick lane change (smooth lane changes were not detectable due to the noisy nature of the data). Note: for the quick lane changes, the three lines that initial go in the positive direction were lane changes from right to left, whereas a majority were left to right.

Table 9. Descriptive statistics of peak accelerations (using absolute values) across driving scenarios.

Driving scenario	Axis of accel.	N	Mean [g force]	SD	Min (weakest)	Max (strongest)
Quick deceleration	X	13	-.57	.05	-.48	-.67
Normal deceleration	X	13	-.25	.03	-.20	-.29
Long traffic circle	Y	13	.41	.03	.36	.45
Normal traffic circle	Y	12	.39	.03	.35	.46
Quick lane change	Y	12	.32	.05	.25	.41
Normal lane change	Y	13	--	--	--	--

5.3.1 Information for Pick-up and Drop-off (PUDO)

Through content analysis, we identified information categories that were associated to tasks within and between pick-up and drop-off (see Table 10). In the following sections, we present the types of information that were mentioned by participants for each task required for PUDO.

Table 10. Lists the different information categories across PUDO tasks.

<div align="center">Information Categories</div>

		Vehicle description	ETA	Current street name	Landmarks	Distance and direction to target	Details on ADS's stopping location (e.g., orientation to curb)	ADS's direction of approach	Objects and obstacles
Pick-up Tasks	Prepare & detect arrival	X	X				X	X	
	Orient to ADS	X	X		X	X	X	X	
	Evaluating & navigating environment				X	X	X		X
	Confirm correct vehicle	X				X			
	Enter ADS	X						X	
Drop-off tasks	Prepare & detect arrival		X	X			X		
	Confirm correct destination			X	X		X		
	Orient to destination				X	X			
	Evaluating & navigating environment				X	X	X		X

5.3.1.1 Pick-up and Vehicle Ingress

Preparing for Pick-up:

When waiting on their requested ADS to arrive at the pick-up location, a majority of participants (9 of 13; 6 were low vision) wanted to have a description of the vehicle picking them up, with the most popular descriptors being the vehicle type or size (e.g., SUV, sedan), the vehicle's color, and make and model (e.g., Chevrolet Malibu). When participants were asked why a vehicle description would be valuable, participants stated it can help with several aspects of pick-up, such as detecting the ADS's arrival, identify the correct vehicle to enter, useful information to provide a bystander

that can help with locating the vehicle, as well as anticipating step-in height when entering the vehicle. For anticipating the arrival of an ADS, participants wanted information about the direction the ADS would approach from (e.g., their left or right; n = 5) and the ADS's estimated time of arrival (n = 3). Participants explained that knowing the direction of the ADS's approach would inform where to focus their attention as well as help determine the side of the vehicle that they would be using to enter vehicle (e.g., passenger or driver's side).

As for detecting when the ADS arrives, a majority of participants (9 of 13) mentioned sending push-notifications to riders' personal devices and having an auditory signal (i.e., a single tone, sounds, or spoken messages; Elbert et al., 2018) be presented from the exterior of the vehicle upon parking (e.g., horn, chime).

Locating the ADS:

Every participant mentioned that they would need information that indicates the location of an ADS in the parking lot, with a majority of participants (12 of 13) describing the need to obtain a general sense of direction and distance to the ADS relative to their position (e.g., "the vehicle is 15 feet to your left"). A few participants even expressed wanting additional details to determine the ADS's location, such as the type of parking spot the ADS is using (n = 3) (e.g., an accessible parking spot, standard spot, no spot/curbside) as well as the ADS's position relative to nearby landmarks (n = 4) (e.g., a specific entrance, object on the sidewalk). Another way for locating the ADS in the parking lot mentioned by a majority of participants (9 of 13) was through the use of an auditory cue emitted from ADS's exterior. Participants described how the auditory cue, such as a horn or a beep, would allow them to spatially locate the vehicle's position and navigate toward it. Lastly, a few participants (n = 3) mentioned wanting this cue to be reproduced on command to help maintain their orientation to the ADS while moving through their environment.

Evaluating path to ADS:

Seven participants wanted to know about the presence of any objects or obstacles (e.g., parked vehicles, fire hydrants, sewage drains, street signs) in their path to the ADS. Some of these participants highlighted two equally important reasons to know about objects in their path: to avoid tripping over them and to serve as landmarks to monitor their progress when navigating to their destination. Five participants mentioned the need to know about the volume of traffic in the area and if they would be required to cross any traffic lanes to reach the ADS. Two participants added

to this by recommending that future ADSs should always park such that it requires the shortest walking distance and there are no objects/tripping hazards between the rider and their target location during PUDO.

Beyond information about objects in the environment, participants also wanted information about the infrastructure in the environment. Six participants mentioned the importance of being informed about the presence of pedestrian infrastructure that had a 90-degree change in elevation, such as curbs and stairs. A few participants specifically highlighted the importance of knowing whether a shift in elevation is upward (step-up) or downward (step-down). Only a few participants (n = 3) mentioned wanting to be aware of nearby accessibility infrastructure (e.g., curb cuts, ramps, handrails, loading zones) as it can help with path planning as well as detect when they are transitioning from the sidewalk to the road.

Confirming ADS before entering:

A majority of participants (8 of 13, or 62%) stated that entering the wrong vehicle was a major safety concern they have with current ride-hailing services and would anticipate having when using future L4+ ADSs. Additionally, 62% of participants also mentioned that areas with more vehicle traffic would make identifying their vehicle more challenging due to their ADS potentially blending in with the other vehicle traffic visually (e.g., white ADS in a sea of white cars) and auditorily (e.g., multiple vehicles pulling up/away from the curb).

A majority (11 of 13) participants indicated that they would want to receive an auditory greeting from the ADS when they reach the correct vehicle. Many participants (n = 8) mentioned that they would want this greeting to include some kind of information that the ADS would have access to via a ride-hailing app, such as the rider's name, destination name, or a private code that was provided to the rider. Also related to the use of auditory signals, 6 of 13 participants mentioned receiving an audio cue from the ADS, such as the same audio cue that they suggested for spatially locating and navigating to the ADS. A few suggested receiving an audio signal on their personal device to avoid attracting attention. Lastly, 6 of 13 participants discussed how the information they would want to receive prior to the ADS arriving (i.e., general vehicle descriptions, ADS's anticipated parking location) could also be used to increase their confidence.

Sometimes, when responding to this structured prompt, which occurred while standing next to the door to the test vehicle, the discussion with participants would shift to talking about information

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they would desire to assist with entering the vehicle. Specifically, 8 participants mentioned information related to entering the vehicle, which included: knowing what side of the vehicle they were approaching, whether there is a specific door they should be using, and whether there are specific seats they should be using. As it relates a specific door to use, participants also mentioned the benefit of receiving a subtle auditory cue from the target door or door handle to better locate it.

Information after entering ADS:

To understand information that should be presented after entering their requested ADS, we asked participants to respond to an open-ended question (i.e., "now that you've entered the vehicle, is there any information you would want to receive before starting your trip?") and then select information items from a list we provided. Due to concerns about exceeding the time allocated for the pre-trip interview, we did skip the open-ended question for one participant but still had them review the list of information. See Table 11 for an overview of participants feedback to both interview questions.

Based on responses to both interview prompts, the two information options that participants desired the most included (1) an overview of their route and destination as well as (2) their ETA. The two least desired pieces of information were the weather and traffic forecasts. There were three items on the list that 100% of participants wanted (i.e., instructions for emergency situations, how to contact a human operator, and selecting a specific drop-off location at the destination) but were not mentioned in responses to the open-ended question.

Table 11. Comparing participants' responses to an open-ended question with their selections from a list to explore information BLV riders might want after entering an L4+ ADS.

Pre-trip information items	Responses to "list of information" question (n = 13)	Responses to "open-ended" question (n =12)
Route overview	100%	92%
Trip time (ETA)	100%	42%
How to contact a human operator	100%	0%
Instructions for emergencies	100%	0%
Option to select a desired drop-off location at the destination	100%	0%
Option to adjust route	92%	0%
Expectations for the drop-off location's environment (e.g., traffic volume, tripping hazards)	92%	8%

Orientation to vehicle interior	85%	8%
Capabilities of L4+ ADSs	77%	0%
Traffic forecast	62%	8%
Weather forecast	54%	0%
Other – Payment methods	n/a	17%
Other – Understand if ADS is up to date	n/a	8%

Starting the trip:

When asked how participants would expect to start the trip, 11 of 13 participants wanted to trigger the start of the trip using either voice commands or a push-button inside the vehicle. Reasons for wanting to initiate the start of the trip included: allows for last minute trip adjustments changes and allows riders to get properly situated. Alternatively, only two participants (both low vision, males) indicated being comfortable with letting the ADS determine when it is safe to depart.

Stopping the trip:

As part of the post-study interview, we asked participants if they would want an interaction to stop the ADS, 12 of 13 participants wanted this feature with most (n = 6) imagining this interaction only being needed as an emergency feature (e.g., ADS is malfunctioning, or a rider is experiencing a health crisis). Some participants mentioned additional information they would expect the ADS to provide if they were to use this stop feature, which included: current location (road name, nearest intersection, address), nearby landmarks (mile markers, buildings) to ensure they can describe their location to someone, nearby traffic conditions, and instructions for getting human assistance. The single participant that didn't want this feature said it was because they didn't want to risk stopping the ADS and not knowing their location, and as a result, being stuck.

5.3.1.2   Drop-off and Vehicle Egress

Anticipating and detecting arrival at destination

Eight of 13 participants mentioned that they would want an ADS to provide a notification that they are nearing or arriving at their destination. Seven participants mentioned that they would like a description about their drop-off location when nearing their destination.

> P204 (B) - A description of where the AV would drop me off or where it will stop and let me get out. Like have it tell me, "You will be at the corner..." or "...in the driveway."

A few participants (n = 4) mentioned that this would be relevant information to help them determine when to start gathering their belongings and prepare to exit the vehicle. One participant mentioned that even after knowing they have arrived at the destination, they want to know exactly when it is safe to unbuckle their seatbelt to avoid unbuckling when it is unsafe to do so even though the vehicle is stationary.

Confirming arrival at correct destination:

A majority (10 of 13) of participants mentioned that if the ADS provided the name and/or address of the destination, they would feel confident that they are approaching the correct location. Several participants mentioned additional information that would increase their confidence in the ADS, which included the following: information about a specific drop-off location at their destination (5 of 13) (e.g., specific entrance if there are multiple), knowing about landmarks they are passing when nearing their destination (3 of 13), or hearing street names they are on when nearing their destination (2 of 13).

Locating the entrance to their destination:

A majority of participants (n = 11) mentioned wanting to know the direction and distance to their final destination when arriving at the drop-off location. Almost half of the participants expressed the need to know the location of the destination relative to nearby landmarks (n = 6) (e.g., type of entrance, objects near entrance). For a location that has multiple drop off locations/entrances (e.g., hospital, a mall, Walmart), 5 of 13 wanted to know the specific location the ADS intended to drop them off (e.g., Main entrance vs. urgent care, Macy's vs. JC Penny, home vs. grocery).

Evaluating path to destination:

Similar to pick-up, a majority (9 of 13) participants wanted to know about the presence of any objects in their path to the destination. Additionally, nine responses suggested the importance of being informed about the presence of infrastructure resulting in 90-degree changes in elevation, such as curbs and stairs. Less than half of all participants (n = 5) mentioned wanting to be aware of nearby accessibility infrastructure. Four participants also included that they would want to know about the general traffic density in the area as well as any traffic lanes they would be required to cross to reach their destination. Also, four participants mentioned wanting to know the type of parking spot they were currently in and/or the vehicle's orientation to the sidewalk. Finally, one

participant wanted to know the surface they would be stepping onto when exiting the vehicle (e.g., street, sidewalk).

Navigating outside the ADS:

A majority of participants (10 of 13) mentioned that they would want the ADS (or an app used for requesting a ride) to provide them with information to assist with navigation after exiting/before entering the ADS. Six participants mentioned having the app provide navigation information (i.e., turn-by-turn instructions or spatial auditory cues that change depending on their orientation to their target), whereas four participants wanted information about the presence of tripping hazards and objects in their path. Three participants stated that they would not need any information after exiting the ADS because they would be able to navigate using information that they wanted from ADS prior to exiting (e.g., directions and distances, landmarks) and/or they would rely on their own O&M skills or navigational aids.

5.3.2   Information Requests During Trips

In total, 75 information requests (IRs) were made by participants across the ET and UT. Reviewing the qualitative data collected during interviews following IRs, we determined that 58 were to obtain information related to driving scenarios and 17 were to obtain general trip information (see Table 12).

Table 12. Counts of information requests per driving scenario or general need.

	Expected trip	Unexpected trip	Total
Information requests (IRs)	**16**	**59**	**75**
IRs for driving scenarios	9	49	58
Quick deceleration	--	11	11
Traffic circle	2	6	8
Lane change	0	8	8
Unexpected stop in parking lot	--	8	8
Rural road	--	8	8
Entering highway	2	2	4
Waiting for red light	2	2	4
Driving slowly	1	1	2
Speed bump	0	2	2
Smooth deceleration	1	1	2
Gravel on paved road	1	0	1
IRs for non-driving scenarios	7	10	17

Update on ETA	3	3	6
Update on current location	2	4	6
Nearby noise	2	1	3
Adjusting trip (i.e., add a stop)	0	1	1
Traffic density	0	1	1

Figure 13. Depicts the locations where IRs were performed along the ET (blue dots) and UT (red dots).

After each trip, participants used a five-point Likert scale to rate their level of agreement with statements about the necessity to receive information for driving scenarios they experienced during a specific trip (1 = strongly disagree and 5 = strongly agree). Across both trips, the driving scenarios that participants agreed with the most (i.e., believed it was necessary to receive information for) were the five scenarios unique to the UT, of which the unexpected stop in a parking lot resulting the in highest level of agreement ($M = 4.62$, $SD = .65$, $Mdn = 5$). Driving

scenarios that participants strongly disagreed with the most included the smooth decelerations, accelerations, and lane changes for both trip types (see Table 13).

To understand if exposure to different driving styles (i.e., trip type) influenced participants' ratings of the necessity for receiving information for the six driving scenarios that were identical across trips (i.e., smooth deceleration, smooth accelerations, smooth lane changes, normal traffic circles, entering/exiting highways, turning onto another road), we performed multiple Mann-Whitney U Tests. Results revealed that participants level of agreement with "it is necessary to receive information when the ADS turns onto another road" was significantly higher after the UT (*Mdn* = 4) compared to ratings collected after the ET (*Mdn* = 3), $z = -2.04$, $p = .041$, with a medium effect size, $r = .40$. No other significant differences were found in driving scenarios between trip type.

Table 13. Descriptive statistics of participants' level of agreement with of how necessary it is to receive information for the different driving scenarios that occurred throughout both trips as well as scenarios unique to the UT (i.e., the first 5 maneuvers in the list below). Maneuvers with an * were unique to the UT.

Trip type (Driving style)	Driving Maneuver	Mean	SD	Median
UT	Unexpected stop in parking lot*	4.62	.65	5
UT	Quick deceleration*	4	.91	4
UT	Quick lane change*	4	.82	4
UT	Full lap of traffic circle*	3.69	1.49	4
UT	Rural road*	3.54	1.33	4
UT	Turning onto another road	3.31	1.38	4
UT	Entering and exiting highway	3.08	1.61	4
ET	Entering and exiting highway	2.69	1.55	3
ET	Turning onto another road	2.54	1.51	3
UT	Normal traffic circles	2.15	1.41	2
ET	Normal traffic circles	2.08	1.26	2
UT	Smooth decelerations	1.69	.95	1
UT	Smooth accelerations	1.38	.51	1
UT	Smooth lane changes	1.38	.51	1
ET	Smooth accelerations	1.31	.48	1
ET	Smooth decelerations	1.31	.86	1

| ET | Smooth lane changes | 1.23 | .44 | 1 |

5.3.2.1 Three Targeted Driving Scenarios

To understand if different driving styles and/or driving maneuvers influenced IRs, we examined the same three locations that were identical across the ET and UT. At these locations, the same maneuvers were performed but with different driving styles depending on the trip type. At these three locations, there were a total of 26 IRs with 24 occurring during the UT and 2 during the ET. For the UT, the quick deceleration event resulted in the most IRs (n = 10), followed by the quick lane change (n = 8), followed by the full lap of a traffic circle (n = 6). For the ET, both IRs resulted from experiencing a normal traffic circle with normal braking and lane changes resulting in no IRs.

A binary logistic regression was performed to examine whether driving style and maneuver type were associated with the likelihood of performing an IR. Inspection of residuals revealed that there were two outliers (Std. residual = -2.58), which were kept in the data set. The model was statistically significant, χ^2 (4, N = 77) = 33.26, $p < 0.001$, suggesting that the model can distinguish between participants who did and did not perform information requests. The model explained between 35.1% (Cox and Snell R square) and 48.6% (Nagelkerke R square) of the variance in the dependent variable and correctly classified 79.2% of cases. As shown in Table 14, driving style, but not maneuver type, significantly contributed to the model. The driving style odds ratio of 32.68 suggests that participants were 32.68 times more likely to request information when experiencing unexpected driving styles compared to expected driving styles.

Table 14. Output of logistic regression that was used to examine if driving style (expected and unexpected) and maneuver type (lane change, deceleration, traffic circle) were associated with the likelihood of performing an IR.

	B	*SE*	Wald	*df*	*p*	*OR*	95% CI *OR*	
							LL	*UL*
Lane change			.57	2	.75			
Deceleration	.38	.76	.26	1	.61	1.47	.33	6.52
Traffic circle	-.17	.75	.05	1	.82	.85	.19	3.69
Driving style	3.49	.81	18.71	1	.00*	32.68	6.73	158.70

Constant	-3.01	.86	12.27	1	.00*	.05

5.3.2.2 IRs for Driving Maneuvers and Styles

When analyzing responses provided during IR interviews and post-trip interviews, we detected that participants primarily wanted information that allows them to understand the *reason* for the L4+ ADS's actions for almost all driving scenarios that resulted in an IR (with speed bumps and gravel on paved road being the only exceptions). For quick decelerations and quick lane changes, 100% of participants wanted to know if the ADS was avoiding an object in the road (e.g., animal, inanimate object, another vehicle) despite the fact that 78% and 62% of participants performed an IR for quick deceleration and quick lane change, respectively. Likewise, 100% of participants wanted to know the reason the vehicle was stationary for an extended period of time during the unexpected stop in the parking lot despite only 62% performing IRs during the UT. Other driving scenarios where participants wanted to know the reason for the ADS's actions included: 62% for a full lap of the traffic circle (but only 46% performed IRs), 62% for driving on the rural road (but only 46% performed IRs), 38% for speeding up to enter the highway (but only 15% performed IRs), 31% for waiting at red lights (but only 23% performed IRs), 23% for smooth decelerations (but only 15% performed IRs), and 15% for traveling at slower speeds (and 15% performed IRs).

Participants wanted information about the reason for an action or behavior to determine if their ADS was acting intentionally, which would increase their trust and confidence in the ADS. Additionally, participants mentioned how this information would allow them to assume the functional status of their ADS, and a lack of information would cause them to believe that the ADS is malfunctioning or confused. Across driving scenarios, the percentage of participants that provided this rationale for wanting information about the reason for the ADS's actions were as follows: 62% for the unexpected stop in the parking lot, 62% for traveling on the rural road, 53% for quick lane change, 46% for quick decelerations, 38% for the full lap of the traffic circle, 31% for waiting at a long red light, 15% for when the ADS was driving slowly, and 15% for smooth decelerations.

The second most common category of information that participants wanted across various driving scenarios was trip-related information, which includes details about their current location, any adjustments to their ETA or original route, changes in road condition, and upcoming road

structures (e.g., traffic circles). The need for this information was often associated with driving scenarios that resulted in participants feeling uncertain either in their perception of their environment and/or if the ADS was in an appropriate location. For instance, five participants that performed an IR for the full lap of the traffic circle were uncertain or unaware that they just used a traffic circle due to the unusual turning sensation. Some thought the long turning sensations resulted from the ADS performing a U-turn, using a cul-de-sac, or using a circular on-ramp to enter a highway. Additionally, because the long turning sensation resembled that of a U-turn, 38% of participants wanted information about their current location or an updated route and ETA. Furthermore, because of their uncertainty, participants also wanted to know about the road structure that caused the sensation prior to reaching it.

> P207 (LV) - Was it a roundabout or was it a complete U-turn and now we have to go on a different route? I would want to know if we are deviating from my original route.

Similarly, participants also wanted advanced notice about normal traffic circles (n = 4) and circular highway on-ramps (n = 1) in order to understand and prepare for the long turning sensations produced by those structures.

For the unexpected stop in a parking lot, 62% of participants were uncertain of their environment and thought they may have arrived at their destination (n = 7) or were waiting for a red light (n = 1). Once the vehicle began moving after the prolonged stop, which occurred once IR interviews started, 31% of participants (n = 4) wanted updates on their current location, ETA, and if their trip was adjusted. For riding on the rural road, 46% of participants wanted to know their current location or to understand if their ADS was re-routed or taking a detour because they did not expect an ADS to purposely select a road in such rough condition. Two other driving scenarios where we noticed any participants wanting trip-related information was quick decelerations and encountering speed bumps. For the quick deceleration, 15% of participants wanted an updated ETA, but only if the reason for the abrupted response was to avoid a nearby accident that would delay their trip. For speed bumps, 15% of participants wanted to know their current location because the feeling of speed bumps caused them to believe they were in a parking lot, but the speed after the speed bump suggested otherwise.

One participant (blind, female) experienced an unplanned driving scenario that involved the ADS yielding to an active emergency response vehicle (i.e., ambulance) that approached from behind,

which also resulted in an IR. Due to its similarity with CDSs explored in Study 1, we determined it was worth exploring the IR interview to see if any common trends from Study 1 are present in the participant's response. As result of experiencing this scenario, the participant wanted to know the type of emergency vehicle as well as the ADS's planned response. The participant stated that due to the stress associated with this type of scenario, they would desire this information because it would allow them to determine if the ADS was handling the situation appropriately.

Finally, we also explored feedback for driving scenarios that were discussed during post-trip interviews but resulted in few to no IRs, which included smooth decelerations, smooth accelerations, and smooth lane changes. The most frequent response participants provided for not wanting any information for the listed driving scenarios was that they are ordinary scenarios and experiencing them suggested that the ADS was working properly (stated by 69% of participants for smooth lane changes, 62% for smooth acceleration, and 62% for smooth decelerations). Finally, several participants mentioned the utility in hearing the ADS's turn signal for driving scenarios that resulted in a few or no IRs, such as smooth lane changes (n = 3) and waiting at a red light (n = 1). For instance, one participant mentioned that while waiting at a red light for a prolonged period of time, hearing a turn signal allowed them to determine that the ADS was not stuck or malfunction, but rather it was waiting to turn and behaving normally.

5.3.2.3   IRs for Driving Environments

To understand if driving environments impact the information desired by participants, we examined the number of IRs at specific areas where transitions in driving environments occurred (i.e., entering and exiting highways, rural roads, and parking lots) as well as reviewed content in participants' responses. The change in environment that resulted in the most IRs was when participants entered a road with rough terrain (N = 9 IRs), followed by entering a parking lot (N = 6 IRs), and entering a highway (N = 4 IRs). No interview responses nor IRs resulted from entering a pre-urban/commercial park roadway. As discussed in preceding and following sections, IRs did occur while riding on sub-urban/commercial park roadways, however, we don't highlight those here because they either resulted from driving scenario unrelated to the driving environment or participants' need for general trip information.

In addition to the planned rural road driving scenario, one participant performed an IR for an unplanned driving scenario that also included rough road conditions (i.e., riding over gravel that

had spilled out on to an otherwise smooth roadway). Due to similarities to the rural road scenario, we included the participant's IR and responses for the unplanned scenario in our analysis of feedback about changes in driving environments.

For scenarios where the ADS shifted from smooth to very rough terrain, 69% of participants mentioned that they would want the ADS to provide the type of road (e.g., country road, construction) and/or a description of the road condition (e.g., bumpy, gravel) before the change in environment occurs. Additionally, 46% of participants wanted to know the name of the road and other nearby landmarks for the following reasons: to feel confident that the ADS is still going to their destination, to understand their surroundings, to be able to share their location when requesting assistance during situations where the ADS malfunctions or leaves the rider stranded, and to avoid the road for future trips. During the post-trip interview, two participants that didn't perform an IR for the rural road scenario mentioned that they would not need information about rough or rural roads because they are used to riding on these types of roads.

Seven of 13 participants that performed IRs for the unexpected stop in a parking lot stated that the lack of detectable nearby traffic (both visually and auditorily) as well as change in the ADS's engine noise caused them to believe that they had changed driving environments. Furthermore, the same participants mentioned how this discernable shift in their environment in addition to the prolonged stop caused them to contemplate whether they had arrived at their destination and should begin exiting the vehicle. During the post-trip interview, only one participant (male, low vision) stated that they did not perform an IR because they were completely unaware that they were stopped in a parking lot due not perceiving any cues that indicated they were in a parking lot. As for why participants want to receive information for the prolonged stop in the parking lot, 62% wanted to understand their location to avoid a confusing situation that could result in exiting the vehicle at the wrong time and/or location.

Finally, for highway environments, 38% of participants wanted to know they were entering and exiting highway because it serves as a landmark to help them monitor trip progress. Furthermore, 31% of participants wanted to receive information about entering the highway to anticipate faster speeds. However, only 15% of participants performed IRs when entering the highway.

Figure 14. Depicts the location of IRs along the Unexpected Trip. The reason for the IR is color coded (including both driving scenarios and general information). The dot size represents the number of IRs made near that location for a particular reason.

Figure 15. Depicts the location of IRs along the Expected Trip. The reason for the IR is color coded (including both driving scenarios and general information). The dot size represents the number of IRs made near that location for a particular reason.

5.3.2.4 IRs for non-driving scenarios

After examining responses to IR interviews, post-trip interviews, and post-study interviews we discovered that participants wanted information unrelated to driving scenarios. Specifically, participants performed IRs to obtain general trip-related information (i.e., updates on their current location and ETA). According to IR interviews, participants (n = 6) wanted to understand their current locations by receiving information about nearby landmarks and/or the name of the road they were on and in their vicinity. Response to post-trip interviews indicated that a majority of participants (11 of 13 participants, 6 were blind) would like ADSs to provide information when turning onto another road (e.g., turn-by-turn directions). As previously mentioned, participants' perceived necessity for this information increased significantly after experiencing the UT compared to the ET. Participants also performed IRs to request information for ETA updates (n =

6) and mentioned that this information would help determine if they were on time/monitor trip progress as well as prepare for their arrival at their destination. As seen in Figure 14 and in Figure 15, locations where IRs were performed solely to indicate the need for getting an ETA and location updates were often near the start of the route (for UT) or near the middle of the route (for ET and UT). Participants' reasons for wanting trip-related information (in order of prevalence amongst participants) were to verify that their ADS was still on the correct route or still going to the correct destination, to discover landmarks along their route, and to increase their confidence in this novel ADS technology.

> P101 (LV) - If it was a route I usually take, I would be wondering if there were any shops or restaurants along my path that I might otherwise be unaware of. And I would like to know what they are.

> P205 (B) - So I can keep track of where I'm going on my mental map. Also, so I know how long until I reach my destination.

Other information participants required outside of driving scenarios were about nearby noises (n = 2) and surrounding traffic density (n = 1). For the IRs about nearby noises, one participant was curious about a car horn they heard in the vicinity and wanted to understand if the horn was directed at their ADS.

> P207 (LV) - A horn just blew in the area. Sounded like it came from a car passing us in the opposite direction. I would like to make sure that we are in the correct lane or that we didn't swerve in the wrong lane. I would generally just like a status check on the car to make sure it is operating correctly.

The other noise-related IR was due to a noise produced by piece of testing equipment rattling in the trunk of the test vehicle, which caused the participant to express that this noise would cause them to be concerned if they were a real L4+ ADS.

> P204 (B) - I want to know that the ADS's systems were fine and working properly. I would be nervous if I heard this noise coming from the back of the AV. Knowing that the AV's status is okay would alleviate my concerns. Also, I would want a method for contacting the ride-hailing service to alert them of this issue.

Relating to interaction requirements, several participants mentioned ideas for accessing trip-related information, which included being able to request it from the ADS at any time or having it presented automatically throughout the trip. For automatic updates, participants also mentioned

the ability to customize the amount of trip-related information automatically provided by the ADSs (e.g., major roads vs. all roads) to suit their personal needs for a trip, which may change depending on the length of trip, familiarity with an area, and comfort with the ADS. Lastly, one participant mentioned that idea of being able to adjust their trip to add or remove stops.

5.3.3 Time to Information Request

Upon examining the data for TIR, we found multiple reasons to only report the descriptive statistics. First, when inspecting TIR data, we determined that data for several events violated assumptions of normality for a repeated measures ANOVA, and thus, explored non-parametric alternatives. Second, because not all participants performed an IR for all driving scenarios, we would be analyzing an even smaller subset of our already limited sample size. As a result, this would further threaten the statistical power of any statistical analyses, which increases the likelihood of incorrectly failing to reject the null (type-II error). Thus, for these two reasons combined, we decided to only report and examine the descriptive statistics of TIR for driving scenarios that allowed for consistent means for determining T_0 (i.e., start of scenario) across participants (see Table 15). Quick decelerations event resulted in the shortest average TIR of 4175.8 ms ($SD = 1425.74$) whereas riding on a rural road had the longest average TIR of 34262.63 ms ($SD = 20149.65$).

Table 15. Descriptive statistics for TIR across driving scenarios.

Driving scenario	N	Mean [ms]	SD
Quick deceleration	10	4175.8	1425.74
Quick lane change	8	19871.25	21162.15
Full lap of traffic circle	6	10574.83	8488.93
Unexpected stop in parking lot	8	17395.38	19864.24
Rural road	8	34262.63	20149.65

Figure 16. Box plot of TIRs across five driving scenarios that were unique to the UT.

5.3.4 Self-reported measures

We used spearman's rank-order correlations to examine the relationship between propensity to trust, TiA scores (for both UT and ET), willingness to accept L4+ ADSs, IRs during the ET, and IRs during the UT (see Figure 17). Propensity to trust was moderately positive and significant correlated with TiA for ET, $r_s(11) = .562$, $p = .046$. Additionally, there were moderately negative and significant correlations between propensity to trust and IRs during UT, $r_s(11) = -.574$, $p = .040$ and IRs during ET, $r_s(11) = -.657$, $p = .015$. Participants' willingness to accept ADSs were not significantly correlated with either IR behavior or participant's trust in automation.

Spearman's rho			Propensity to Trust	ET Trust	UT Trust	All IRs during ET	All IRs during UT	Pre-trip Willingness to Accept	ET Willingness to Accept	UT Willingness to Accept
Spearman's rho	Propensity to Trust	Correlation Coefficient	1.000	.562*	.007	-.657*	-.574*	.446	.271	.383
		Sig. (2-tailed)	.	.046	.981	.015	.040	.127	.370	.197
		N	13	13	13	13	13	13	13	13
	ET Trust	Correlation Coefficient	.562*	1.000	.303	-.219	-.077	.150	.286	.280
		Sig. (2-tailed)	.046	.	.315	.473	.801	.625	.344	.354
		N	13	13	13	13	13	13	13	13
	UT Trust	Correlation Coefficient	.007	.303	1.000	.312	.004	.044	.307	.349
		Sig. (2-tailed)	.981	.315	.	.299	.989	.886	.307	.242
		N	13	13	13	13	13	13	13	13
	All IRs during ET	Correlation Coefficient	-.657*	-.219	.312	1.000	.508	-.387	-.163	-.266
		Sig. (2-tailed)	.015	.473	.299	.	.076	.191	.596	.380
		N	13	13	13	13	13	13	13	13
	All IRs during UT	Correlation Coefficient	-.574*	-.077	.004	.508	1.000	-.492	-.228	-.319
		Sig. (2-tailed)	.040	.801	.989	.076	.	.088	.454	.288
		N	13	13	13	13	13	13	13	13
	Pre-trip Willingness to Accept	Correlation Coefficient	.446	.150	.044	-.387	-.492	1.000	.854**	.844**
		Sig. (2-tailed)	.127	.625	.886	.191	.088	.	.000	.000
		N	13	13	13	13	13	13	13	13
	ET Willingness to Accept	Correlation Coefficient	.271	.286	.307	-.163	-.228	.854**	1.000	.964**
		Sig. (2-tailed)	.370	.344	.307	.596	.454	.000	.	.000
		N	13	13	13	13	13	13	13	13
	UT Willingness to Accept	Correlation Coefficient	.383	.280	.349	-.266	-.319	.844**	.964**	1.000
		Sig. (2-tailed)	.197	.354	.242	.380	.288	.000	.000	.
		N	13	13	13	13	13	13	13	13

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Figure 17. SPSS output of Spearman's correlations between participants' IR behaviors and self-reported ratings for (1) trust in automation as well as (2) willingness to accept L4+ ADSs.

5.3.4.1 Trust in automation

The mean propensity to trust score across all participants was 3.41 ($SD = .39$, $Mdn = 3.33$). The mean score for overall TiA for ET was 3.76 ($SD = .29$, $Mdn = 3.79$) and for the UT was 3.34 ($SD = .43$, $Mdn = 3.43$). We performed a Wilcoxon signed-rank test to detect shifts in perceived ratings of trust between the two repeated trip types, which revealed that trust scores were significantly lower after the UT compared to trust scores collected after the ET, $Z = -2.67$, $p = .008$, with a large effect size, $r = .58$.

Additionally, we performed separate Wilcoxon signed-rank tests to detect shifts amongst ratings in each TiA subscale between trip types (see Table 16). Participants' ratings to understandability and predictability subscale were significantly lower for the UT ($Mdn = 3.00$) compared to the ET ($Mdn = 4.25$), $Z (2) = -2.96$, $p = .003$, with a large effect size, $r = .82$. There were no significant differences for the other TiA subscales between trip types.

Table 16. Statistically significant effects of TiA subscale ratings through Wilcoxon signed-rank tests.

				Percentiles				
TiA Subscale	Trip Type	Mean	SD	25th	50th (Median)	75th	Z	p

Reliability and Competence	UT	3.87	.54	3.33	3.83	4.50	-1.53	.125
	ET	4.12	.40	3.92	4.17	4.42		
Understandability and Predictability	UT	3.21	.68	2.75	3.00	3.63	-2.96	.003*
	ET	4.02	.67	3.63	4.25	4.50		
Familiarity	UT	1.42	.67	1.00	1.00	1.75	-.53	.596
	ET	1.58	.95	1.00	1.00	2.00		
Trust	UT	3.92	.61	3.50	4.00	4.25	-1.77	.076
	ET	4.35	.52	4.00	4.00	5.00		

5.3.4.2 Perceived enjoyment, satisfaction, and safety

After each trip, participants were asked to rate their level of agreement with three statements relating to their perceptions toward the trip they just experienced. Wilcoxon signed-rank tests were performed to detect shifts in perceived ratings to the three statements between trip types. We detected no significant differences in participants' ratings of enjoyment, satisfaction, and safety between trip types (see Table 17).

Table 17. Statistically significant effects of perceived enjoyment, satisfaction, and safety per trip type through multiple Wilcoxon signed-rank tests.

Item	Trip-type	Mean	SD	Median	Z	p
Enjoyment	ET	5	0	5	-1.73	.083
	UT	4.77	0.439	5		
Satisfaction	ET	5	0	5	-1.41	.157
	UT	4.85	0.376	5		
Safety	ET	4.92	0.277	5	-1.41	.157
	UT	4.77	0.599	5		

5.3.4.3 Willingness to Accept L4+ ADSs

A Friedman's ANOVA revealed a significant difference in participants' willingness to accept scores (i.e., SDCAS score) depending on when the scale was administered, $\chi^2 (2) = 12.29$, $p = .002$. The median SDCAS scores for the UT, ET, and pre-trip were 3.56, 3.50, and 3.22, respectively. We performed a post-hoc analysis with multiple Wilcoxon signed-rank tests was conducted with a Bonferroni correction applied (resulting in a significance level set at $p < 0.017$) to detect where the significant difference occurred. SDCAS scores were significantly higher for the ET compared to the pre-trip, $Z = -2.56$, $p = .010$, with a large effect size, $r = .50$. There were

no significant differences in SDCAS between ET and UT ($Z = -.32$, $p = .752$) or between pre-trip and UT ($Z = -2.32$, $p = .021$).

Additionally, we performed separate Friedman's ANOVAs to detect shifts amongst ratings in each SDCAS dimension between pre-trip, ET, and UT (see Table 18). There was a significant difference in participants' Perceived Ease of Use (PEU) scores depending on when the scale was administered, χ^2 (2) = 16.17, $p < .001$. Post-hoc analysis revealed that PEU scores were significantly higher after the ET compared to the pre-trip, $Z = -2.81$, $p = .005$, with a large effect size, $r = .55$; PEU scores were significantly higher for the UT compared to the pre-trip, $Z = -2.67$, $p = .008$, with a large effect size, $r = .52$. There was no significant difference in PEU scores between ET and UT, $Z = -.68$, $p = .498$. There was a significant difference in participants' Perceived Reliability (PR) scores depending on when the scale was administered, χ^2 (2) = 10.22, $p = .006$. Post-hoc analysis revealed that PR scores were significantly higher for the ET compared to the pre-trip, $Z = -2.67$, $p = .008$, with a large effect size, $r = .52$. There were no significant differences in PR between ET and UT ($Z = -1.55$, $p = .121$) or between pre-trip and UT ($Z = -1.28$, $p = .201$).

Table 18. Statistically significant effects of SCDAS dimensions as presented through series of Friedman's ANOVAs.

Dimension	Trip-Type	Mean	SD	Median	χ^2 (df = 2)	p
Appropriateness	Pre-trip	2.82	.80	3.00	.80	.670
	ET	2.95	.52	2.67		
	UT	2.90	.60	2.67		
Cost	Pre-trip	3.05	.78	3.00	.53	.767
	ET	3.00	.78	3.00		
	UT	3.18	.79	3.00		
Intention to Use	Pre-trip	3.13	.88	3.33	.87	.649
	ET	3.33	.54	3.33		
	UT	3.28	.62	3.33		
Perceived Ease of Use	Pre-trip	3.46	.78	3.67	16.17	.001*
	ET	4.21	.55	4.00		
	UT	4.18	.59	4.00		
Perceived Reliability	Pre-trip	3.15	.77	3.33	10.22	.006*
	ET	3.62	.65	3.67		
	UT	3.41	.65	3.33		
Perceived Usefulness	Pre-trip	3.90	.76	3.67	.80	.670
	ET	3.85	.73	4.00		
	UT	3.92	.81	4.00		

Figure 18. Median scores for each SDCAS dimension across the pre-trip, ET, and UT.

5.4 Discussion

We conducted this study to address gaps in literature on BLV individuals' requirements for future L4+ ADSs as well as investigating common and uncommon L4+ ADS driving scenarios in more ecological valid settings. Furthermore, we conducted this study to build upon Study 1 by exploring scenarios that occur with current ride-hailing services that we also anticipate occurring with any future automated ride-hailing services. The results of this study provide valuable insights into information BLV riders will require to independently perform PUDO and when experiencing various types of driving maneuvers, styles, and environments while riding in an L4+ ADSs. Additionally, Study 2 findings were used to reinforce or generate design guidelines and recommendations for developing accessible HMIs for L4+ ADSs (see Section 0). Below, we discuss our findings, their implications, and future directions for the three research questions for this study. After addressing each research question, we also present other relevant findings from the study as well as study limitations.

5.4.1 RQ4: What information do BLV riders value when being picked-up and dropped-off by L4+ ADSs?

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Results from the ingress task and post-study interviews revealed several key findings regarding BLV riders' requirements for L4+ ADSs pick-up and drop-off (PUDO) purposes. Our findings shed light on the importance of providing specific information categories that will be valuable to BLV riders during various stages within and between PUDO (see Table 10). For instance, participants desired the same information when evaluating the environment for both pick-up and drop-off portions of a trip. To address RQ4, we discuss information categories that our findings suggest could be valuable to BLV riders for tasks that are similar across pick-up and drop-off, which include: preparation, anticipation and detection of ADS's arrival to PUDO locations, orientation and mobility, and confirmation of correct ADS and destination before entering/exiting vehicle. Throughout each task, we also address potential modalities for presenting desired information to BLV riders as well as highlight any noticeable differences in desired information and presentation modalities between pick-up and drop-off.

5.4.1.1 Preparation

Our findings reveal information that BLV riders would find valuable for just the pick-up portion of the trip (i.e., vehicle descriptions and ADS's direction of approach) as well as for both pick-up and drop off (i.e., ADS's anticipated parking location).

For pick-up, our findings suggest that BLV riders could benefit from receiving a basic description of the vehicle picking them up (i.e., size, color, and make/model), which is also supported by findings from our previous focus groups (see Section 4.4.3). Depending on a rider's visual acuity, having this information in advance would help visually detect the arrival of their requested vehicle and/or correctly identify their requested ADS. For individuals that are completely blind, having the vehicle description can still be useful during situations where they can request assistance from a person in their vicinity; a strategy BLV individuals often use with current public transit options (Azentok et al., 2011; Banovic et al., 2013; Saha et al., 2019). Thus, this finding suggests that developers of L4+ ADSs should anticipate BLV riders wanting to use currently adopted strategies and ensure that L4+ ADSs and any supporting services (e.g., mobile apps) allow BLV individuals to obtain information about the vehicle's description.

Access to vehicle descriptions would also allow BLV riders to anticipate required step-in heights for entering and exiting a vehicle. Furthermore, vehicle descriptions would allow individuals who use guide dogs to anticipate if there will be sufficient space inside the vehicle for them and their

guide dog. While this was a concern raised by only one participant, it does align with previous work that indicates BLV individuals' transportation behaviors changing when using a guide dog (e.g., selecting specific seats on buses or trains) (Marin-Lamellet et al., 2001). Furthermore, because modern transit services have a history of discriminating against individuals whose disabilities are visible, such as guide dog users (Bezyak et al., 2017), it is crucial that future L4+ ADSs are designed to avoid any form of discrimination or barriers in order for this to be a truly independent means of transportation for BLV individuals. Based on our findings, we propose that future L4+ ADS ride-hailing services should allow riders to review vehicle descriptions prior to requesting a ride to ensure they can select a vehicle that best accommodates individuals' mobility or other personal needs.

Other information BLV riders would find useful prior to the ADS's arrival include details of where the ADS will park and its orientation to the sidewalk and/or to the rider. Specifically relating to the pick-up portion of trips, our findings suggest that BLV riders could benefit from understanding the direction their ADS will approach from as well as instructions for how to enter the vehicle (e.g., what door to use, seating location). Information about where an ADS will approach from would not only improve BLV riders' ability to detect the ADS's arrival by directing their attention toward a more specific location, but it could also help riders with entering the ADS by allowing them to determine if they are facing the passenger or driver side of the vehicle.

For both pick-up and drop-off, participants highlight the value in understanding the type of parking spot the ADS anticipates using or how it will be oriented to the sidewalk (i.e., parallel vs. perpendicular). Specifically, participants stated that this information would allow them to predict the presence of objects or infrastructure in an ADS's vicinity. For instance, if BLV rider is aware that the ADS will park in an accessible parking space, they might anticipate using an accessible walkway to enter/exit the vehicle, walking a shorter distance to/from ADS, and using a curb cut to enter/exit the sidewalk. Additionally, because certain navigation aids provide different information to its user (e.g., guide dogs are good at avoiding objects, white canes are good at finding objects), having information on the type of parking spot could even inform BLV riders' selection of navigation aids before the trip. In sum, our findings suggest that to help BLV riders prepare for PUDO, they would benefit from understanding a basic description of their requested ADS, what direction it will approach from, and the type of parking spot it will use.

5.4.1.2 Anticipation and detection of ADS's arrival at PUDO locations

For both pick-up and drop-off, participants wanted information that allows them to predict the ADS's proximity to and/or determine its arrival at intended PUDO locations. One obvious reason BLV riders would benefit from this information would be to know when to begin preparing (e.g., gather belongings, start monitor surroundings) as well as understand when it is appropriate to enter or exit the vehicle. Specifically for pick-up, many participants stated that without this information, they might not know that their ADS has arrived, especially in a busy area where there are many vehicles coming and going. For drop-off, this information is crucial in that it informs BLV riders of when it is appropriate and safe to exit the vehicle. This feedback is further reinforced by participants' responses to the unexpected stop in the parking lot, which indicates that prolonged stops in "quiet" areas (i.e., low traffic volume or ambient road noise) might cause BLV riders to incorrectly think they have reached their destination. Thus, without proper clarification from L4+ ADSs about nearing and reaching the drop-off location, BLV riders may feel unsure about when they can safely exit the vehicle.

As for methods for providing information to BLV riders to help anticipate and detect arrival during PUDO, participants recommended presenting auditory signals on a rider's personal device, the ADS's in-vehicle HMI, and from the ADS's exterior. Our findings suggest that auditory signals presented on a rider's personal device and ADS's HMI could be used to provide BLV riders with an ETA and/or arrival notifications for PUDO. Specifically for pick-up, a majority of participants indicated value in presenting an auditory cue from the vehicle's exterior (e.g., chime or car horn) to detect the ADS's arrival. Furthermore, for cues presented for the ADS' exterior, some participants suggest that BLV riders should have prior awareness of any auditory cues to increase the likelihood that riders detect and understand that a cue in their environment is actually their ADS announcing its arrival.

5.4.1.3 Orientation and Mobility

During PUDO, when an L4+ ADS arrives at a location, BLV riders will need to be able to orient themselves to a target (i.e., a vehicle or entrance to a building) and safely navigate to it. This finding aligns with related research, which reported that BLV individuals were concerned by the prospect of having to independently orient themselves to their destination after exiting an ADSs at their destination (Brinkley et al., 2017). Our findings suggest that in order for BLV riders to

independently locate and navigate to desired targets during PUDO, they will require information about the general direction and distance to a target relative to the BLV riders' location (e.g., "10 feet to your left"). A study by Saha et al. (2019) explored solutions for helping BLV individuals complete the "last mile" (i.e., navigating from transit drop-off to the final destination), which also indicated directions and distance to a target is critical piece of information to provide BLV individuals. Our findings also suggest that BLV riders' navigation and mobility skills (e.g., use of a white cane to detect objects along a path) could be further supported by providing details about landmarks nearby a desired target and/or the type of parking spot the ADS is using. Specifically, for PUDO locations with multiple entrances (e.g., hospital, mall), participants wanted to know the specific entrance the ADS intended to park near to allow for a smoother transition when entering/exiting the vehicle. While it is intuitive to recognize how information about landmarks or types of parking spots is useful for BLV individuals that are familiar with a PUDO location, it is also useful information for individuals navigating unfamiliar areas as it helps individuals construct mental maps that they be used for current and future navigation purposes (Gupta et al., 2020; Banovic et al., 2013). Meaning a broader audience would benefit from receiving this detailed information, which we believe further supports the need for ADSs to provide this information during PUDO.

Our findings reveal that BLV riders could benefit from knowledge of objects and obstacles in their path, such as parked vehicles as well as *pedestrian infrastructure*, which are surfaces and built elements that support pedestrian travel (e.g., stairs, pedestrian crosswalks, light poles/metal signs, curb cuts). As it relates to pedestrian infrastructure, a majority of participants highlighted the need to be aware of 90-degree shifts in elevation to avoid tripping or falling over them. Additionally, our findings also suggest the need to point out nearby accessible infrastructure (e.g., curb cuts, accessible loading zone) and types of walking surfaces they will encounter in their path (e.g., grass, sidewalk, street surface).

Similar to previous work focusing on BLV individuals' orientation and mobility (Saha et al., 2019; Williams et al., 2014; Banovic et al., 2013), our findings also suggest that the primary reasons BLV riders would value information about objects and surfaces in their path would be to (1) help avoid tripping over them, and/or (2) to use as landmarks when for navigating to and from the ADS. Another important reason BLV riders may need this information, specifically relating to accessible infrastructure, is to increase their awareness of transition between the sidewalk and the road via a

curb cut. Thus, when developing L4+ ADSs, and specifically the information they provide about the environment, designers should take a complimentary approach, as suggested by Kameswaran et al., (2020), to allow L4+ ADSs to support the information BLV riders may obtain when using traditional navigational aids.

The last type of information participants wanted was the density and flow of vehicle traffic in the area. This information would help BLV riders evaluate potential safety risks and approach their environment with appropriate levels of caution. Taken together, there is a large amount of information that BLV riders may find valuable when trying to orient and navigate to a target in PUDO. As a result, we recommend future work should continue to explore the value of the identified information in order to avoid overloading BLV riders with information.

While the information desired by participants to locate and navigate toward a target was generally the same for both pick-up and drop-off, participants' ideas for how ADSs should provide this information varied depending on the portion of the trip. The primary difference was the desire for having an auditory signal be presented from the ADS's exterior during pick-up as this would provide BLV riders with an immediate spatial awareness of the ADS's position. Many participants added that the signal could be the same one used to announce the ADS's arrival. Furthermore, participants' responses indicate that the utility of this auditory signal from the ADS could be increased if BLV riders were able to reproduce the cue on command to help maintain an accurate orientation to an ADS while navigating through the environment. However, previous work reports that BLV individuals find it difficult to detect auditory announcements provided by current transportation options (e.g., bus route announcement) in noisy environments (Bezyak et al., 2017; Flores & Manduchi, 2018).

Other methods included using personal devices or an ADS's in-vehicle HMI to provide BLV riders with important information prior to and/or while navigating to a target. Specifically, our findings suggest that BLV riders would appreciate access to static information prior to starting the navigation task (e.g., distances and directions, anticipated obstacles in their path). Our results also suggest that BLV riders may want to use their personal device to receive real-time information about their proximity to objects or turn-by-turn directions when navigating to and from their ADS. However, some participants expressed disinterest toward using a handheld personal device to receive any information because it would most likely require headphones and/or require listening

to lengthy verbal instructions, which could compete with important auditory information in the environment that participants attend to in order to navigate successfully and safely. This limitation to using handheld devices to receive navigation information aligns with similar findings reported in previous work on advanced navigation tools used by BLV individuals (Kuriakose et al., 2020; Gupta et al., 2020). Considering these findings, all methods for receiving information to orient and navigate during PUDO have potential benefits and limitations that may depend on the PUDO environment as well as riders' orientation and mobility skills, and thus, further research in required to determine appropriate presentation modalities L4+ ADSs should adopt.

5.4.1.4 Confirmation

For the pick-up portion of trips, a major safety concern expressed by a majority of participants was entering the wrong vehicle. With the introduction of driverless vehicles, BLV individuals will not be able to rely on current strategies for identifying their desired vehicle, which involve communicating and coordinating with a human in the requested vehicle (Brewer & Kameswaran, 2019). Some participants mentioned that the information received prior to the vehicle's arrival, such as general vehicle descriptions and anticipated parking location, could also help increase their confidence in independently locating the correct vehicle. However, as many participants pointed out in our study and in other related work (Bezyak et al., 2017; Flores & Manduchi, 2018), this information might not be as useful in more challenging scenarios. For instance, in a PUDO location with many vehicles similar in size and/or color in a small vicinity, the information could help with locating the ADS's general location but might not help BLV riders pinpoint their ADS amongst the other nearby vehicles. Thus, other means might be necessary to ensure that a BLV rider can identify their correct vehicle.

Our findings suggest one possibility for ensuring BLV riders know that they are entering the correct ADS, which was to have ADSs provide an auditory cue or verbal greeting once a rider reaches the ADS. To feel confident that they are at the correct vehicle, participants wanted a verbal greeting that included information such as their name, destination, a private code, or other personal information that a user may have provided in a mobile app when planning a trip/requesting a ride. Furthermore, participants also recommended receiving audio cues and audio greetings on a personal device (rather than the ADS's exterior) as a means to accomplish the locating and confirming tasks more discreetly.

Previous work on understanding BLV individuals' needs for future ADSs indicated concerns related to being able to confirm that the ADS has taken them to the correct location (Brinkley et al., 2017; Brinkley et al., 2019). Our findings align with this work as well as provide potential information that ADSs could provide to increase BLV riders' confidence, which included announcing the riders' destination name or address, details about the drop-off location, landmarks they are passing near the destination (e.g., shops or businesses in the area), or hearing street names when nearing the destination.

5.4.1.5   Reviewing pre-trip information after entering the vehicle

After entering an ADSs, our findings suggest that BLV riders may want to access a variety of information prior to starting their trip (see Table 11). When considering the information that was most frequently provided as well as selected by participants, we believe our findings highlight the need to provide BLV riders with a route overview and ETA before starting the trip. This finding is also supported by the previous work suggesting that this is similar information that BLV individuals already seek out when planning trips (Kameswaran et al., 2020; Banovic et al., 2013; Azentok et al., 2011). Perhaps, an additional explanation for why participants want this information is that it could provide reassurance that an ADS will take them to the correct destination.

While our findings do indicate BLV riders may want to access a wide range of information items, it is unrealistic to think that all of the desired items could be presented efficiently before a trip without overloading the rider with information. Thus, future could explore what information included in Table 11 would prove beneficial to BLV riders before starting the trip.

5.4.2   RQs 5 & 6: Driving Maneuvers and Styles

In addition to understanding requirements for PUDO, the present study also sought to explore the relationship between driving style and maneuver type to understand the likelihood of BLV individuals requesting information from an L4+ ADS. Of the total number of IRs performed by participants, 79% occurred during the UT, with 83% of those IRs resulting from driving scenarios. Furthermore, we examined participants' IRs at three locations that were identical for both trips where the same driving maneuvers were performed (i.e., deceleration, lane changes, turning in a traffic circle) but with different driving styles for each trip. Our results indicated that driving style significantly contributed to participants' likelihood of making information requests, while the type

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of driving maneuver did not. Specifically, participants were approximately 33 times more likely to request information when experiencing unexpected driving styles compared to expected driving styles. Taken together, we feel that these findings underscore the importance of considering driving style as a crucial factor in determining when BLV riders will require information from L4+ ADSs.

5.4.2.1 *RQ6. How do differences in L4+ ADS driving styles influence information requested by BLV riders?*

Situating our findings within the existing literature is challenging given the lack of studies examining BLV riders' requirements for different ADSs driving scenarios. However, Wiegand et al. (2020) studied information requested by sighted participants for different (video recordings of) L4+ ADS driving behaviors, which reports relatively similar findings related to riders requesting more information for unexpected ADS driving behaviors. Wiegand et al. (2020) suggested that sighted riders of L4+ ADSs may require information when they are not able to visually detect the reason for the unexpected driving behavior (e.g., an unobservable pedestrian causing the ADS to not turn at a green light). Similarly, our results suggest that BLV riders might use non-visual cues, such as auditory or haptic feedback produced by the ADS or environment, to evaluate if the ADS's driving style aligns with their expectations or if they need more information to understand what is happening.

Previous work by Ekman et al. (2019) to explore sighted participants preferences toward ADS driving styles, indicated that sighted riders may prefer a "defensive" (i.e., comfortable, smooth, and greater following distances) driving style due to the increased distance it creates between their ADS and other on-road objects, which allows riders more time to predict their ADS's responses to those objects. During post-trip interviews, BLV participants in our study often said that smooth driving styles across different maneuvers was useful for determining that the ADS was working properly. Thus, in comparison to previous work, our findings suggest that certain ADSs' driving style might be preferred by BLV riders because it allows them to evaluate the functional status of their ADS rather than predict upcoming maneuvers.

Another finding that we believe could explain the difference in IRs for driving styles was participants' ratings for trust in ADSs after each trip type. Primarily, experiencing multiple unexpected driving styles throughout a single trip caused perceived ratings of trusts in ADSs to significantly decrease compared to a trip where the ADS performed maneuvers using smoother

driving styles. This finding aligns with pervious literature that indicates that experiencing more defensive ADS driving styles increased riders' trust in ADSs (Dillen et al., 2020; Cramer et al., 2020; Ekman et al., 2019). However, we did not find significant correlations between participants' trust in ADSs and their IR behaviors, and thus, cannot confirm that participants' trust influenced their IR behaviors. While this lack of a significant relationship could be a result of our selected measure of trust, there is also potential that it is other underlying factors (e.g., participants' level of stress) causing IRs. Thus, future work should continue to explore relationships between BLV riders' trust along with other factors that may also be influencing BLV riders' need for information from L4+ ADSs.

Lastly, we anticipated different driving styles to impact BLV riders' willingness to accept ADS based on previous literature that suggested undesirable driving styles influenced sighted riders' willingness to accept this technology (Dillen et al., 2020; Cramer et al., 2020; Ekman et al., 2019; Bellem et al., 2018). However, our findings suggest that driving styles experienced in each trip type did not influence BLV riders' willingness to accept L4+ ADSs. This result aligns with perceptions of BLV individuals reported in prior work about using future ADSs, which indicated that the potential for increased independence and mobility would overshadow the risks associated with using L4+ ADSs (Brinkley et al., 2017; Bennett et al., 2020; Brewer & Kameswaran, 2018).

5.4.2.2   RQ5. What driving maneuvers during L4+ ADS trips warrant information from BLV riders?

While our results suggest that ADS driving style has a stronger influence on BLV riders' information requesting behavior compared to driving maneuvers, we do not consider this finding to necessarily mean that BLV riders would not benefit or desire information about specific driving maneuvers. For instance, of the three driving scenarios that participants least desired information about (i.e., smooth decelerations, smooth lane changes, and smooth accelerations), the only scenarios participants performed IRs was smooth decelerations. Furthermore, participants often mentioned information about smooth decelerations could help determine that the ADS is operating appropriately.

Beyond results from IRs this specific maneuver, other findings from our study suggest the benefits of understand when and why the ADS is stop, such as to avoid confusing BLV riders when they are nearing their destination (see Section 5.4.1.2). Previous work mentioned in Section 3.2 also describes how BLV individuals often track trip progress by corresponding a vehicle's motion with

a mental map of their route. However, without the ability to obtain information from another human in the vehicle, BLV riders might not be able to differentiate the cause of a maneuver (e.g., stopping for pedestrian in a crosswalk rather than for an anticipated stop sign controlled intersection), which could lead to confusion when tracking their route mentally. Based on BLV individuals' current behaviors for monitoring trip progress in addition to our limited findings, we believe future work should explore whether there are potential benefits for providing BLV riders with information about specific driving maneuvers.

5.4.3 RQ7: What driving environments during trips in L4+ ADS warrant information from BLV riders?

Our results suggest that L4+ ADS HMIs should provide advanced notice to BLV riders about bumpy and gravel roads (e.g., rural roads) along their route as these roads produce sensation riders might not anticipate experiencing during ordinary trips. Furthermore, our results suggest that BLV riders want to know about when they are entering highway in order to understand the reason for any increases in ADS's speed. These findings are contrary to previous work that indicated driving scenarios in urban environments elicited the greatest safety concerns and discomfort in sighted riders compared to riding on the highway and rural roads (Frison et al., 2019). While differences in driving environments utilized in each study could potentially explain the incongruent findings (i.e., we were unable to explore an urban environment), another explanation could be differences in how sighted and BLV riders can detect objects in the driving environment. For instance, safety concerns in urban environments may result more from riders being able to visually detect information in the environment (e.g., proximity to other vehicles and pedestrians in a close-quarters environment), whereas safety concerns in rural or highway environments may result more from riders being able to detect haptic and audio information from the environment (e.g., feeling/hearing the harsh terrain or the ADS increasing speed). However, because there is limited previous research on this topic, future research should continue to explore how driving environment influences L4+ ADS riders' experiences and need for information.

Lastly, our findings suggest that BLV riders can detect shifts from the roadway with moving traffic to environments with reduced speeds and less traffic (e.g., parking lot, residential area). As this finding provide important insight for ensuring riders detect their arrival at the drop-off location, we provided our discussion relating to this finding in Section 5.4.1.2.

5.4.4 Desired Content for Requested Information

In addition to wanting to understand when BLV riders will likely require information from an ADS, we also set out to understand the content L4+ ADS HMIs should provide BLV riders across different driving scenarios. Our findings suggest that participants primarily wanted information that would allow them to understand the reasons for the ADS's actions and behaviors. These findings align with previous work with sighted participants, which indicated that riders want information that explains the cause of the maneuver (i.e., 'why' information) as well as the type of maneuver the ADS performed (i.e., 'how' information; Koo et al., 2015; Koo et al., 2016).

While understanding the reason for the ADS's actions was desired for a majority of driving scenarios throughout both trip types, the desire for this type of information was especially prominent for driving scenarios involving quick decelerations, quick lane changes, and unexpected stops in a parking lot. Our findings suggest that BLV riders would want to know if the ADS was avoiding obstacles or other vehicles in the road, as this information would increase their trust and confidence in the ADS. Furthermore, this information could allow them to gauge the functional status of the ADS and differentiate between intentional actions and potential malfunctions or confusion. Previous work has indicated that sighted individuals want information that increases system transparency, such as comprehending objects in the environment detected by ADSs and ADSs' upcoming maneuvers (Oliveira et al., 2020; Diels and Thompson, 2018; and Miglani et al., 2016).

In comparison it seems that our findings align with previous research in that BLV riders also desire information that increases system transparency. However, one potential difference in how sighted and BLV riders want to use this information to increase system transparency could be that sighted riders want to use information to "proactively" detect issues with the system (e.g., riders want the ability to align objects detected by the ADS with what they see in the environment to determine if ADS is perceiving the environment correcting; Milgani et al., 2016), whereas our findings currently suggest that BLV riders need information to "retroactively" evaluate if an action performed by ADS is appropriate. However, this is not to say that BLV riders only want retroactively presented information, and thus, future work should explore the timing of information that can provide BLV riders with increased system transparency.

Another significant category of information sought by participants was trip-related information, which includes details about their current location, adjustments to their ETA or route, as well as rough road conditions and road structures along the route. Our findings suggest that BLV riders would want to be able to access this information at any time throughout a trip in L4+ ADSs either through automatic updates or upon request. Our findings support BLV riders' need to access information to determine their current location that was also reported by Brinkley et al., (2017).

Additionally, participants also wanted trip-related information, specifically their current location or changes to their route when feeling uncertain about their environment or about the ADS's behavior. For instance, participants wanted to receive advanced notice about traffic circles to understand and prepare for the long turning sensations produced by those structures. Participants also sought updates on their current location and trip adjustments when experiencing unexpectedly long stops, when riding on rough roads, as well as other unexpected events, such as quick decelerations and full laps of a traffic circle. Additionally, participants' perceived necessity for information for turn-by-turn updates was significantly higher after the UT compared to the ET. In previous work by Banovic et al. (2013) who explored information BLV individuals would like when navigating on-foot found that participants would request information in responses to cues from the environment (e.g., sounds, changings in walking surfaces, smells) or after experiencing interruptions during a walking navigation task. While this is related to walking, we believe our findings are similar in that BLV riders' need for trip-related information often resulted from changes in sensing different motions as well as environments. Taken together, we feel that it will be important for BLV riders to know their location when the ADS is operating expected, but potential more so when it starts behaving unexpectedly.

5.4.5 Interaction requirements

While the study was not intentionally designed to reveal substantial insight into interactions requirements, we were still able to identify some interactions BLV riders may desire from L4+ ADSs. Our findings suggest that BLV riders want the ability to use physical or verbal commands to control when the ADS starts. Furthermore, almost all participants desired the ability to command an ADS to stop if deemed necessary, which was not an interaction requirement mentioned by participants in Study 1 (see Section 4.4.2). In situations where an ADS is commanded to stop by

BLV riders, our findings suggest that it will be important to inform them about on their current location, nearby landmarks, and surrounding traffic conditions.

From discussions about stopping the ADS as well as other driving scenarios, a few participants also indicated the importance for being able to contact and receive remote human assistance. Finally, as it relates to PUDO, our results highlight several potential interaction requirements, of which we believe being able to trigger an auditory signal from the exterior of the vehicle could provide the greatest benefit to BLV riders. For instance, a single auditory cue (e.g., chime, horn) provided from the exterior of an L4+ ADSs that users could also repeat on-demand could improve BLV riders' ability to (1) detect the ADS's arrival, (2) obtain a spatial awareness of the ADS's location, (3) re-orient themselves to the ADS's during navigation, and (4) confirm they are at the correct ADS prior to entering the vehicle.

5.4.6   Study limitations:

Our study design had several noteworthy strengths, which include generating a study that was accessible for BLV individuals, increased ecological validity of an independent riding experience, and consistently reproducing unexpected driving scenarios safely on real roads. Nonetheless our study findings should be considered in light of the limitations, which are discussed in greater detail below.

While the sample size for our study was similar to the median sample size for accessibility research (Mack et al., 2021) and average size for studies involving only people with visual impairments (Brulé et al., 2020), we acknowledge that our sample size was small, and therefore, our findings should be interpreted in light of limited statistical power.

Another limitation with our study was related to our adaptations to commonly used WOZ techniques in ADS related research. Specifically, we did not hide the safety driver as we did not want to BLV participants feel as if we were taking advantage of their limited vision to deceive them into thinking it was real ADS, and consequently lose their trust or willingness to participant in future research efforts. However, a few participants made comments during the study that indicated their behavior would be different if they were no driver present. Thus, while we do not think it is beneficial to deceive BLV participants, more effective strategies should be explored for simulating a more authentic L4+ ADS experience.

Finally, our study design and measures of trust in ADSs did not allow us to differentiate what exactly caused a decrease participants' trust in automation. Currently, our study can only infer that experiencing a trip with several unexpected driving scenarios will decrease trust scores compared to an expected trip. To better understand how ADSs can maintain or even increase riders' trust, more work should explore methods for determining if specific driving scenarios, or a sequence of driving scenarios, influence riders' trust. This work could allow us to understand how to design ADSs to intervene and provide information in order to avoid losing riders' trust.

6 Study 3

6.1 Objective

Identify benefits and challenges BLV riders encounter while using an HMI prototype during a simulated L4+ ADS trip.

In Study 3, we simulated a L4+ ADS ride-hailing trip on real roads that required BLV participants to experience a variation of expected and unexpected driving scenarios as well as perform a drop-off task at the conclusion of the trip. BLV participants used an HMI prototype to receive information and perform user interactions throughout the trip. We designed the HMI prototype based on findings from Study 1, Study 2, and established accessibility standards and used it as a high-fidelity physical prompt to elicit feedback about information and interactions that can be provided in future L4+ ADSs. Feedback was used to refine previous or inform new guidelines and recommendations for designing L4+ ADS HMIs to be accessible to BLV riders. The research questions specific to Study 3 are as follows:

> RQ8. What information provided by the HMI prototype is valuable for BLV riders for different L4+ ADS driving scenarios?
>
> RQ9. What are BLV riders' perceptions of interaction modalities offered by the HMI prototype?
>
> RQ10. What challenges do BLV riders' encounter when using the HMI prototype during a negotiated drop-off scenario?

6.2 Method

6.2.1 Participants

We recruited 12 participants (female = 6, avg. age = 56.33, $SD = 19.27$; male = 6, avg. age = 66.17, $SD = 13.47$; overall avg. age = 66.25, $SD = 16.66$) from the New River Valley (VA) area that self-identified as blind or low vision and were 18 years of age or older. Ten participants self-reported having low vision and two reported being completely blind. Additionally, because we wanted to investigate requirements for assisting BLV individuals with independently exiting a vehicle during drop-off, we recruited participants that required no physical mobility assistance (e.g., crutches,

wheelchair, another individual) when walking and getting in/out of vehicles. As done in our second study, we evaluated participants' familiarity with the area (familiar = 6, avg. rating = 2.36, SD = .97).

Due to using similar roads and driving scenarios that were used in previous studies, we tried to recruit participants that did not participant in previous studies. However, after a comprehensive recruitment effort we were only able to recruit 11 participants that did not participate in previous studies. Even though we had a sample size that was similar to the median sample size for accessibility research (Mack et al., 2021) and average for studies involving only people with visual impairments (Brulé et al., 2020), we determined that we had the time and resources to run an additional participant. Thus, we recruited one participant that participated in our second study (female, blind), which allowed us to generate a balanced sample for gender as well as increase the number of totally blind participants in the study.

Participants were recruited via fliers posted across Virginia Tech's campus and advertisement emails sent out to the Graduate Student and Industrial and Systems Engineering listservs. We contacted BLV individuals that participated in previous research efforts. Lastly, similar to previous study efforts, we received assistance with disseminating our recruitment materials from local and national organizations serving the BLV community.

Table 19. A breakdown of participant demographics.

Self-reported degree of vision	Count	Perc.
Blind	2	16.7%
Low Vision	10	83.3%
Length of time with vision loss		
Since birth	4	33.3%
$\leq$ 20 years	7	58.3%
21 – 50 years	1	8.3%
50+ years	0	0%
Gender		
Female	6	50%
Male	6	50%
Age Range		
18 – 24	0	0%
25 – 34	0	0%
35 – 44	3	23.1%
45 – 54	2	15.4%

54 – 64	2	15.4%
65+	6	46.2%
Race		
White	9	100%
African American	2	16.7%
Latino	1	8.3%
Familiarity with area		
Not familiar	6	50%
Familiar	6	50%

6.2.2   Simulated Trip

We designed one simulated L4+ ADS trip that was split into four trip segments that exposed participants to driving maneuvers performed using a variety of driving styles across different types of driving environments (e.g., a combination of similar scenarios from ET and UT from Study 2; see Section 5.2.2). Between each trip segment, the test vehicle stopped in pre-determined parking lot so participants could respond to a post-trip segment interview. The first three trip segments each took about five to ten minutes to complete and required participants to travel two to three and a half miles. These first three segments simulated different ride-hailing experiences by exposing participants to different driving scenarios. The first segment required participants to ride on the highway and urban/commercial park roadways (i.e., Virginia Tech's campus). During this first trip segment, participants only experienced smooth and comfortable driving styles. The second trip segment had participants experience an unexpected detour to avoid a fictional traffic jam that was present on the originally planned route. The detour caused participants to travel on bumpy rural roads that were covered in gravel. The third trip segment had participants ride on the highway and experience one quick lane change and one quick deceleration at a stop sign in a commercial park environment. Outside of these two unexpected events, participants experienced smooth and comfortable driving styles. The location where the two unexpected events occurred were spaced out by approximately two miles to avoid overwhelming the participants with unexpected events.

Figure 19. The three images depict the route used for the first (bottom), second (middle), and third (top) trip segments. Icons are presented along each route to show where information was provided from the HMI prototype.

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We designed the fourth trip segment to simulate the experience of nearing and arriving at a drop-off location at a rider's destination. During this final trip segment, participants are nearing their destination and are informed that the optimal drop-off location (i.e., curbside parking that was 10 feet away from the entrance to their destination) is no longer available and that they must review information provided by the HMI prototype to select a preferred drop-off location. The segment would be complete once they selected a location and the test vehicle parked in the parking lot.

6.2.3   Equipment

We used a 2012 Toyota Camry 4-door sedan to simulate L4+ ADS ride-hailing experiences. The interior of the test vehicle was outfitted with a camera and microphone to record participants' behaviors during trips. We had the safety driver from Study 2 operate the test vehicle due to their ability to consistently reproduce driving styles (see Section 5.3) that we wanted to replicate in the simulated trip for this study. Even though the safety driver had experience performing the driving scenarios we wanted participants to experience, they were still required to complete multiple practice sessions to familiarize themselves with the new route and study procedures. The driver's speed as well as longitudinal and lateral forces were monitored to confirm that they could still consistently produce desired driving scenario.

We developed an HMI prototype to serve as a high-fidelity prompt to generate feedback from participants about various types of information and interactions that could be provide to BLV individuals while riding in L4+ ADSs. The HMI prototype consisted of a large touchscreen tablet (i.e., Samsung Galaxy Tab S8 Ultra) that was housed in a custom 3D-printed case and mounted on the back of a seat directly in front of participants (see Figure 20). The tablet's display and speakers were used to present auditory information as well as visual information. The content of the presented information is detailed in a later section.

While we did present visual information on the touchscreen display, evaluating this information was not an objective of the study because designing accessible visual information for a digital interface is already well documented in resources like the WCAG 2.0 (Caldwell et al., 2008). The main reason for including visual information on the touchscreen was to help maintain or increase a level of immersion in the imagined scenario for participants whose vision would allow them to see some visual information from the screen. For instance, if participants were able to detect

objects moving on the screen, such as the vehicle's indicator navigating the map, this could provide a higher sense of fidelity to the simulated experience.

Because Study 1 findings indicated a variety of interaction modalities that BLV riders would expect when inputting information into the system (i.e., touch, voice commands; see Section 4.4.2), we developed the HMI prototype to allow participants to use a variety of interactions modalities. Additionally, findings from Study 1 and Study 2 suggest the utility in providing BLV riders access to system interactions that allow riders to (1) control when the ADS should start the ride, (2) to speak to a human operator, and (3) request the ADS to stop if the rider deems it necessary. Therefore, we created the HMI prototype to allow us to further explore the use of physical buttons and verbal commands as interaction modalities as well as explore the use of these three system interactions across different driving scenarios. For the physical input modality, we installed push buttons under the touchscreen for each of the three system interactions. Additionally, during the negotiated drop off phase of the trip, participants could use touchscreen gestures (swipe left/right, double tap) to review and select drop-off locations. Because we were able to hear participants at all times during trips, we used Wizard of Oz techniques (detailed later in this section) to simulate the use of verbal commands as a redundant input modality for all touch-based input modalities.

Physical and Tactile Information

Although findings from our previous studies did not establish a need for physical (i.e., physical information presented in the environment, e.g., large text) and tactile information (i.e., braille or raised text) to be present inside L4+ ADSs, we still included them on our HMI prototype to further explore additional methods for understanding how we can increase the accessibility of an L4+ HMI. Additionally, at the time of developing the HMI prototype, we were unaware of any existing accessibility guidelines that cover the design of physical controls, visual text or icons, and raised/tactile information for vehicle interiors, and thus, we saw this as an opportunity to help fill this gap. Without existing design references, we refer to guidance provided in the 2010 ADA Standards for Accessible Design (Department of Justice, 2010) for signage and elevator call buttons.

For the design of our tactile information, we provided two pieces of information: raised text and raised icon on the button. Upon reviewing the ADA guidelines (i.e., can use either braille or raised

text) for tactile information as well as after consulting with O&M experts, we decided to use raised text instead of braille. Furthermore, we had concerns with 3D printing provided the detail required to print braille compared to raised text. The dimensions and spacing between letters were based on ADA standards as well as the size of the buttons met ADA standards for elevator cars. Finally, we used our best judgement when selecting the icons for the buttons, which resulted in a sideways triangle for the Start button, a phone with a question mark for the Support button, and lastly, an arrow swerving to the right for the Pull over button.

Figure 20. The HMI prototype consisted of a touchscreen tablet within a 3D printed case that offered tactile information and three physical push buttons underneath the touchscreen. The design of tactile information (raised text and icons) was based on ADA guidelines. The touchscreen provided limited visual information (for study immersion purposes) and offered touchscreen gestures only during the drop-off task.

To provide participants with an experience of a fully functioning HMI that can provide information throughout the trip and allow them to interact with the simulated L4+ ADS using interactions afforded by the HMI prototype, we utilized a Wizard of Oz approach (Baltodano et al., 2015). For

this approach, we had a researcher performed the role of the *interaction wizard* and was responsible for monitoring trip progress, occurrences of driving scenarios, and participants' interactions with the HMI prototype to determine when to manually trigger information to be presented. To manually present information during sessions, the interaction wizard used a custom-built interface that contained a list of playable information (see Figure 21).

Figure 21. The interaction wizard's interface. The list of playable information during the trip is listed vertically whereas the list of information for the negotiated drop-off is grouped at the top-left of the interface.

We originally developed the interaction wizard's interface with the intention that the interaction wizard would perform their responsibilities remotely using a modified version of the REX system from Study 2 (see Section 5.2.3). However, practice sessions revealed that an inadequate view of the driving environment caused the interaction wizard to miss situations that required information as well as provide inaccurate explanations. For instance, the interaction wizard would see the test vehicle approach an intersection and begin slowing, so the wizard triggers the information: "stopping for a red light." However, the traffic light had actually turned green and the test vehicle was only slowing behind traffic that had just begun moving toward the intersection. As a result, we had the interaction wizard sit in the test vehicle with participants to better monitor the driving environment (see Figure 22).

Figure 22. Depicts the interior of the test vehicle with the HMI prototype mounted in front of the participant's seating position. The interaction wizard was seated to the left of the participant where they would use the interface to control the information presented on the HMI prototype.

Information provided by HMI prototype

Using findings from Study 1 and 2, we designed information that was presented via the HMI prototype during the first three trip segments. Information provided by the HMI prototype can be split into five categories:

- *System transparency* – information on what the ADS is doing (i.e., stopping, speeding up/slowing down, I had to swerve…) and why (i.e., …for a stop light, for a traffic circle, to enter/exit the highway, to avoid an object in road).

- *Landmarks* – information about nearby landmarks, which included road structures (i.e., traffic circles, highways, going under US 460) as well as nearby buildings or areas (i.e., Virginia Tech baseball stadium, Steger Hall, Alphin Stuart Livestock Arena, Virginia Tech Montgomery Executive Airport).

- *Road condition* – advanced notice of poor road conditions (i.e., We will be driving on rough terrain for about a half mile.)

- *Nearing destination* – information on remaining time until riders reach their destination (i.e., We are 5 minutes/1 minute away from your next destination.)

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- *Route changes* – information on when the planned route has been adjusted and the reason for that adjustment (i.e., Severe traffic jam detected. Taking a detour to reach your next destination.)

Across the three trip segments, participants had the potential to receive 26 to 30 explanations from the HMI prototype depending on how many red lights they encountered.

In addition to this information, we also considered providing turn-by-turn navigation as this information category was mentioned in Study 1 and 2. However, we determined adding information about upcoming turns and road names would add about 28 additional pieces of information and double the list of information. Because we feared that this could make the list of information unmanageable for the interaction wizard and cause potential mistakes and inconsistencies between participants, we decided to not present this information manually. During practice sessions, we tried using the Google Maps mobile app to provide turn-by-turn information but determined that our planned route was so unique that it made managing/overriding Google Maps' recommended adjustment difficult. As a result, we decided to not include all the road names and turn-by-turn directions and took this as an opportunity to understand if this type of information would still be needed by BLV riders when they were also receiving the other information categories.

During the final driving scenario, participants experienced the negotiated drop-off scenario, which started when the simulated ADS is approaching a parking lot. At that time, the HMI will provide an overview of the intended drop-off location that also happens to be the most accessible drop-off location (i.e., curbside drop-off, shortest walking distance, and a straight path to the building's door with no tripping hazards along the way). Upon reaching the parking lot, participants will be informed that the original drop-off location is no longer available. As a result, participants will have to interact with the HMI prototype (using touchscreen gestures and/or verbal commands) (see Figure 23) to review and select a desired drop-off location from a list of options provided by the ADS. Based on related work as well as findings from Study 1 and Study 2, each drop-off option presented by the HMI prototype included details such as the required walking distance, presence of tripping hazards, useful landmarks, topography, and nearby pedestrians (see Section 4.4.3 for Study 1 results and Section 5.3.1for Study 2 results).

Figure 23. Depicts information presented on the touchscreen. While receiving feedback on the visual design of our HMI prototype wasn't an objective, we included this image as it provides an idea of the information participants received verbally.

6.2.4 Measures

Pre-trip Interview – Accessibility of Physical Information

To start the pre-trip interview, we informed participants about the presence of three physical buttons on HMI prototype but did not inform them about the purpose of these buttons. Instead, we asked participants to try and perceive the large, raised text as well as raised icons on the buttons and then guess the purpose of each button. In attempts to avoid situations were failing to correctly perceive the physical information on the HMI resulted in participants feeling negative reactions toward the study, researchers, or themselves/their abilities, we repeatedly informed participants leading up to the task that the purpose of this exercise was to evaluate the accessibility of our design and was not an evaluation of their abilities.

We recorded participants' guesses for each button, any useful observations on how they were attempting to sense the information, and any comments they made during the task. Participants were allowed to respond with "I'm not sure" if they couldn't use the information to formulate a guess. Additionally, for each button, we had participants provided a rating for how confident they were that their guess was correct using a 5 point-Likert scale (1 = not at all confident, 2 = slightly

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confident, 3 = somewhat confident, 4 = fairly confident, 5 = completely confident). Any "I'm not sure" responses were assigned a "0" for the confidence rating.

Next, we informed participants on the actual purpose of the three buttons and had them respond to a semi-structured interview. Specifically, the interview was used to understand participants' thoughts about the current design of the physical information and their ideas for adjusting the design to better suit their needs. Listed below are the semi-structured interview questions we administered, which we developed such that they could be answered regardless of the modality participants use to sense the information (e.g., vision or touch):

- If I didn't explain the location and purpose of these buttons, would you have been able to find and understand this information on your own?
- Are there any modifications you would make to this design?
- What are your thoughts on the design of the raised text?
- What are your thoughts on the raised icons used on the buttons?
- Do you have any thoughts about the placement of the tactile information related to where you are seated?
- Would you prefer alternative methods for activating the features offered by these buttons? If so, what would those alternative methods be?

System Interactions

During the simulated trip, participants were allowed to voluntarily perform system interactions using either the buttons or verbal commands. If participants performed a system interaction, we recorded where the interaction occurred along the trip as well as ask participants questions about the interaction during a later interview (to avoid them missing more information provided by the HMI prototype) to understand the type of system interaction selected and reason they performed it. At the end of the trip, during the post-study interview, participants were asked to provide more context and reasoning for any selected input modalities.

Evaluating information for driving scenarios

After each trip segment, participants performed a post-segment interview to capture their perceptions of the information they received for that driving scenario. To start the interview, participants responded to the following two prompts:

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- "Please select the statement that best fits your opinion about the information provided by the HMI during that last part of the trip (statements were coded using the assigned number): (1) it was not informative at all, (2) it could have provided more information, (3) it was perfect, (4) it could have provided less information, or (5) it provided way too much information."
- "What was your reason for selecting that statement?"

To understand if driving scenarios impacted opinions about the information received during the trip segment, we had participants rate their level of agreements with two statements (i.e., "I understood the intent of the ADS" and "I felt that I had an accurate understanding of my environment.") using a five-point Likert Scale response (i.e., 1 = strongly disagree, 2 = rather disagree, 3 = neither agree nor disagree, 4 = rather agree, 5 = strongly agree).

For final part of post- segment interviews, we asked participants to respond to a semi-structured interview, which included the follow prompts (regardless of trip segment):

- What were your thoughts about the information provided during the previous trip segment?
- Was there any information that you wished the HMI prototype provided you?
- Was there any information that you thought was unnecessary?

The following interview prompt was exclusive to the second trip segment, which had participants experience a detour:

- Because of the detour, the HMI provided information about landmarks that you were not aware of before starting the trip. What are your thoughts about receiving information about those landmarks or landmarks in an unfamiliar area?

Negotiated Drop-off

To understand the accessibility of the HMI prototype to assist with the negotiated drop-off task, we measured task performance (i.e., participant successfully reviewed different parking spot options and select the appropriate spot based on provided criteria). Participants were informed that upon arrival at their destination, they would want to park near the "main lobby entrance" (as opposed to the "urgent care entrance"). We also asked participants, when given the option by the HMI prototype, to review a list of drop-off locations. Thus, the criteria for task success when

participants opted in to review a list of drop-off locations as well as selected a location by the main lobby entrance. We also noted how many steps it took participants to select a spot as well as instances participants had to be reminded of instructions for using the HMI.

Lastly, we performed a semi-structured interview with participants to investigate the (1) utility of the information we provided to help participants understand their environment, (2) concerns or ideas for improving the HMI prototype for this specific task, and, (3) general thoughts about future L4+ ADSs providing this feature for negotiating appropriate drop-off locations. Participants' feedback will be used to develop recommendations for designing information that can help BLV riders evaluate and select a preferred drop-off location. Furthermore, depending on participants' opinions, we would develop guidelines for developers to use when determining how L4+ ADSs should go about selecting drop-off (and perhaps pick-up) locations (e.g., with or without input from BLV riders).

Post-Study Surveys and Interview:

The final interview was used to investigate any interactions participants tried to perform during the trip in order to understand participants' reasoning for selecting one input method over the other (i.e., voice commands, buttons, variation of both). If participants performed no input interactions, we used this opportunity to clarify that their behavior was intentional (e.g., they did not feel the need to stop the ADS or call for human assistance). Lastly, we asked participants to identify the biggest benefit as well as biggest limitation of using the HMI prototype during their simulated experience. Before concluding the post-study interview, participants were offered the opportunity to make any final comments about the simulated L4+ ADS experience or the overall study.

Trusting in automation: To gain a general sense of BLV participants' trust when using the HMI prototype for a simulated trip, we had participants responded to select subscales from the TiA scale (Körber, 2019) that were more applicable for our study (i.e., Reliability/Competence, Understanding/Predictability, and Trust in Automation). Specifically, compared to Study 2, we removed the familiarity subscale (i.e., "I already know similar systems" and "I have already used similar systems") as these items often confused participants and were deemed irrelevant to the study since L4+ ADSs are not readily available to the public. We also administered the Propensity to Trust subscale during the intake session to understand participants baseline willingness to trust (see Appendix B for TiA scale items).

Usability: We also measured participants' perceived usability using the Usability Metric for User Experience (UMUX), which has four Likert-scale items that measure perceived usability of a product or system (Finstad, 2010; see Appendix F).

6.2.5 Procedure

To simulate how some BLV individuals prepared for a trip in an unfamiliar area, we provided participants with an overview of the entire trip (i.e., all four trip segments) as well as a refresher of each of the four trip segments before they experienced them. To help provide participants with a more immersive experience, we asked them to imagine that they were using the L4+ ADS to run errands on their way to their final destination, which would have required them to stop at three locations prior to their destination.

Eligible participants visited the VTTI campus for a study session that lasted approximately one hour. As in Study 2, we offered participants the option to have a member of our research team transport them to and from the study location. Upon arrival at the study location, we guided participants to a conference room to conduct the intake session. During the intake session, we read the IRB approved informed consent form to participants and answered any questions they had. We informed participants that the study involved riding on public roads in a vehicle that was configured to simulate an L4+ ADS ride-hailing vehicle, which was actually operated by a trained safety driver at all times. If interested in continuing, participants completed a portion of the TiA (i.e., Propensity to Trust subscale) to provide their initial levels of trust in technologies. Then, to represent how some BLV individuals might have prepared for a trip by reviewing the route ahead of time, we provided participants with a route overview, which also included information about useful landmarks they would pass along the way (i.e., landmarks the HMI prototype would point out).

After completing the intake session, participants were seated in the second row on the right side of the test vehicle. We introduced participants to the HMI prototype and explained how it would present information throughout their trip. Additionally, we provided an explanation of the location and purpose of the physical buttons. After allowing participants to perceive the buttons themselves, we conducted a brief semi-structured interview to capture participants' initial opinions toward the HMI prototype and the physical buttons.

Next, we instructed participants to use the buttons as they deemed appropriate during any driving scenarios. Participants also received instructions for specific verbal commands that could be used as an alternative input modality for each button (e.g., "ADS, call customer support"). Lastly, we informed participants that buttons (such as the pullover button) would not actually control the ADS but rather connect them with the remote researcher to perform a quick interview about their choice of interaction. To actually stop the study session and their trip, participants were instructed to speak directly to the safety driver. Prior to starting the trip, participants were provided a sample of the auditory information from the HMI prototype and asked if they needed to increase or decrease the volume. Additionally, participants were instructed that they could request the volume to be adjusted during post-trip segment interviews.

During the simulated L4+ ADS trip, all participants experienced the same driving scenarios and information from the HMI prototype in the same order. After each driving scenario, participants performed a post-scenario interview. At the end of the trip, participants encountered the negotiated drop-off scenario where they had to use the HMI prototype to select the correct drop-off spot based on criteria provided by the remote researcher (e.g., the spot with the least number of tripping hazards). After completing the negotiated drop-off task, participants completed a brief interview while being driven back to the VTTI parking lot. To conclude the study, participants completed the post-study interview with the remote researcher. Afterward, we provided participants with compensation and thanked them for their time. Participants that required transportation were then provided a ride.

6.3 Results

6.3.1 Preliminary analyses:

The same processes for preliminary data analysis and content analysis from Study 2 were utilized for this study (see Section 5.3). To understand if gender should be included as a covariate, we performed Mann-Whitney U Tests and discovered no significant differences between genders and ratings to any of self-reported surveys we administered in the study (i.e., post-trip segment interview items, TiA subscales, and UMUX subscales).

All participants received all trip segments and planned driving scenarios within each segment. As for missing data, the first participant in our study did not receive the pre-trip interview prompt for

guessing the purpose of each button because the idea for this prompt was generated as a result of their session. Because this was the only change made to our study procedure, we kept the remainder of their data. Also, to avoid exceeding the allotted time for the study session, one participant did not receive the UMUX questionnaire.

6.3.2 Accessibility of Physical Information

To further our understanding for how to design physical information to be presented in L4+ ADSs, we examined participants' ability to successfully identify and interpret the three system interactions presented using three push buttons with raised icons on them and raised text labels above the buttons. Ninety-one percent of participants (10 of 11) correctly identified the Start button, but only 73% (8 of 11) correctly interpreted that it was used to start the trip. Seventy-three percent of participants (8 of 11) correctly identified the Support button with only 36% (4 of 11) correctly guessing that the interaction was used to speak with a human operator to get additional information or assistance. Examining incorrect guesses for the Support button revealed that 36% of participants believe the button would allow them to get additional information or assistance from the ADS. Fifty-five percent of participants (6 of 11) correctly identified and guessed the purpose of the Pull Over button, which made it the only button where everyone that was able to identify the button could also accurately interpret its purpose. Finally, the physical information for the Pull Over button as well as Support button resulted in three participants responded with "I'm not sure" whereas only one participant responded this way for the Start button.

Participants felt the most confident in their guesses for the Start button ($Mdn = 5$, $M = 4.45$), followed by the Support button ($Mdn = 4$, $M = 3.18$), and then Pull Over button ($Mdn = 3$, $M = 2.82$). When examining the confidence scores for all instances where guesses were correct ($N = 18$ of 26), the average confidence rating was 4.67, which indicates that people who perceived the button felt 'fairly' to 'completely confident' that they knew the purpose of the button. Alternatively, of the guesses that were incorrect across all buttons ($N = 8$ instances), the average confidence score was 3.88, which indicates that participants felt 'somewhat' to 'fairly confident' that they knew the purpose of the button when they were in fact wrong.

Participants utilized a variety of strategies when attempting to interpret the physical information for system interactions, of which the most popular was to feel the raised icons and text ($n = 8$). Many participants ($n = 6$) used their residual vision to perceive the icons on the buttons and/or

large text, which often required participants to lean in to get closer to the HMI to see the information or use a magnification device. For some participants that couldn't interpret system interactions using the physical information, they said that the placement of the buttons (i.e., left to right) help them assume that the first button was the Start button (n = 3).

> P12 (B) - I have no idea what this button is by relying on just the raised text and icon. But using my best guess of what the first button in a row of buttons is, I think this would be Start.

6.3.2.1 Open-ended responses

When examining responses to the pre-trip interview questions, we discovered that all 12 participants believed that they would have been able to locate the tactile information on their own if the researcher did not indicate their location during the instructions. When asked to provide a reason for their confidence in locating the tactile information independently, some low vision participants stated that their visual acuity still allowed them to detect that there was information presented beneath the display (n = 5). Over half of the participants (n = 7) mentioned that they would have located the tactile information independently due to their natural tendency to feel and explore their nearby surroundings, with three participants adding on that they typically anticipate tactile information to be located beneath displays.

When asked about specific aspects of the physical information and how it could be improved, a majority of participants (9 of 12) mentioned the need for braille to be added to HMI prototype with many (n = 5) recommending that the braille be placed below or beside the push button. Half of the participants mentioned the need for larger buttons with larger icons to improve their ability to detect and comprehend the icons. Four participants suggested creating large buttons that contains the larger icon, large text, and added on braille to improve the detection of the buttons as well as help separate each of the system interactions. This suggestion for increasing icon size is reinforced by participants' comments during the button guessing task, which revealed that only five participants were able to detect that the icon for the Start button was the "play button" (i.e., sideways triangle) and that 10 participants were not able to determine icons used for the Support and Pull Over buttons. Other popular suggestions for improving the physical components of our HMI prototype included inverting the colors to have a black background and white text/icons to increase the contrast and improve the detection and legibility of the icons and text (n = 5), adding

space between individual raised letters to make them easier to distinguish and increase the visual and haptic legibility of the text (n = 5), and having verbal descriptions that label the buttons and/or explain its purpose prior to the trip or prior to activating them (e.g., first press gives verbal description, second press activates button) (n = 4).

Prior to informing participants that they could use verbal commands as a redundant input modality to the push buttons, we asked if they had any ideas for alternative modalities that they would want to use in addition to the buttons. Over half of the participants (n = 7) said just having push buttons is acceptable, with two of those participants stating that they would not want to use verbal inputs due to previous issues with using verbal commands to interact with technology. Three participants stated that they would want the option to use verbal input in addition to the push buttons. Finally, when asked about other system interactions they would to be available, five participants offered four different ideas, which included: an emergency version of the Pull Over button that would immediately stop the ADS (rather than have it determine the best place to stop first), a button for re-routing or adjusting your trip, a way to get more information on ADS's actions, and a way to get information about their current location on demand.

6.3.3 Perceptions of Information for Trip Segments

6.3.3.1 *Self-reported measures*

After each trip segment, participants were asked to select a statement that best matches their opinion of the information provided by HMI prototype for that trip segment. For the first trip segment, 58% of participants selected "it was perfect" and 42% selected "it could have provided more information" (*Mdn* = 3, *M* = 2.58, *SD* = .52). For the second segment, 50% of participants selected "it could have provided more information," 42% selected "it was perfect," and 8% selected "it was not informative at all" (*Mdn* = 2, *M* = 2.33, *SD* = .65). For the third segment, 75% of participants selected "it was perfect" and 25% selected "it could have provided more information" (*Mdn* = 3, *M* = 2.75, *SD* = .45) (see Figure 24). A Friedman ANOVA revealed no significant differences in participants' rating of the information provided throughout each three trip segments, χ^2 (2) = 5.38, *p* = .07.

Figure 24. Histograms depicting participants' perceived ratings for how informative the HMI prototype was for each trip segment (where 1 = it was not informative at all, 2 = it could have provided more information, 3 = it was perfect, 4 = it could have provided less information, or 5 = it provided way too much information.)

Additionally, after trip segments, participants used a five-point Likert scale to rate their level of agreement (1 = strongly disagree and 5 = strongly agree) with the following two statements: "I understood the intent of the ADS" and "I felt that I had an accurate understanding of my trip." The descriptive statistics of ratings for each statement are listed in Table 20 and Table 21. We performed Friedman tests to detect significant shifts in participants' ratings for each statement across trip segments. There were no significant differences in participants' ratings for understanding the ADS's intentions between trip segments, $\chi^2 (2) = 2.00$, $p = .368$, but there was a significant difference in rating for perceived trip accuracy between trip segments, $\chi^2 (2) = 7.54$, $p = .023$). We conducted a post-hoc analysis with multiple Mann-Whitney U Tests with a Bonferroni correction applied (resulting in a significance level set at $p < 0.017$) to detect where the significant difference occurred, which detected no significant differences between the three trip segments.

Table 20. Descriptive statistics for participants' perceived understanding of ADS intentions per trip segment.

Trip segment	Mean	SD	Median
1	4.83	.39	5
2	4.67	.49	5
3	4.83	.39	5

Table 21. Descriptive statistics for participants' perceived trip accuracy per trip segment.

Trip Segment	Mean	SD	Median
1	4.83	.39	5
2	4.17	1.34	5
3	4.92	.29	5

Prior to experiencing the simulated trip, participants responded to a subscale of the TiA questionnaire to measure their propensity to trust (i.e., willingness to trust automation). After the trip was completed, participants responded to the remainder of the TiA questionnaire to measure their trust in automation after experiencing a simulated trip while receiving information from our HMI prototype. The average propensity to trust scores was 3.92 ($SD = .57$, $Mdn = 3.83$), while the

average of the overall TiA was 4.27 (SD = .42, Mdn = 4.38). The descriptive statistics for the subscales used to generate overall TiA can be found in Table 22. Spearman's rank-order correlations revealed no significant relationships between propensity to trust scores and each TiA subscales nor to the overall TiA score ($p > 0.05$). Thus, we believe that these trust ratings are not reflective of participants' willingness to trust automation.

Table 22. Descriptive statistics for TiA subscales.

TiA subscale	Mean	SD	Median
Reliability and Competence	4.05	.42	4.17
Understandability and Predictability	4.40	.47	4.50
Trust	4.67	.54	5.00

6.3.3.2 Open-ended feedback

In this section, we first describe participants perceptions of the provided information and needs that relate to general L4+ ADS ride-hailing experiences that we discovered across the three trip segment interviews. Next, we breakdown the participants thoughts about the HMI prototype relating to specific driving scenarios that occurred during the second and third trip segments.

General information:

Across the three trip segments, we identified three categories of information presented by the HMI prototype that participants appreciated, which were information about (1) landmarks, (2) ADS's actions, and (3) upcoming road structures and road conditions. Many participants liked that the HMI announced landmarks they were passing during the trip (n = 11). As discussed in more detail later, participants found this information useful in familiar and unfamiliar locations throughout the simulated trip. Participants (n = 10) also valued information that allowed them to understand the actions of the ADS, such as stopping at stop signs/traffic lights, speeding up/slowing down to enter/exit highway, and using traffic circles. Lastly, participants (n = 7) also liked that the HMI provided advance notice of upcoming traffic circles, speed bumps, and rough road conditions. Participants stated that having information about these three information categories increased their comfort levels (n = 7), helped monitor trip progress (n = 7), as well as increased their confidence and trust in the system (n = 6).

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P06 (LV) - If I had not known about the traffic circles ahead of time, I would have been scared.

P12 (B) - The information the interface provided made the entire trip so much less stressful.

During post-trip segment interviews, participants were asked to identify any information they thought was unnecessary. For the first and third trip segments, 100% of participants stated that they did not think any of the information provided by the HMI was unnecessary. For the second trip segment, only one participant mentioned that information about the rough road was unnecessary because, *"I think you can feel that" -P06*.

During the post-study interview, participants were asked to identify the biggest benefit offered by the HMI prototype. Our intention was to use this question to identify aspects of the HMI design that participants found the most useful, however, the most common response (n = 4) was that experiencing our HMI prototype during a simulated L4+ ADS experience gave participants excitement and hope for this technology to serve as an independent means of travel in the future.

P11 (LV) - Because I can't drive anymore, this experience gives me hope that I don't have to depend on people to take me where I need to go, and I can just take myself! I would buy this when it comes out.

P05 (B) - Having the ability to possibly be on the road again. I went blind a year and a half ago and I spent most of my time being stuck at home. And the possibility of being back on the road again gives me hope. The idea of this gets my heart pumping. When I first went blind, everything felt hopeless. […] the idea of having access to an ADS, that is awesome. I'm very much looking forward to what is to come with this technology.

As for additional information that participants wished the HMI provided, a majority (8 of 12) wanted the HMI to provide road names they encountered throughout the entire trip, with three participants stating that receiving road names is especially useful when traveling in unfamiliar locations. Additionally, five participants wanted the HMI to provide a better sense of direction for upcoming maneuvers (e.g., turning left onto Main Street, heading North on US-123). Other information that participants wanted the HMI prototype to provide were the following: ETA and destination name or address before each trip (n = 3), notifications about trip delays (n = 3), traffic density along their route (n = 2), ADS's speed (n = 1), and scenic descriptions of their environment for entertainment purposes (n = 1).

When participants were asked to identify the main limitation of the HMI prototype, the most common response (n = 4) was that the HMI did not provide information similar to turn-by-turn directions (i.e., direction of maneuver to enter a new street). Other limitations mentioned by participants included: not getting more details about detour (n = 2), explaining buttons/instructions for HMI (n = 2), not being able to adjust route/approve detour and that the rider is just at the ADS's mercy (n = 1), and not being able to understand the operational status of ADS (n = 1).

Landmarks:

Across all trip segments, 11 of 12 participants stated that they appreciated the HMI prototype presented information about landmarks regardless of if participants had prior or no prior awareness of the landmarks on their trip. For the first and third trips segments, the ADS followed the exact route and provided the landmarks the interaction wizard provided in their route descriptions before starting the trip. Alternatively, for the second trip segment, the ADS immediately detoured, which resulted in participants not experiencing any of the route described by the interaction wizard. The purpose of this was to explore how participants felt about getting information about landmarks when participants were aware (familiar) and unaware (unfamiliar) of the landmarks/route details in advance. When aware of landmarks along their route ahead of time, 7 of 12 participants stated that information about landmarks they were passing was useful for monitoring trip progress and confirming that the ADS was still on the correct route to reach the correct destination. When not aware of landmarks in advance (i.e., due to unexpected detour), 11 of 12 participants stated that having the HMI announce landmarks they passed was useful for several reasons described in the following paragraphs.

Learning and building mental maps for future trips. Participants (n = 6) found the information about landmarks helpful in building a mental map of unfamiliar areas. Hearing about landmarks during the trip allows them to learn about these landmarks and recognize them if they pass through the same route again in the future. Any landmark, regardless of familiarity, assists in building a mental map and maintaining location awareness.

Comfort and confidence in the ADS. Participants (n = 5) expressed that hearing about landmarks in unfamiliar areas provided them comfort and confidence. It reassured them that the AV knew its location and was operating correctly. Having this information also made them feel more confident in the AV's capabilities.

Reference points for emergency situations. Participants (n = 4) mentioned that landmarks can also serve as reference points in unfamiliar areas, which is critical whenever in there is a possibility for getting lost or needing to request assistance due to the ADS malfunctioning or breaking down. Thus, if ever needed, participants emphasized the importance having landmarks as reference points in order to guide themselves or others to a known location.

Rider engagement and desire for more landmarks. Many participants (n = 5) mentioned that getting information about landmarks in an unknown or known area can make the trip engaging and enjoyable. A few participants even mentioned that they would have liked receiving more information related to landmarks than the HMI prototype provided.

Unexpected Detour:

When the detour occurred during the second trip portion, 8 of 12 participants wanted two pieces of information from the HMI, which were (1) an overview of the new route when the detour is first announced (i.e., a new ETA and road names along route), and, (2) turn-by-turn navigation to know their current location while on the detour. Similar to knowing landmarks, several participants stated that information about road names along the new route is crucial because it provides a sense of where they will be going as well as provided information that can be used in situations where they need to inform someone about their location if something were to happen to the ADS.

> P11 (LV) - That way if anything would have happened to the ADS or me, I would at least have an idea of my location if I needed to request assistance.

> P12 (LV) - If something were to happen to this vehicle, I would have no way to call out for help and let someone know where I am [without road names or nearby landmarks].

Seven participants appreciated that the HMI provided a reason for the detour (i.e., to avoid a traffic jam) as well as advanced notice about the rough road condition, which allowed them to anticipate and prepare for such conditions. Three participants wanted the HMI to recommend the detour as an option and allow riders to decide whether the ADS should take the detour or remain on the original route. Finally, four participants did not require any additional information from the HMI prototype during the second trip segment.

Unexpected lane changes and quick deceleration:

Relating to the unique driving scenarios that occurred during the third trip segment (i.e., quick swerve and quick deceleration), 10 of 12 participants expressed satisfaction with the information provided by the HMI prototype. Participants found the information helpful for understanding the ADS's behavior and feeling more comfortable during the trip.

> P09 (LV) - The information provided for the sudden swerve and quick stop prevented the situation from feeling scary.

> P04 (LV) - I felt that information provided by interface about the quick swerve and quick deceleration were necessary because it kept me from feeling too startled as well as it was similar to information human drivers would typically tell you too.

As for additional information the HMI could have provided, one participant wanted more details about objects the ADS avoided (i.e., a human or inanimate object) while another participant wanted information about the unexpected driving scenarios provided before the maneuver, if possible. Three participants did not require any additional information from the HMI prototype during the third trip segment.

6.3.4   Interactions with HMI prototype

6.3.4.1   Interactions during trips

In an attempt to capture preference of interaction modality, participants were instructed to use either the push button or voice command to trigger the start of each trip segment as well as the drop-off task, which resulted in 48 interactions. A majority (62.5%) of these interactions were performed using the physical "Start" button. Of the verbal interactions (n = 18), only 44.4% were performed using the correct verbal command included in the provided instructions.

Across all trip segments, only five system interactions were performed. All five interactions were participants using the "support" system interaction, and all were performed by three female participants. Two interactions occurred during the first trip segment (one with button and one with voice), two during the second trip segment (one with button and one with voice), and one during the third trip segment (with voice). Participants stated that they wanted to use the support button to determine their location (n = 2), to get more information about the detour (n = 2), and to determine the vehicle's speed when on the highway (n = 1).

There were a few instances where participants almost performed a system interaction (i.e., put their finger on a button) during the simulated trip. Near the end of the first trip segment, one participant almost used the support button, and one almost used the pull over button after they received the announcement that they were passing the Steger Hall building. Both participants mentioned being concerned that they were passing their first destination, but stopped once they heard the turn signal activate. Additionally, during the third trip segment, one participant almost used the "support" button after experiencing both the quick swerve and the quick deceleration but stopped once the HMI provided information about the driving scenario.

> P12 (B) - During the [third] trip, the AV anticipated events that I would have called support for, but it provided me with information I needed so I didn't press the button.

For the participants that performed and almost performed system interactions during the trip, we asked them to explain their reason for using one interaction modality over the other. Participants often stated that they just used the interaction modality that they personally like to use when using technologies that offer both verbal and touch inputs. However, one participant mentioned that they intended to use the button, but due to not being able to find it quickly, reverted to using a voice input. Lastly, five participants mentioned that it will be useful to include both physical and verbal modalities in future L4+ ADSs to increase accessibility for themselves and other BLV riders.

Several participants provided reasons for not using system interactions offered by the HMI as well as interactions that they would desire future L4+ ADSs to include. Three participants stated that they never felt concerned enough to perform interactions, with a couple stating the lack of concern resulting from the HMI prototype providing sufficient information throughout the entire trip (P01) or during the unexpected maneuvers during the third trip segment (P06):

> P01 (LV) – I never felt that I wanted the ADS to stop, and I never felt that I need to contact customer support. I felt fine letting the ADS do its thing because it was giving me enough information. I never felt scared or like I needed to get out of the vehicle.

> P06 (LV) – The information made me feel comfortable enough that I would not have asked the ADS to pull over. So even if I couldn't figure out how to use the support feature or gotten my current location information when I needed it, I still probably wouldn't have stopped the ride.

As for desired system interactions, five participants suggested the need for L4+ ADS HMIs to offer adjustable amounts of information about one's location throughout trips. These participants

suggested ideas included simply enabling and disabling turn-by-turn directions (n = 2), adjusting the level of detail relating to roads they encounter during a trip (e.g., all roads or only major roads) (n = 2), and receiving scenic descriptions of their surroundings for entertainment purposes (n = 1):

> P10 (LV) – I think there needs to be a button or a way to increase the verbosity (the amount of) information that the HMI provides. For example, we went over a bridge, I think some people might want to know that they just crossed over "road name" to help them know where they are along the route.

Also, specifically relating to detours, two participants mentioned that the rider should have the ability to accept or reject a detour to make sure they feel comfortable with the route being used by the ADS.

> P08 (LV) – I would have like the interface to recommend the detour as an option and let me control whether we take the detour or maintain our current route. Because I might not feel safe traveling on the roads for that detour, so I would like to decline the detour.

6.3.4.2 Usability Metric for User Experience (UMUX)

During the post-study interview, participants reported their level of an agreement to four statements about the usability of the HMI prototype for the entire simulated trip. Descriptive statistics for each statement are listed in Table 23. To determine the overall UMUX score using the four Likert-scale items, we followed scoring methods presented by Finstad (2010) to adjust the raw responses to be represented on a range from 0 – 100. The average UMUX score for all participants to be 89.77 (*SD* = 15.38), which indicated participants felt that the HMI prototype offered a good usability experience.

Table 23. Descriptive statistics for individual UMUX items.

Statement	Mean	SD	Median
The HMI's capabilities met my requirements.	4.36	.92	5
Using the HMI was a frustrating experience.	1.27	.65	5
The HMI was easy to use.	4.73	.47	5
I had to spend too much time correcting things with the HMI.	1.45	.69	5

6.3.5 Drop-off task

6.3.5.1 Self-reported measures

After the drop-off task, participants were asked to select a statement that best matches their opinion of the information provided by HMI prototype for the drop-off task. Most participants (67%) indicated that the information provided by the HMI prototype "was perfect" and 33% indicated that the HMI "could have provided more information" ($M = 2.67$, $SD = .49$, $Mdn = 3$).

Additionally, participants used a five-point Likert scale to rate their level of agreement (1 = strongly disagree and 5 = strongly agree) with the following statement: "I had an accurate understanding of the parking lot environment." As seen in Figure 25, participants' ratings to the statement about the parking lot environment suggest that the information provided by the HMI prototype allowed them to have an accurate understanding of the environment.

Figure 25. Frequency of agreement for understanding the parking lot environment.

6.3.5.2 Task success

To understand if participants encountered issues while using the HMI prototype during the negotiated drop-off task, we first examined tasks success rate. Criteria for success was when participants selected to review the list of drop-off locations as well as selected the most accessible location (i.e., an accessible spot closest to the destination). Eight participants were able to use the interactions and information from the HMI prototype to select the accessible parking spot located

nearest the destination's entrance. One participant correctly interacted with the HMI but selected the accessible parking spot that was not nearest to the entrance. However, their responses to the post-task interview revealed that they only cared about selecting a spot that did not require them to cross a traffic lane, and thus, they felt that either accessible spot met their requirement. Thus, because the participant's reasoning indicates that they used the HMI to select a spot that met their accessibility needs, we decided to count their attempt as a success, which brought the total number of successful attempts to nine. Two of the three participants that failed the task resulted from needing reminders for the verbal command to interact with the HMI. One of the participants that failed didn't select to review more drop off spots when prompted, which resulted in the participant keeping a drop off spot that would have required them to cross a traffic lane.

Figure 26. Depicts the steps participants took to either succeed or fail the drop off task.

6.3.5.3 Spot selection

Ten participants selected the accessible parking spot nearest the main lobby entrance, one participant selected the accessible parking spot farthest from the main lobby entrance, and one participant select a standard parking spot that required crossing a traffic lane to reach the main lobby entrance.

When asked to explain their reasoning for selecting their drop-off spot, nine participants mentioned they prefer to be dropped-off as close as possible to the door of their destination, eight participants mentioned wanting to avoid drop-off locations that require crossing traffic lanes to reach their destination, and five participants wanted a location that eliminates or reduces the number of

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tripping hazards in their path. When asked if they prioritize avoiding hazards or reducing walking distance when selecting a drop-off spot, seven participants selected said reducing distance, four said avoiding tripping hazards, and one found both equally important and couldn't select just one.

6.3.5.4 Interactions with HMI

When examining how participants interacted with the HMI prototype during the drop-off task, we observed that nine participants used only verbal commands, two used only touchscreen gestures, and 1 used a combination of verbal commands and touchscreen gestures.

After selecting the spot, participants received one final piece of information from the HMI prototype that included the side of the vehicle to exit on, turn-by-turn instructions for how to navigate to the door of their final destination, and information that increased awareness of any hazards in their path to the door. A majority of participants (n = 11) mentioned that they would like to access the navigation information after exiting the vehicle, especially for situations where the ADS cannot use a drop off close to their destination. Several participants (n = 4) suggested that there should be a way to request the ADS to send the instructions to their personal device.

At the end of the post-drop off task interview, participants were asked if they wanted this feature for selecting a drop-off spot to be included in future L4+ ADSs. Eleven participants stated that they would want this option to be included and only one participant was fine with the ADS selecting the spot. The lone participant's reason was that by the time Level 5 ADSs exists, the technology should be advanced enough to always select the most optimal drop off spot.

6.3.5.5 Suggested Improvements

During the interview following the drop-off task, participants were asked to provide suggestions that would improve their ability to review and select a drop-off spots. Six participants had no suggested improvements to the information or interactions provided by the HMI. From the other six participants that did offer improvements, the following four suggestions were identified: have the HMI present all drop off spots prior to asking riders to select one (n = 4), allow riders to repeat a spot's description (n = 3), only offer spots that do not require riders to encounter tripping hazards or cross a traffic lane (n = 2), and specifying the type of tripping hazards (n = 1).

6.4 Discussion

For Study 3, we designed an HMI prototype for L4+ ADSs that incorporates BLV riders' information and user interaction requirements identified from Study 1 and Study 2. Through BLV participants' feedback on the information and interactions provided by the HMI prototype for specific driving scenarios, we were able to further our understanding of how HMIs for L4+ ADSs can support BLV riders' needs, which were used to revise and add to our design guidelines and recommendations (see Section 0). Below, we discuss the three research questions to be answered for this study, other relevant findings from the study and lastly, the study limitations.

6.4.1 RQ8: What information provided by the HMI prototype is valuable for BLV riders for different L4+ ADS driving scenarios?

Our findings identified three categories of information presented by the HMI prototype that participants found valuable during trip segments and driving scenarios, which were information about (1) landmarks, (2) ADS's actions, and (3) upcoming road structures and road conditions.

Findings from our study consistently support the need for L4+ ADS HMIs to inform BLV riders about landmarks they are passing by during trips (e.g., buildings, shops, restaurants), regardless of a rider's familiarity with a route or area. When BLV riders are familiar with a route/location, understanding landmarks as they drive by would help with monitoring trip progress by comparing that information to a mental map of the route. This finding is aligned with previous work demonstrating the utility of BLV individuals having information about landmarks for on-foot navigation (Gupta et al., 2020; Saha et al., 2019; Banovic et al., 2013; Quiñones et al., 2011, Azenkot et al., 2011). Furthermore, our novel research expands upon the existing literature by showing that this information could also be useful while riding in a vehicle. Beyond monitoring trip progress, our findings suggest that providing information about landmarks can reassure BLV riders that their ADS is following the correct route and/or going to the correct destination. Landmarks can also be used by BLV riders to learn about new places along a known route (i.e., add to previously constructed mental maps). This is an important finding as this has been identified as a challenge BLV individuals face, making it an obstacle that future assistive technologies (e.g., L4+ ADSs) may be able to address (Banovic et al., 2013).

When using L4+ ADSs to travel in unfamiliar areas, receiving information about landmarks that BLV riders pass by could allow BLV riders to construct mental maps of a route in real-time, which could allow them to recognize a route/area during future trips. Furthermore, having an awareness

of landmarks along an unfamiliar route could provide a more immediate benefits to BLV riders that could help them avoid becoming stranded or lost during more undesirable situations (e.g., ADS stops due to a malfunction). During such extreme situations, knowledge of landmarks that BLV riders have passed leading up to where the ADS stopped could allow them to retrace their steps to reach nearby location or call and share their awareness of nearby landmarks with someone (e.g., emergency services) who can use that information to determine their location. Furthermore, our results suggest that information about landmarks while traveling in an unfamiliar area could build BLV riders' trust and confidence in an L4+ ADS as it causes riders to believe that the ADS knows their location when the rider does not.

For the present study, we provided structural landmarks (e.g., buildings on campus) to participants, however, previous work has identified many different types of stimuli (e.g., structural auditory, olfactory, tactile) that BLV individuals use for landmarks during walking navigation (Saha et al., 2019). However, access to different stimuli (e.g., smell of a coffee shop) produced by the environment will be difficult or impossible to detect while riding inside a vehicle. Additionally, the variety of objects constitutes even structural landmarks is vast (e.g., bus shelters to large stadiums), and it would quickly become overwhelming for riders if L4+ ADSs were to provide information about any structural landmark (or other type of useful landmark) it encountered. Thus, future work research should explore BLV riders' preferences toward different types of landmarks and/or how frequently L4+ ADSs announce landmarks to obtain further insight into how this information could be used to improve BLV riders' awareness, safety, and satisfaction when using L4+ ADSs.

Participants feedback across trip segments suggest that the information provided by the HMI prototype allowed them to understand the ADS's intentions and have an accurate understanding of their trip (see Section 6.3.3.1). However, a majority of participants still desired the following two categories of information that were not provided by the HMI: street names and directions of maneuvers, which in combination make up turn-by-turn directions used on most GPS navigation apps (e.g., turning left onto Main Street). While we are not suggesting that information about road names is more or less important than the types of information we provided, we do find it interesting that despite access to an HMI that seemingly provided sufficient information during trips that participants still desired this information.

Our findings related to BLV riders' need to understand an ADS's actions as well as upcoming road structures and changes in road surfaces further support similar findings from Study 2 (see Section 5.3.2.2). Also, by providing explanations for both unexpected and expected driving scenarios (i.e., smooth and quick decelerations), we were able to expand on Study 2 findings by discovering findings that support the value in providing information for same driving maneuver that differs in driving styles. We believe that this suggest that BLV riders could use this information to monitor trip progress as well as verify that the ADS is operating correctly.

During interviews, participants often stated that the information provided throughout the trip increased their trust and confidence in the ADS, which is further illustrated in participants' high ratings of trust in automation after the simulated trip. However, to determine if participants' trust in automation was a result of receiving information from the HMI rather than another or combination of factors (e.g., exposure to a simulated L4+ ADS), future research is required. For instance, visual inspection of TiA scores reported between the present study and Study 2, which had participants experience similar driving scenarios (e.g., quick deceleration) with no provided information, advocates for future work to explore how the presence or absence of information for different trip types and/or driving scenarios influences BLV riders' trust in ADSs.

6.4.2 RQ9: What are BLV riders' perceptions of interaction modalities offered by the HMI prototype?

6.4.2.1 Physical and Tactile Information

By focusing participants' feedback on the design characteristics of physical buttons and tactile information, we were able to generate feedback that allowed us to understand the applicability of ADA recommendations for tactile information (Department of Justice, 2010) as well as understand how to improve the accessibility of the tactile information on L4+ ADS HMIs.

To help BLV riders detect physical and tactile information located on an HMI in L4+ ADSs, our results suggest it should be placed below any touchscreens/displays as this is an area BLV riders' may attempt to feel when exploring their surroundings to find physical information. Several BLV participants were able to correctly assume that the button farthest to the left was the Start button solely based on it being placed first in the row. This finding supports the ADA's recommendation to place button based on the order in which you want users to interpret them. Our findings seem to support the use of the ADA's recommended dimensions for large text in a vehicle cabin setting as

these dimensions allowed several low vision participants to detect and comprehend presented text on our HMI. Furthermore, because low vision participants tended to lean in to visually perceive the large text, we suggest either allowing HMIs to be moveable or be placed such that riders can easily lean in to get a better view of the information. Other popular suggestions for improving the detectability and legibility of physical information provided on the HMI prototype included inverting the colors to increase the contrast and improve the detection and legibility of the icons and text (e.g., white text on a black background) as well as increasing the size of the icon beyond the recommended size provided in ADA 2010.

Relating to the design of tactile information (i.e., raised icons and text), the most frequently provided feedback was to include braille in place of the raised text. However, participants often admitted that they did not currently have the ability to read braille themselves, but rather recommended it as they believed it would increase the accessibility for other BLV individuals. Thus, we are unsure if the use of braille or raised text is a better approach for providing tactile information in L4+ ADSs. For icons, our findings suggest that increasing the size could help BLV riders interpret their design. Additionally, our findings suggest that BLV riders might have a difficult time interpreting non-standardized icons, which could be a challenge as ADSs will introduce a lot of non-standardized interactions (e.g., pull over). For the raised text, BLV riders' ability to touch and understand large text, sufficient space should be provided between individual raised letters. Due to limitations of 3D printing, we were unable to achieve and, as a result, compare feedback to ADA's recommended dimensions for spacing between raised text while in a vehicle setting.

Finally, several participants also mentioned the utility in having verbal descriptions that label the buttons and/or explain its purpose prior to the trip or prior to activating them. This finding supports a BLV riders' need identified by Brewer and Kameswaran (2018), which was in-vehicle HMI, may require auditory feedback to understanding outcomes of using certain in-vehicle controls/buttons prior to activation.

6.4.2.2 Interactions during trips and dop-off

Our findings suggest that when BLV riders are provided information, they may seldomly perform system interactions (even when experiencing unexpected driving scenarios). However, more research is required to determine the necessity of system interaction as many factors could have

influenced the lack of interaction from participants, such as differences in demographic background or experience with L4+ ADSs. Of the few interactions that were performed during the trip, all of them were for the Support button. When considering how participants performed all interactions for various aspects of our trip (i.e., start the trip, request support, and review drop-off locations), our results suggest that a BLV riders should have access to redundant input modalities.

As for findings related to interactions that were not offered by our HMI prototype, our findings from the present study (as well as findings from Studies 1 and 2) suggest that BLV riders' will want to adjust the amount information provided by an L4+ ADS's HMI. Specifically, BLV riders may want the ability to enable and disable turn-by-turn directions, adjust the level of detail relating to roads they encounter during a trip, or possibly receive scenic descriptions of their surroundings for entertainment purposes. Two participants wanted to control whether the ADS took a detour or not, which is similar to findings from Study 1 (see Section 4.4.2). Finally, a finding that supports Study 2 (see Section 5.3.1.1) was that participants wanted access to turn-by-turn instructions and information about obstacles in their path on a personal device after exiting the vehicle.

6.4.3 RQ 10: What challenges do BLV riders' encounter when using the HMI prototype during a negotiated drop-off scenario?

Based on 9 of 12 participants successfully completing the negotiated drop-off task as well as a majority reporting that they had an accurate understanding of the parking lot, it was difficult to identify challenges related to using the HMI for this task. Challenges encountered by participants failing the task were related to difficulty remembering how to interact with the HMI (e.g., verbal commands and touchscreen gestures). This finding suggests the need for BLV riders to have the ability to repeat instructions when needed. Additionally, our findings suggest the BLV riders may benefit from receiving fewer drop-off spots as well as provide options to repeat information about each on-demand.

Our findings suggest that BLV riders may base their selection of a drop-off spot using the following criteria: distance and direction from the drop-off location to the door of their destination, if crossing traffic lanes is required, and the number of tripping hazards in their path. While participants indicated a strong desire for a negotiated drop-off feature to be included in L4+ ADSs (see Section 6.3.5.4), if allowing riders to select a preferred drop-off spot is not a feasible feature

to implement in future ADS, these findings could be used to inform how L4+ ADSs select accessible drop off locations for BLV riders.

6.4.4 Study Limitations:

Our study design had several noteworthy strengths, which include having BLV participants engage with an HMI prototype during various simulated L4+ ADS in real-world settings, getting an in-depth understanding of participants' perceptions of the HMI prototype, and again, replicating unexpected driving scenarios safely on real roads. Nonetheless our study findings should be considered in light of the limitations, which are discussed in greater detail below.

During the simulated trip, participants were accompanied by a researcher that performed the responsibilities of the interaction wizard (i.e., making the HMI appear to be functional). Compared to the REX system in Study 2, we felt that this approach allowed us to better observe and efficiently communicate with participants to gain a more in-depth understanding of participants' perceptions of the HMI prototype. Additionally, we felt that the researcher's presence in the vehicle resulted in participants engaging more in tasks and providing more feedback during trip-segments and post-segment interviews. However, there are obvious limitations to this methodology, such the Hawthorne effect causing this increased engagement from participants or causing superficial engagement with the HMI prototype. This was not necessarily a bad outcome, however, because this was a study that relied on participants engaging with the interface and communicating their thoughts about the HMI prototype.

This study revealed further insight into the utility of certain information, such as awareness of landmarks and road structures, to help riders understand their location along a trip as well as build a mental map in unfamiliar areas. However, we didn't provide participants with other information that could have help them determine their location, such as road names or turn-by-turn directions during trips, which limits our knowledge around how all of this information provided at once influences BLV riders' awareness of their trip as well as satisfaction with their experience (e.g., information overload). Thus, future work could utilize a comparative study design to better understand the limits of information overload for BLV riders to understand if the common view mentioned by participants (i.e., "the more information, the better") has a limit. Finally, this study does have limitations due to a small sample size, which are similar to those listed in Study 2 (see Section 5.4.6).

7 Expert Review of Guidelines and Recommendations

7.1 Objective

As a result of each study, we formulated and/or refined design guidelines and recommendations (G/Rs) for L4+ ADS HMIs and other aspects of the L4+ ADS experience (e.g., entering a vehicle) to be accessible for BLV riders. A final objective of this work was to obtain feedback from subject matter experts with backgrounds and experience in relevant fields. Specifically, experts' feedback was used to (1) better understand the potential for each G/R to improve the accessibility of L4+ ADSs, and (2) identify and remove G/Rs that experts believed would not improve the accessibility of L4+ ADSs.

7.2 Defining Guidelines and Recommendations

Akoumianakis and Stephanidis (1998) describe a *guideline* as a statement that consolidates existing and evidence-based knowledge that is to be used as a general rule of thumb when designing a product/system for a specific context. The following is an example of a guideline to be used when designing accessible user interfaces: "provide a method for carrying out mouse or other pointing device functions with the keyboard, or a keyboard emulator" (p. 1288). *Recommendations* are "detailed design decisions" for artifacts that make up a design (e.g., size of digital buttons on a touchscreen interface). Because design recommendations detail specific design artifacts rather than broad design patterns, they are not supposed to be interpreted subjectively.

7.3 Method

7.3.1 First Iteration of Guidelines and Recommendations

Using findings from Studies 1, 2, and 3, we generated 28 guidelines and 44 recommendations to be reviewed by experts (see Table 24). We generated a G/R for any information or interaction requirements that were stated by at least 25% of participants. We felt that this approach would avoid ruling out any G/Rs that have the potential to increase accessibility while also not including G/Rs that are representative of an individual's perspective. Findings from Study 1 were used to produce the foundation of these G/Rs as it addressed a wide range of topics (e.g., using personal devices to interact with L4+ ADSs, entering and exiting the vehicle, desired information when emergency vehicles are in the vicinity). While findings from both Study 2 and 3 were useful in

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reinforcing G/Rs related to driving scenarios experienced during a trip (e.g., guideline 20 and its subsequent recommendations), findings from each provided unique contributions to the G/Rs that were not addressed in previous work. For instance, Study 2 contributed to generating guidelines (e.g., guidelines 12-13) and recommendations for existing guidelines for PUDO related issues (e.g., recommendations 8.2-8.4). Study 3 was useful in generating G/Rs related to providing tactile information inside the vehicle (e.g., guideline 16), which was not addressed in either Study 1 or Study 2.

Table 24. Lists the 28 guidelines (G) and recommendations (R) as well as links each G/R to findings from our three studies. The three columns on the left (with labels for each study numbers) can be used to locate findings from each study that were used to generate or reinforce G/Rs. Note: to avoid confusion with experts not familiar with SAE terminology as well as to improve readability of G/Rs we opted to use *Fully Automated Vehicle* (FAV) in our G/Rs rather than L4+ ADS or ADS.

G	R	Guidelines and *Recommendations*	Study 1	Study 2	Study 3
1		Allow riders to use a personal device (e.g., their smartphone, refreshable braille display) to perform all interactions with the FAV before, during, and after trips.	Section 4.4.2	Section 5.3.1.1 and 5.3.1.2	
2		Provide easy access to remote human assistance throughout the entire ride-hailing experience (i.e., navigating to the vehicle during pick-up, during the trip, and navigating to the destination after exiting the vehicle).	Section 4.4.1		
	2.1	*In-person assistance* – for specific situations that cause riders to feel unsafe to navigate an environment independently, such as situations where the FAV stops on the side of the highway due to a malfunction, riders should be able to request in-person human assistance.	Section 4.4.1		
3		Allow riders to create a user profile that contains personalized settings for routes (e.g., avoid highways) and in-vehicle interactions (e.g., screen reader on or off) that will be applied to all future trips.	Section 4.4.2		
4		Anytime a rider is provided with a route overview, which occurs throughout several guidelines included in this document, riders should be able to access information that allows them to compare the system's route with their knowledge of a familiar area and/or familiarize themselves with a route in an unknown area.	Section 4.4.1	Section 5.3.2	Section 6.3.3
	4.1	*Turn-by-turn directions* – riders should be able to determine all of the streets along their route as well as understand how the FAV plans to navigate through those streets.	Section 4.4.1	Section 5.3.2	Section 6.3.3
	4.2	*Major landmarks* – riders should be able to understand the presence of major landmarks, such as buildings (e.g.,	Section 4.4.1	Section 5.3.2	Section 6.3.3

		restaurants) and road structures (e.g., roundabouts, bridges), throughout their route.			
	4.3	*Rough roads* - riders should be aware of any roads on their route that could result in extended exposure to rough or bumpy riding conditions (e.g., gravel roads, construction zones, rural roads). Awareness of these roads ahead of time can instill riders' confidence in the system's performance that they may otherwise doubt if they were to encounter these roads unexpectedly.	Section 4.4.1	Section 5.3.2.3	Section 6.3.3.2
5		During trip-planning, riders should be able to review and adjust routes recommended by the system to increase their sense of familiarity and/or comfort with their upcoming trip.	Section 4.4.2	Section 5.3.1.1	
6		Prior to an FAV arriving at the pick-up location, riders should be able to access a basic description of the dispatched vehicle, such as the make and model, vehicle type (e.g., truck, SUV, sedan), and color. This information can help riders prepare for entering the vehicle as well as identify the vehicle independently or by sharing this information with someone in their vicinity when asking for assistance.	Section 4.4.3	Section 5.3.1.1	
	6.1	*Step-in heights* – provide estimated step-in heights for larger vehicles to help riders prepare for entering and exiting the vehicle. If possible, allow riders to avoid certain step-in heights and/or vehicle types to better suit their needs.	Section 4.4.3	Section 5.3.1.1	
7		Riders should be informed on the FAV's estimated time of arrival to the pick-up location as well as receive a notification on when the FAV arrives.	Section 4.4.3	Section 5.3.1	
	7.1	*Announcing the FAV's arrival* – consider providing an auditory cue (e.g., a chime) from the vehicle's exterior and/or sending a notification to the rider's personal device when the ADS arrives. If using an auditory cue, inform riders of a specific cue to listen for ahead of time.	Section 4.4.3	Section 5.3.1.1	
	7.2	*Anticipating direction of approach* – consider providing information that allows riders to predict the direction an FAV will approach from when arriving at the pick-up location. This information in can guide riders' attention to certain stimuli, such as general vehicle noises to a specific auditory cue) being presented from a specific direction.		Section 5.3.1	
8		Upon parking at the pick-up or drop-off location, riders must be able to determine the FAV's location relative to their current position (for pick-up) or to their destination (for drop-off).	Section 4.4.3	Section 5.3.1	Section 6.3.5

	8.1	*General direction* – at a minimum, riders should understand where the FAV is located relative to their current position (e.g., the FAV has parked to your left). This could be accomplished through a description provided to a personal device or by presenting an auditory cue from the FAV that can help riders spatially locate the FAV.	Section 4.4.3	Section 5.3.1	Section 6.3.5
	8.2	*Landmarks* – consider providing landmarks that are nearby the FAV.	Section 4.4.3	Section 5.3.1	
	8.3	*Type of parking spot* – consider clarifying the type of parking spot the FAV is using (e.g., standard vs. accessible parking spot vs. curbside).		Section 5.3.1	Section 6.3.5
	8.4	*Orientation to sidewalk* – consider providing information on FAV's orientation to the sidewalk (perpendicular vs. parallel). This information can allow riders to predict objects or tripping that might be in the vicinity of the parked FAV.		Section 5.3.1	
	8.5	*Remote human assistance* – consider providing a means for riders to use their personal device to receive remote human assistance with locating the parked FAV.	Section 4.4.3	Section 5.3.1	
9		When selecting a potential pick-up and drop-off locations, the FAV should consider the following criteria, in order of importance: a spot that does not require riders to cross traffic lanes, the shortest walking distance to get to or from the FAV, and the fewest tripping hazards.		Section 5.3.1	Section 6.3.5.3
10		During pick-up and drop-off, riders should be able to receive information that supports their ability to independently navigate to and from the FAV. At a minimum, this information should allow the riders to orient themselves to the location of the FAV (for pick-up) or destination (for drop-off) and understand the distance they will need to travel to reach it.	Section 4.4.3	Section 5.3.1	Section 6.3.5
	10.1	*Maintaining an accurate orientation* – consider solutions that allow riders to receive spatial auditory cues from to help re-confirm or adjust their orientation to the FAV or their destination.		Section 5.3.1.1	
	10.2	*Providing directions to personal device* – Provide any available navigational information to a rider's personal device so that they can review them as necessary while navigation to and from the vehicle.		Section 5.3.1	Section 6.3.5.4
	10.3	*Tripping hazards* – consider informing riders about the presence of tripping hazards along their path. For hazards resulting from a 90-degree shift in elevation, such as curbs or stairs, riders should understand if that shift in elevation is upward or downward.	Section 4.4.3	Section 5.3.1	Section 6.3.5.3

	10.4	*Accessible infrastructure* – consider informing riders about accessible infrastructure along their path. This information can support a rider's navigation skills by helping them predict the presence, or lack thereof, of tripping hazards as well as anticipate shifts in environments that otherwise may not be detected with using assistive devices (e.g., seamlessly transfer from sidewalk to street surface when using a curb-cut).		Section 5.3.1	Section 6.3.5
	10.5	*Less detectable objects* – consider informing riders about objects that are not as easily detectable by guide dogs or white canes, such as tall, metal signs often located in parking spots or along sidewalks.			Section 6.3.5
11		During pick-up, the rider should be able to confirm that they have located the correct vehicle using information presented via the FAV's exterior or through a mobile app.	Section 4.4.3	Section 5.3.1.1	
	11.1	*Auditory cues* – auditory cues provided from the FAV's exterior or that are sent to a personal device for navigational purposes can also be used to help confirm the vehicle.		Section 5.3.1.1	
	11.2	*Greeting the rider* – consider providing an auditory greeting to the rider when they have arrived at the correct vehicle. This greet could include the rider's name or other information a rider has entered into a mobile app. If this method is adopted, riders should be informed about the greeting to help avoid entering a wrong vehicle prior to reaching their vehicle.		Section 5.3.1.1	
	11.3	*Vehicle descriptions* – vehicle descriptions (see Guideline #6) provided to riders in advance can also help riders identify the correct vehicle.	Section 4.4.3	Section 5.3.1.1	
12		Riders should understand what side of the vehicle they will be approaching in advance.		Section 5.3.1.1	
	12.1	*Specific door for entry* – if there is a specific door that riders are required to use to enter the vehicle, this should be clarified ahead of time. Also, consider provide an auditory cue from the required door to help riders spatially locate the correct door handle.		Section 5.3.1.1	
13		After entering the vehicle, riders should be able to control when the trip starts to allow sufficient time to get situated and oriented to the vehicle's interior before the vehicle begins moving.		Section 5.3.1.1	
14		After entering the vehicle, riders should receive a brief description of their planned trip, which at a minimum should offer riders the capability to review the details of their route (e.g., road names, turn-by-turn directions) and determine an estimated time of arrival.		Section 5.3.1.1	Section 6.2.5

	14.1	*Drop-off location preferences* – consider allowing riders the ability to specify their preferences for a drop-off location, such as options to avoid locations that require the rider to cross a lane of traffic after exiting the vehicle.		Section 5.3.1	Section 6.3.5
15		After entering the vehicle, the rider should be introduced to any important interactions that are available to them during the trip, such as requesting remote human assistance or requesting the FAV to pull over. For each interaction, the rider should understand its purpose and options for performing the interaction (e.g., push buttons, voice activation).		Section 5.3.1	Section 6.3.2
16		If physical push buttons are provided in the vehicle's cabin, the buttons or associated labels should be easily detectable by individuals with low vision as well as by individuals who may rely on touching their surroundings to orient themselves to their space.			Section 6.3.2
	16.1	*Placement* – (assuming an interface is mounted directly in front of all passengers) push buttons and any accompanying tactile information should be placed beneath the display.			Section 6.3.2
	16.2	*Tactile information* – for labelling buttons, it is recommended to try and use both braille and raised, large text. If limited to one, it is recommended that braille is used with large text that is flush with the surface. Braille should be placed beside or below the push button.			Section 6.3.2
	16.3	*Contrast* – to increase legibility and detectability, use white text/icons over a dark background.			Section 6.3.2
	16.4	*Avoid accidental activation* – Allow riders that rely on touch to explore their surrounds to investigate any interfaces in the vehicle without accidentally activating interactions using the touchscreen or physical buttons.			Section 6.3.2
17		Riders should be able to adjust the frequency and type of information provided by the system during trips to match how their needs may shift, such as when traveling in familiar or unfamiliar area.	Section 4.4.2	Section 5.3.2	Section 6.3.4
	17.1	*Information categories* – allow riders to understand any categories of information that the system can provide (e.g., turn-by-turn navigation, major landmarks, or nearby objects) and options to opt-out of receiving updates on any categories.	Section 4.4.2	Section 5.3.2	Section 6.3.4
	17.2	*Frequency* – riders should be able to customize the frequency that information is provided during their trip by selecting time intervals (e.g., provide our current location every 1, 5, or 15 minutes) or specifying	Section 4.4.2	Section 5.3.2	Section 6.3.4

		qualifiers (e.g., only the major street names along the trip).			
18		At any time, riders should be able to access information to determine their trip progress, such as ETA, current street name, and/or remaining distance.	Section 4.4.1		
19		Riders should be immediately informed about any major deviations from their original route or ETA or unexpected road conditions.	Section 4.4.1	Section 5.3.2	Section 6.3.3
	19.1	*Trip Delays* – Riders should be immediately informed about any delays to their original ETA, which should include the reason for the delay and their new ETA.	Section 4.4.1	Section 5.3.2	
	19.2	*Mandatory detours* – Riders should be immediately informed about any mandatory detours as well as the cause for the detour. The system should also provide an overview of the new route resulting from this detour. For situations where a route overview cannot be provided in advance, riders should still receive information about street names and landmarks as they encounter.	Section 4.4.1	Section 5.3.2	Section 6.3.3
	19.3	*System recommended detours* – situations where the system detects a detour that increases trip efficiency, the system should never proceed with the detour without receiving approval from the rider first. This avoid situations where a rider is forced to deviate from a route that they are more familiar with and/or have constructed a mental map for. Prior to requesting the rider's permission, the rider should be able to review the detour and understand the system's reasoning for the detour.			Section 6.3.3
20		Riders should be aware of the FAV's upcoming actions. If the FAV is not able to provide an explanation of its action in advance, such as when performing an evasive maneuver, it should provide the rider with an explanation as soon as possible.	Section 4.4.1		
	20.1	*Traditional indicators* – turning signals should continue to be provided as an auditory signal inside the vehicle. While simple, a turn signal provides useful insight that the AV is making intentional movements as well as helps rider anticipate lateral movements.		Section 5.3.2	
	20.2	*Entering and exiting highways* - riders should be informed when they are entering and exiting highways in advance. This allows riders to confirm that the vehicle's acceleration is intentional as well as to understand major landmarks along their trip.		Section 5.3.2.3	Section 6.3.3
	20.3	*Expected vs. unexpected stops throughout a trip* – To avoid confusing anyone following a mental map of their route, riders should be able to determine when the FAV is stopping for an expected part of the rider's trip (e.g.,		Section 5.3.2.2	Section 6.3.3

		stopping for a stop sign) or an unexpected reason (e.g., stopping for construction zone).			
	20.4	*Unexpected maneuvers* - When the ADS performs an unexpected maneuver, the rider should be provided an explanation that includes the reason for that maneuver and an update on the FAV's status.	Section 4.4.1	Section 5.3.2.2	Section 6.3.3
	20.5	*Exiting area that required unexpected slow speed* – When the FAV is exiting an area that required speeds slower than the posted speed limit, like a construction zone or traffic jam, the ADS should notify the rider in advance before returning to the posted speed. Without proper awareness of a change in driving environments, BLV riders may feel unprepared for any changes in driving behavior (e.g., sudden acceleration) or possibly concerned if they think they are still in a risky environment (e.g., construction zone).	Section 4.4.1		
21		Riders should be aware of nearby humans during unique scenarios requiring stop-and-go or stationary traffic (e.g., work zone, police checkpoint) in case they want seek additional sources of information from outside the vehicle.	Section 4.4.1		
22		Riders should be notified when they are nearing their destination with enough time to gather their belongs and prepare for exit.	Section 4.4.3	Section 5.3.1.2	
	22.1	*Provide details on intended drop-off location* – consider providing riders with details on where the FAV will park relative to the door using distance and directional information (e.g., 10 feet to the left of the destination). Also, provide information about potential tripping hazards riders could anticipate after exiting the vehicle.		Section 5.3.1.2	Section 6.3.5.3
	22.2	*Multiple drop-off locations* - If there are multiple drop-off points due to either a destination having multiple entrances (e.g., specific wing at a hospital) or locations in close proximity (e.g., a strip mall), riders should know what location the FAV intends on dropping them off.		Section 5.3.1.2	Section 6.3.5.3
23		When nearing the destination, riders should have a clear understanding of whether the FAV is stopping because it arrived at the destination or stopping for any other reason (e.g., a traffic light). This information can prevent riders from trying to exit the vehicle early.	Section 4.4.3	Section 5.3.1.2	
24		At the beginning of the trip, riders should be informed on what actions to expect from the FAV and proper procedures they should take if an emergency situation was to occur during the trip.		Section 5.3.1.1	

25		Riders should be immediately aware of the presence of an active emergency response vehicle, its location relative to the FAV, as well as understand how the FAV intends respond.	Section 4.4.1	Section 5.3.2.2	
	25.1	*Type of emergency vehicle* – if possible, provide the type of emergency response vehicle (e.g., fire truck, police cruiser) as this can help riders understand if the system is responding appropriately.	Section 4.4.1	Section 5.3.2.2	
26		If deemed necessary by the rider, they should have the ability to request the FAV come to an emergency stop.	Section 4.4.2	Section 5.3.1.1	Section 6.3.2.1
	26.1	*Introducing interactions for emergencies* – During the introduction of any interactions that could lead to negative consequences, riders should understand appropriate times to use such interactions along with any consequences for misusing or abusing these interactions.		Section 5.3.1.1	
27		If human assistance is dispatched, riders should be able to determine when assistance will be arriving to their location. Furthermore, riders should be notified when someone is approaching the vehicle to avoid startling riders.	Section 4.4.1		
	27.1	*Anticipation* – inform riders of where to expect the person to arrive at the vehicle (e.g., passenger side of the vehicle).	Section 4.4.1		
	27.2	*Trusted vs. Unknown personnel* - If possible, the rider should be aware if the approaching person is trusted/known by the ADS or if they are a stranger.	Section 4.4.1		
28		Scenarios where the FAV ends the trip prematurely due to a system malfunction or physical damage, riders should be provided with their current location (at a minimum) and nearby landmarks. Riders can relay this information to other sources when seeking assistance.	Section 4.4.1		Section 6.3.3.2
	28.1	*Damage type and severity* - The FAV should immediately inform riders of any negative developments in its ability to function along with the severity of the damage to help riders decide if it is safe to remain in the vehicle.	Section 4.4.1		
	28.2	*Instructions for a safe exit* – if the situation requires riders to exit the vehicle immediately, the system should provide instructions for a safe exit (e.g., away from moving traffic) as well as provide a safe location for where to go after exiting the vehicle.	Section 4.4.1 and 4.4.3		

7.3.2 Participants

We recruited and screened eight experts to review our G/Rs, however, one expert had to drop-out due to scheduling conflicts after reviewing nine guidelines (we kept in their feedback for those G/Rs). Experts were from the United States (n = 6) and Great Britain (n = 2). Table 25 indicates the areas of expertise selected by experts.

Table 25. Experts' areas of expertise

Areas of expertise	N	Percent
Accessibility	5	15.63%
Assistive technologies	2	6.25%
Human factors	4	12.50%
Automated technologies	5	15.63%
Human-computer interaction	5	15.63%
Standard or policy development	4	12.50%
User experience	7	21.88%
Other	0	0.00%
Total	32	100.00%

7.3.3 Survey

We used QuestionPro to build and distribute a survey, which included all of our G/Rs as well as instructions for the experts. Experts were provided with relevant definitions as well as important considerations to keep in mind while reviewing the guidelines, which were the following:

- These are the first iteration of the G/Rs specific to using FAVs as a ride-hailing service (e.g., Uber).

- When reviewing the G/Rs please base your feedback on the accessibility alone and ignore legal liabilities or company policy implications.

- We are assuming that developers of this technology would also be referring to well-established resources for designing accessible digital interfaces, such as the W3C's Web Content Accessibility Guidelines (WCAG). And thus, we do not go into the details covered extensively in those resources. If any similarities do exist, that is because participants in

our research efforts provided a substantial amount of feedback on a topic that we felt it necessary to highlight within our set of G/Rs.

- When reviewing the G/Rs, please only focus on how they impact the accessibility of FAVs for BLV riders. We ask that you ignore the technical feasibility and legal liabilities, or company policy implications associated with adopting these G/Rs.

The survey requested experts indicate their area(s) of expertise, but no other demographic data were collected. To reduce the time required to complete the survey, recommendations were lumped in with guidelines for a single question. For each G/R, experts were required to respond to the following question:

"To what extent would this guideline, and any accompanying recommendations, increase the accessibility of FAVs for blind and low vision riders?"

(1 = Not at all, 2 = Very little, 3 = Slightly, 4 = Moderately, 5 = Very much, 6 = Extremely)

Additionally, experts were provided an optional open-ended area to provide additional thoughts or suggested edits from each G/R.

7.4 Expert Feedback & Updated G/Rs

Experts' feedback (see Table 26) shows that there was only one G/Rs that had low enough ratings to be removed from the list (i.e., Guideline 21). We decided to keep the second lowest rated guideline (i.e., Guideline 5) as we felt mean and median ratings indicated a potential for it to increase accessibility.

Table 26. Experts' ratings of G/Rs (sorted by mean ratings).

Guideline	Area	n	Mean	SD	Median
2	Universal	8	5.63	0.52	6.0
18	Riding	7	5.57	0.79	6.0
23	Riding	7	5.57	1.13	6.0
1	Universal	8	5.50	0.53	5.5
9	PUDO	8	5.50	0.76	6.0
28	Emergency	7	5.43	0.98	6.0
8	PUDO	8	5.38	1.06	6.0
19	Riding	7	5.29	1.11	6.0
22	Riding	7	5.29	1.50	6.0
3	Universal	8	5.25	0.46	5.0
4	Universal	8	5.25	0.71	5.0

10	PUDO	7	5.14	0.69	5.0
27	Emergency	7	5.14	1.07	5.0
7	PUDO	8	5.13	1.13	5.5
6	PUDO	8	5.00	1.07	5.0
13	PUDO	7	5.00	0.82	5.0
17	Riding	7	5.00	1.29	6.0
20	Riding	7	5.00	1.00	5.0
26	Emergency	7	5.00	0.82	5.0
14	PUDO	7	4.86	1.21	5.0
15	PUDO	7	4.86	1.21	5.0
11	PUDO	7	4.71	0.95	5.0
12	PUDO	7	4.71	1.38	5.0
16	PUDO	7	4.71	1.38	5.0
25	Emergency	7	4.71	1.50	5.0
24	Emergency	7	4.57	1.40	5.0
5	PUDO	8	4.38	1.41	4.5
21	Riding	7	2.86	1.07	3.0

Because the main objectives for the expert review process were to (1) better understand their potential to improve the accessibility of L4+ ADSs and (2) to identify G/Rs to be removed from the list, we did not do a detailed analysis (i.e., content analysis) of the open-ended feedback provided by experts. However, a preliminary reviewal of the open-ended responses across all G/Rs suggests that experts' open-ended responses may reflect their positive ratings. For instance, consider the experts' opinions for Guideline 4:

> Expert 1 - This is an excellent recommendation. It will set FAV the experience apart from other forms of public transportation. Well done.

> Expert 2 - This will take FAV's to the next level for rider experience. This will make the experience pleasurable and safe.

> Expert 3 - I think for the rider to be able to confirm (though descriptive, sensory cues) they are on the right track is useful to enhance confidence and reduce anxiety.

8 Conclusion

The overarching goal of this dissertation research was to identify BLV riders' user requirements for L4+ ADS HMIs by exploring both common and uncommon tasks associated with using ride-hailing services. We then sought to generate design guidelines and recommendations using BLV

riders' feedback to increase the accessibility of L4+ ADSs. To accomplish these goals, we collected focus group and experimental data over the course of three studies on BLV riders' information and interaction requirements for L4+ ADSs. BLV rider feedback was collected across a range of different ADS driving scenarios (e.g., yielding to emergency vehicle) and tasks performed by riders (e.g., locating the ADS during rider pick-up) to ensure that our findings support BLV riders' needs throughout future L4+ ADS trips. In Study 1, we investigated the similarities and differences between sighted and BLV participants' user needs for L4+ ADSs across several challenging driving scenarios. In Study 2, we examined BLV participants' information requests in real-world settings, which enabled us to better understand BLV riders' needs during a simulated L4+ ADS experience. In Study 3, we used BLV riders' feedback from Studies 1 and 2 to develop an HMI prototype for L4+ ADSs. We then allowed BLV participants to engage with the HMI prototype, which served as a high-fidelity prompt as a tool to elicit targeted feedback toward specific aspects of the prototype during a simulated L4+ ADS trip.

This dissertation project yielded several key findings, which we have summarized below. First, we show that at a high level, sighted and BLV participants share many information and user interaction requirements for L4+ ADSs (e.g., customizing trip preferences and user settings). We found that the differences between sighted and BLV participants emerged in terms of the low-level details of shared requirements. For example, while both sighted and BLV participants want the ability to request remote human assistance, BLV individuals reported wanting this system interaction across multiple scenarios in order to gain a better understanding of their surroundings. Alternatively, sighted individuals only reported wanting this interaction during the degraded state scenario to ensure appropriate steps were being taking to resolve the situation. Second, we found that BLV riders require information about surrounding landmarks in both familiar and unfamiliar locations, as this information allows them to orient themselves along their route as well as update and/or construct a mental map in real time. An additional, important benefit of providing details about landmarks is that this equips BLV riders with the information necessary to convey their location to others in the event of an L4+ ADS malfunction. Third, our research shows that BLV riders will prioritize selecting a drop-off location based on required distance and navigational hazards (e.g., crossing traffic lanes, tripping hazards). Thus, providing these details is essential to making L4+ ADS accessible to BLV riders during pick-up/drop-off. We address these study findings in greater

detail, as well as showcase the implications of our results more broadly, in the guidelines and recommendations we developed to increase accessibility in L4+ ADSs.

As it stands, there are many barriers that BLV riders must overcome in order to use current transportation options, which can negatively impact BLV individuals' quality of life. The emergence of L4+ ADSs have the potential to allow the BLV community to independently travel, although research on the development of this technology has thus far largely excluded this community. Overall, our research clearly demonstrates the utility of involving the BLV community in the development of L4+ ADS to generate an independent means of transportation that meets the specific needs of the BLV community. Having identified several BLV user requirements, further work is needed to better understand how to effectively design HMIs to meet these requirements across an array of driving scenarios.

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Appendices

Appendix A: Focus Group Script (Study 1)

Construction Zone:

We are going to start with the first scenario, which involves you encountering a construction zone that interrupts your trip.

Scenario 1: Alternative Path + Worker giving directions

Imagine you are riding in an AV on a two-lane road at 35 mph with no other vehicles around. Your AV begins passing signs that suggest there is a construction zone ahead, but at this moment this construction zone is far away and not in your AV's line of sight. However, these signs suggests that your AV will eventually need to slow down or come to a stop due to an upcoming construction zone.

- What, if any, information would you want to be presented to you by the AV at this moment?
- How would you expect that information to be presented to you?

As you continue down the road, the construction zone is now detectable, but it is at a distance that would NOT require your AV to start slowing down. At the beginning of the construction zone, there is a construction worker that is holding a sign that can either show STOP or SLOW. Currently, the worker's sign shows STOP.

- What information would you want presented to you by the AV at this moment, if any?
- How would you expect that information to be presented to you?
- What, if any, concerns do you have at this stage in the scenario about how the AV would handle interacting with the construction worker holding the sign?

Continuing on with this scenario, your AV gradually slows down as it gets closer to the construction zone. Eventually, it follows the construction worker's instructions and comes to a complete stop about 10 feet away from the worker. The construction zone blocks all lanes of travel on the roadway, but off to the right side of the road, there are traffic cones, small lights, and other signage that indicate an alternative path that goes along the right-shoulder and around the construction zone. When the worker eventually changes the sign to show SLOW, your AV is expected to ignore the normal painted lines that it would typically follow and drive through the alternative path.

- What information, if any, would you want to be presented to you while you are waiting for the worker to change the sign from STOP to SLOW?
- What information, if any, would you want to be presented to you once the worker has changed the sign to SLOW?
- Once the AV has started driving on the alternative path, would you want any additional information from the AV?

Concluding Question for Construction Scenario:

That concludes the description for the construction scenario.

- Of all the events described for this scenario, which event concerns you the most if you were to experience it while riding in an AV? We will give you a few seconds to think about it, and then we will go around and have everyone share.
- What could be done, if anything, to make you feel more comfortable about the AV for [insert event]?

Emergency Response Vehicles

The next scenarios will involve you and the AV encountering emergency responder vehicles.

Scenario 2: Move Over Law

Imagine you are riding at a speed of 60 mph in the far-right lane on a 3-lane highway. About 100 yards ahead of you, there is a stationary police car with its lights on that has pulled over a civilian vehicle in the right-shoulder. According to the move-over law, if there is an emergency vehicle stopped on the shoulder, vehicles in the right lane should move one lane to the left when passing, or slow down if moving over is not possible.

- What information, if any, would you want to be presented to you by the AV at this moment?
- How would you expect that information to be presented to you?
- Moderator should try to understand what info participants would want prior to the AV taking action or while it is taking action.

Scenario 3: Approaching LE]

For this next scenario, you are still riding in your AV on the highway at 60 mph in the far-right lane on a 3-lane highway. About 50 yards behind you there is a police vehicle with its lights and sirens on approaching in your lane. There are no other vehicles between your AV and the approaching police car behind you.

- What information, if any, would you want to be presented to you by the AV at this moment?
- How would you expect that information to be presented to you?

Let's say the officer in the police car had the ability to send simple messages directly to your AV without you knowing. These messages would explain the officer's intentions and what actions they would like your AV to take. For instance, in this scenario, the officer is responding to an incident up ahead and will try to pass your AV. So, the message the officer might send to your AV could be, "I am responding to an incident ahead, merge to the left to clear the lane."

- Would you want to be informed that this communication was occurring? Why or why not?
- If you would like to be informed of this communication, what information would you want to receive?

Scenario 4: AV yielding to LEO vehicle at intersection

Now imagine you are stopped for a red light at a busy four-way intersection in an urban environment. You are in the right lane, and your AV is the only vehicle in this lane. There are two more lanes to your left, which have vehicles in both of them. Unexpectedly, there is an emergency response vehicle with their lights and siren on approaching from behind you in the right lane. Even though the light is still red, your AV begins to move forwards into the intersection to clear the lane and allow the emergency response vehicle to turn right at the intersection.

- What information would you want to be presented to you by the AV at this moment, if any?
- How would you expect that information to be presented to you?

Degraded State:

The next scenario will involve your trip being interrupted due to the AV making an unexpected stop.

Scenario 5: Degraded State Functionality

Imagine you are riding at a speed of 60 mph in the far-right lane on a 2-lane highway. Unexpectedly, your AV detects an issue with your vehicle, which causes it to pull over and stop in a safe location in the right shoulder such that it isn't hindering traffic on the highway.

- What information would you want to be presented to you by the AV throughout this scenario, if any?
- How would you expect that information to be presented to you?
- If not brought up by group, probe the group about their anticipated solutions for completing their trip/receive new transportation. How would they want to go about requesting it? Monitor progress? Passing the time?

After your AV comes to stop, you are informed that another AV is already on its way to pick you up and will complete the remainder of your trip. You are also informed to remain seated and buckled up until your new AV arrives. Lastly, you are informed that a tow truck is being sent out to pick up the AV you are currently in.

- How would you want to receive the information that I just listed for this scenario? Would you expect this information to be presented by the AV or would you rather have a human call into your vehicle and explain it?
- While you are waiting for the new AV to arrive, what information would you want to be presented, if any? How would you want that information presented?

After waiting about 5 minutes, a tow truck arrives first and parks behind your AV. The tow truck operator exits their vehicle and approaches your AV to evaluate the situation.

- What information would you want to be presented to you by the AV throughout this scenario, if any?
- How would you expect that information to be presented to you?
- Would you want to communicate with the tow truck operator? If so, how would you want to go about doing that? What information would you want to communicate to the tow truck operator?

The tow truck operator returns to their vehicle. You continue waiting in your AV for 2-3 more minutes before the new AV arrives. Now that the new AV has arrived, you are expected to exit your AV and find your way to the new AV and enter it.

- Once the new AV has arrived, what information would you want presented by the AV you are currently in, if any?
- If not addressed = What info do you want before exiting the vehicle?
- Would you expect any information to be presented to you while walking to the new AV? If so, what would that information be? How would you like it to be presented?

Appendix B: Trust in Automation (Körber, 2018)

Instructions provided to participants' post-trip:

This survey will allow us to understand your current trust in automated vehicles (AVs). For this survey, I will read 16 statements out loud and then I want you to rate on a scale from 1–5 how much you agree or disagree with that statement. With 1 being "strongly disagree" and 5 being "strongly agree."

Please keep in mind that you are responding based on the experience you just had in the simulated AV. Please try to respond to all the items in the questionnaires, but don't spend a lot of time on an item – your first impression is fine.

		Strongly disagree	Rather disagree	Neither disagree nor agree	Rather agree	Strongly agree	No response
1	The system is capable of interpreting situations correctly.	(1)	(2)	(3)	(4)	(5)	○
2	The system state was always clear to me.	(1)	(2)	(3)	(4)	(5)	○
3	I already know similar systems.	(1)	(2)	(3)	(4)	(5)	○
4	The developers are trustworthy.	(1)	(2)	(3)	(4)	(5)	○
5	One should be careful with unfamiliar automated systems.	(1)	(2)	(3)	(4)	(5)	○
6	The system works reliably.	(1)	(2)	(3)	(4)	(5)	○
7	The system reacts unpredictably.	(1)	(2)	(3)	(4)	(5)	○
8	The developers take my well-being seriously.	(1)	(2)	(3)	(4)	(5)	○
9	I trust the system.	(1)	(2)	(3)	(4)	(5)	○
10	A system malfunction is likely.	(1)	(2)	(3)	(4)	(5)	○
11	I was able to understand why things happened.	(1)	(2)	(3)	(4)	(5)	○
12	I rather trust a system than I mistrust it.	(1)	(2)	(3)	(4)	(5)	○
13	The system is capable of taking over complicated tasks.	(1)	(2)	(3)	(4)	(5)	○
14	I can rely on the system.	(1)	(2)	(3)	(4)	(5)	○
15	The system might make sporadic errors.	(1)	(2)	(3)	(4)	(5)	○
16	It is difficult to identify what the system will do next.	(1)	(2)	(3)	(4)	(5)	○
17	I have already used similar systems.	(1)	(2)	(3)	(4)	(5)	○
18	Automated systems generally work well.	(1)	(2)	(3)	(4)	(5)	○
19	I am confident about the system's capabilities.	(1)	(2)	(3)	(4)	(5)	○

Questionnaire „Trust in Automation" (TiA) | Moritz Körber, Technical University of Munich

Appendix C: Self-Driving Car Assessment Scale (SDCAS)

Please listen to the follow statements and then rate on a scale from 1–7 how much you disagree or agree with that statement. With 1 being "strongly disagree," 4 being "Neither agree nor disagree," and 7 being "strongly agree."

Perceived reliability

1) Automated vehicles will be safe.
2) I would trust an automated vehicle to get me to my destination.
3) People will need to monitor automated vehicles closely to be sure the computers don't make mistakes.

Cost

4) I would be willing to pay more for an automated vehicle ride-hailing service compared to what I would pay for a traditional ride-hailing service (e.g., Uber).
5) The benefits of an automated vehicle ride-hailing service would outweigh the amount of money it would cost.
6) The cost of an automated vehicle ride-hailing service would be the most important thing I would consider before using it.

Appropriateness

7) I do not think that computers should be driving cars.
8) It is important for a human to be able to take back control from an automated vehicle.
9) There are some driving scenarios that will be too difficult for an automated vehicle to handle.

Perceived usefulness

10) Access to an automated vehicle ride hailing service would allow me to be more productive.
11) An automated vehicle would allow me to be more safe when traveling in a vehicle.
12) Automated vehicles will reduce traffic problems.

Perceived ease of use

13) Automated vehicles ride-hailing service will be easy to use.
14) It will be a lot of work to figure out how to use an automated vehicle ride-hailing service.
15) It would take me a long time to figure out how to use an automated vehicle ride-hailing service.

User Experience

16) I like to use technology to make tasks easier for me
17) I have bad experiences when I try to use new technology instead of doing things "the old-fashioned way"
18) There are tasks in my life that have been made easier by computers doing the work for me

Intention to use

19) I would like to use an automated vehicle ride-hailing service.

20) Even if I had access to an automated vehicle ride-hailing service, I would still use my current methods of transportation.
21) In an automated vehicle ride hailing service, it will be important to me to have the option to turn off the computer and request a human driver to takeover.

Appendix D: Vehicle Ingress Semi-Structured Interview Script (Study 2)

For this task, I will be verbally guiding you through the controlled area of the parking lot and up to the simulated automated vehicle. Along the way, I will ask you to respond to some interview questions. Although I will be with you at all times (for this task), I would like for you to imagine yourself in a scenario where you have already requested a fully automated vehicle through a ride-hailing app and you are intending to ride by yourself. Meaning that potentially there is no one else around to provide information on when your AV has arrived, where your AV has parked relative to your location, and no one to assist with enter the AV. Again, this is a scenario we would like you to imagine while responding to interview questions. As a final reminder, I will be recording this interview using a recording device, so please speak as clearly as possible. Do you have any questions before we begin?

> [If participants ask about whether or not they should imagine being in a familiar location, respond with: "we would like you to imagine this scenario as if it were happening in this exact location we are at today."]

[Start recording device and administer the questions below:]

[While still standing on sidewalk, ask the following questions]

1. Prior to the arrival of your requested automated vehicle, what information would you want? How would you want that information to be presented to you?
2. Now imagine that the automated vehicle has arrived and parked somewhere in this parking lot, what information would you require to locate it? (From the ADS or smartphone?)
3. (Optional questions if topics are not addressed:)
   a. What is the most important information for you to know before you start moving through the parking lot?
   b. When using current ride-hailing services, if any, what steps do you take to locate your requested vehicle in a parking lot?

[Moving through parking lot]

4. Now that we are walking through the parking lot, what is the most important information for you to know?

[When participant is at the vehicle]

5. What information would make you feel confident that you are at the correct vehicle?

> [Note: be ready to stop response of participant starts to provide design ideas. Just want information needs]

[Once seated in vehicle]

6. Reflecting on the environment you just experienced, can you think of a different scenario and/or environment that would be more challenging to find your requested automated vehicle?
7. What about a scenario/environment that would be the easiest to locate your requested automated vehicle?

In a few minutes, we are going start the trip…

8. What information would you like before starting the ride?

    [Start open ended. If participant can't think of anything, provide the following list and have participant indicate if they would find the information useful be responding with "Yes" or "No"]

    List of possible information ideas:

    > Your current location and final destination
    >
    > Estimated time of arrival
    >
    > Capabilities of the AV
    >
    > Instructions for emergency situations
    >
    > How to contact human operators
    >
    > Information to help you orienting yourself to the inside of the vehicle (e.g., button locations)
    >
    > Traffic forecast
    >
    > Weather forecast
    >
    > Options to adjust route (e.g., add stops, select preferred route, etc.)
    >
    > Information on the outside environment to expect when reaching your destination
    >
    > Options to select a specific drop off location

9. For today, I will be telling the AV when to start the trip. However, if it was up to you, how would you expect to start your trip? For instance, would you want to the vehicle to wait for you to give a command to start driving, or would you want the vehicle to do it automatically once it knows you are safely seated and ready to go?

Appendix E: Pre-trip script (Study 2)

Just as a reminder, today we would like you to imagine that you are using an automated vehicle that you requested from a ride-hailing service. We want you to imagine that you are in a situation where you are using this AV by yourself. If it helps, imagine that you are using this AV to go to the store. The AV currently does not have the ability to explain its upcoming or previous actions or provide information about the trip or surrounding environment.

Both trips will start and end in this parking lot. We planned these trips such that the AV will drive through different types of environments that may include urban, rural, and suburban roadways as well as highways. We also programmed the AV to expose you to various driving styles.

The AV will not provide you with information during these trips. The reason for this is because we want to understand what information individual riders, such as yourself, want to receive when using an AV ride-hailing service by yourself. So, to indicate when you want information during today's trips, press this button…[give participant button].

For example, if the AV accelerated quickly and you want information about that behavior, press the button! This could be information about why the AV behaved this way or more generally about your current location given the AV's behavior. Alternatively, you can request information that is unrelated to the AV's driving behavior, such as your current location or trip progress. We ask that you press the button EVERY TIME you want information. Even if it may seem repetitive. For instance, if the AV were to quickly accelerate again, and you want information about this behavior again, press the button. Does this make sense?

Whenever you press this button, I will receive a notification at my desk. At that time, I will speak with you through the teleconference call that is always running on the tablet mounted in front of you. At that time, I will ask you a few questions to help me understand why you pressed the button. Also, when pressing the button, please hold it for a couple of seconds to make sure I receive the notification on my end. If I do not start speaking after you press it, try pressing the button again.

As a final reminder, you will be audio and video recorded at all times in the vehicle. You will be allowed to take breaks in between trips. And if for any reason, you would like to stop participating, please let me or the safety driver know. [Show where window button is]. Okay, I am going to head back to my desk to get set up. Once I am ready, I will speak with you through the teleconference call on the tablet and provide the final instructions.

Appendix F: Usability Metric for User Experience (UMUX)

1) The HMI's capabilities meet my requirements:

(Strongly disagree) 1 2 3 4 5 (Strongly agree)

2) Using the HMI is a frustrating experience:

(Strongly disagree) 1 2 3 4 5 (Strongly agree)

3) The HMI is easy to use:

(Strongly disagree) 1 2 3 4 5 (Strongly agree)

4) I have to spend too much time correcting things with the HMI:

(Strongly disagree) 1 2 3 4 5 (Strongly agree)

Appendix G: IRB Approval Letter for Focus Group (Study 1)

VT VIRGINIA TECH

Division of Scholarly Integrity and Research Compliance
Institutional Review Board
North End Center, Suite 4120 (MC 0497)
300 Turner Street NW
Blacksburg, Virginia 24061
540/231-3732
irb@vt.edu
http://www.research.vt.edu/sirc/hrpp

MEMORANDUM

DATE: September 28, 2022

TO: Michael Mollenhauer, Joseph L Gabbard Jr, Eric Tait Bloomquist, Christine M Link-Owens, Stephanie Ann Baker, Carolina Santos, Hongrui Shan, Zheng Huang

FROM: Virginia Tech Institutional Review Board (FWA00000572)

PROTOCOL TITLE: Investigating Visually Impaired and Sighted Riders' Information and Interaction Requirements for Highly Automated Vehicles: Focus Group Interviews

IRB NUMBER: 21-358

Effective September 28, 2022, the Virginia Tech Human Research Protection Program (HRPP) determined that this protocol meets the criteria for exemption from IRB review under 45 CFR 46.104 (d) category(ies) 2(ii).

Ongoing IRB review and approval by this organization is not required. This determination applies only to the activities described in the IRB submission and does not apply should any changes be made. If changes are made and there are questions about whether these activities impact the exempt determination, please submit an amendment to the HRPP for a determination.

This exempt determination does not apply to any collaborating institution(s). The Virginia Tech HRPP and IRB cannot provide an exemption that overrides the jurisdiction of a local IRB or other institutional mechanism for determining exemptions.

All investigators (listed above) are required to comply with the researcher requirements outlined at:

https://secure.research.vt.edu/external/irb/responsibilities.htm

(Please review responsibilities before beginning your research.)

PROTOCOL INFORMATION:

Determined As: **Exempt, under 45 CFR 46.104(d) category(ies) 2(ii)**
Protocol Determination Date: **April 28, 2021**

ASSOCIATED FUNDING:

The table on the following page indicates whether grant proposals are related to this protocol, and which of the listed proposals, if any, have been compared to this protocol, if required.

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Appendix H: IRB Approval Letter for Simulated Commutes (Study 2 and Study 3)

MEMORANDUM

DATE: November 22, 2022

TO: Michael Mollenhauer, Eric Tait Bloomquist, Christine M Link-Owens, Marty Miller, Jacob Aaron Walters

FROM: Virginia Tech Institutional Review Board (FWA00000572)

PROTOCOL TITLE: Investigating Blind and Low Vision Rider's Requirements During On-Road Simulated Highly Automated Vehicles Ride-Hailing Commutes

IRB NUMBER: **21-1068**

Effective November 21, 2022, the Virginia Tech Institution Review Board (IRB) approved the Amendment request for the above-mentioned research protocol.

This approval provides permission to begin the human subject activities outlined in the IRB-approved protocol and supporting documents.

Plans to deviate from the approved protocol and/or supporting documents must be submitted to the IRB as an amendment request and approved by the IRB prior to the implementation of any changes, regardless of how minor, except where necessary to eliminate apparent immediate hazards to the subjects. Report within 5 business days to the IRB any injuries or other unanticipated or adverse events involving risks or harms to human research subjects or others.

All investigators (listed above) are required to comply with the researcher requirements outlined at:

https://secure.research.vt.edu/external/irb/responsibilities.htm

(Please review responsibilities before beginning your research.)

PROTOCOL INFORMATION:

Approved As: **Expedited, under 45 CFR 46.110 category(ies) 6,7**
Protocol Approval Date: **December 30, 2021**
Progress Review Date: **December 30, 2022**

ASSOCIATED FUNDING:

The table on the following page indicates whether grant proposals are related to this protocol, and which of the listed proposals, if any, have been compared to this protocol, if required.

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Appendix I: IRB Approval Letter for Expert Review

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VT VIRGINIA TECH.

MEMORANDUM

DATE:	April 14, 2023
TO:	Michael Mollenhauer, Eric Tait Bloomquist
FROM:	Virginia Tech Institutional Review Board (FWA00000572)
PROTOCOL TITLE:	Expert review of accessibility design guidelines for fully autonomous vehicles
IRB NUMBER:	**23-441**

Based on the submitted project description and items listed in the Special Instructions section found on Page 2, the Virginia Tech Human Research Protection Program (HRPP) has determined that the proposed activity is not research involving human subjects as defined by HHS and FDA regulations.

Further review and approval by the Virginia Tech Human Research Protection Program (HRPP) is not required because this is not human research. This determination applies only to the activities described in the submitted project description and does not apply should any changes be made. If changes are made you must immediately submit an Amendment to the HRPP for a new determination. Your amendment must include a description of the changes and you must upload all revised documents. At that time, the HRPP will review the submission activities to confirm the original "Not Research" decision or to advise if a new application must be made.

If there are additional undisclosed components that you feel merit a change in this initial determination, please contact our office for a consultation.

Please be aware that receiving a "Not Research" Determination is not the same as IRB review and approval of the activity. You are NOT to use IRB consent forms or templates for these activities. If you have any questions, please contact the Virginia Tech HRPP office at 540-231-3732 or irb@vt.edu.

PROTOCOL INFORMATION:

Determined As:	**Not Research**
Protocol Determination Date:	**April 14, 2023**

ASSOCIATED FUNDING:

The table on the following page indicates whether grant proposals are related to this protocol, and which of the listed proposals, if any, have been compared to this protocol, if required.

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