Designing HMI for BVI Users in Fully Automated Vehicles: A Participatory and In-the-field Approach

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Abstract

Fully Automated Vehicles (FAVs) have the potential to provide blind and visually impaired (BVI) individuals with mobility independence. However, understanding their user experience in this new form of transportation presents challenges. Researchers in human-computer interaction and accessibility lack comprehensive guidance on conducting safe and ecologically valid studies with BVI participants. This poster reviews the literature and proposes a methodology for conducting field research with BVI users in automated vehicles, particularly in designing the human-machine interface (HMI) for FAVs. We present the participatory and in-the-field method with example study designs: a focus group for field study and an on-road driving study with a Wizard of Oz FAV. This method will assist researchers in gaining deeper insights into the interaction between BVI users and automated vehicles in the real world.

CCS Concepts

• **Human-centered computing** → **Accessibility design and evaluation methods**; • **Applied computing** → *Transportation*; • **Social and professional topics** → People with disabilities.

Keywords

Fully automated vehicles, blind and visual impaired, focus group, Wizard of Oz study

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1 INTRODUCTION

As Automated Vehicles (AVs) increasingly transition from concepts to real-world applications, their potential benefits across new user groups, particularly Blind and Visually Impaired (BVI) individuals, are critical to explore. Fully Automated Vehicles (FAVs), or Level 5 automated vehicles as defined by the Society of Automotive Engineers (SAE) [19], necessitate minimal direct human intervention in driving. The minimal intervention requirement in FAV can benefit the approximately 43 million blind people worldwide [11], enhancing their mobility and independence [16]. To unlock this potential, key challenges remain for BVI users, not least since vision plays a critical role in driving or being driven as driving is inherently a highly visual task [13]. Conventional human-machine interfaces (HMI) also heavily rely on vision ability, creating natural barriers for individuals with visual impairments and impeding in-vehicle communication between BVI users and the FAV. Therefore, to integrate BVI individuals into the use of FAVs, it is essential to conduct research on their user experience (UX) in this scenario and develop tailored HMIs.

In a broader context of AVs, researchers have looked into BVI people's needs, concerns, and preferences by reflecting on previous ridesharing experiences or envisioning autonomous driving scenarios [4, 6]. Qualitative research methods such as surveys and focus groups are widely employed to investigate factors that influence the experience of BVI users. By gaining insights from BVI participants' self-reflections, Brewer et al.'s preliminary studies highlighted the situation awareness of BVI users while being driven and their trust issues towards FAVs [2, 3]. Consequently, emerging assistive HMIs addressing the needs of BVI users focus on conveying traffic information [17] or allowing BVI users to alter the route [12].

Our understanding of BVI users' experience is mostly based on interviews, surveys, or workshops, so under a hypothetical situation, since the FAVs for BVI are not yet available. Assistive HMIs inspired by such thought experiments lack real-world evaluation. Driving simulators used in previous studies, designed primarily with visual cues, have questionable immersion for blind participants, especially in simulating vehicle dynamics [7]. In assistive technology and AVs, there is inadequate knowledge of the in-situ experience of BVI users in FAVs, and there are limited applicable insights from real-world studies of BVI users concerning proposed HMIs.

Our paper presents a participatory, in-the-field method supplemented with the Wizard of Oz (WoZ) autonomous driving [1], engaging BVI users throughout the assistive HMI design and evaluation process. We illustrate this method through two study designs to comprehensively understand BVI users' experience and rigorously evaluate proposed assistive solutions. Study 1 involves focus groups conducted in a WoZ FAV, where a driver simulates FAV operations in a six-seat SUV, transporting three participants and

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a moderator along a predetermined route. By creating the in-situ experience, the focus group is intended to generate detailed insights into BVI users' needs, preferences, and design concepts. Study 2 introduces a WoZ FAV integrated with designed artifacts for field evaluation. Rather than performing the scheduled driving behavior solely, the driver acts as an interaction wizard, executing driving behaviors that respond to BVI users' inputs during the trial.

Contribution Statement: This paper contributes to the design methodology by presenting a method that integrates the participatory design principle with an in-the-field approach. This method will assist readers in designing exploratory and evaluation studies with BVI users, particularly in the context of FAV.

2 RELATED WORK

2.1 BVI's UX in AVs

Research on the UX of BVI users in the broader context of AVs primarily focuses on potential activities and human factors impacting their experience. Most studies use hypothetical scenarios and employ participatory methods such as focus groups; for instance, Brinkley et al. explored BVI users' journeys through surveys and focus groups, highlighting potential activities such as monitoring the road, chatting, and reading [4]. From the scope of human factors, trust issues and the need for situation awareness (SA) were recurrent themes, with participants expressing concerns about information on other vehicles, landmarks, and emergency responses [6]. Brewer et al. linked participants' reflections to ridesharing experiences, emphasizing similar disorientation concerns [3]. Additionally, Brewer's workshop on hypothetical AVs underscored the importance of SA, as BVI participants desired a "sense of control" by maintaining situation awareness of both the environment and vehicle dynamics [2].

However, most exploratory studies rely on envisioned scenarios, limiting real-world insights [9]. Huff et al. proposed quasi-naturalistic observation using remote communication and GoPro cameras to capture BVI users' naturalistic ridesharing experiences, suggesting that in-the-field observation provides more comprehensive insights [14].

While WoZ FAVs offer immersive settings for sighted users [8], few studies with BVI users are conducted in highly immersive scenes, restricting participants' reflections. Our proposed study aims to examine BVI participants' interactions with FAVs, particularly focusing on vehicle dynamics and realistic surroundings, emphasizing the importance of immersive experiences when researching with BVI individuals.

2.2 HMIs for BVI Users in AVs

Designing HMIs to fulfill the BVI individuals' autonomy and safety needs in FAV has focused on audio and haptic modalities. Examples include a multisensory HMI with mid-air gesture control for altering routes using haptic feedback [12] and *OnBoard*, a tangible interface providing traffic information through audio and tactile feedback [17]. Despite their potential, these HMIs have not been evaluated in realistic settings due to possible concerns about safety or cost; evaluations typically use fixed-based simulators designed for sighted users, which poorly simulate spatial sounds, haptics, and vehicle dynamics. Recognizing the importance of immersive experiences for autonomous mobility reflections [10], it is crucial to evaluate assistive technologies with BVI users in real road tests. There are a few studies with BVI users conducting open road evaluations. *ATLAS*'s on-road evaluation was conducted in a Real Road Autonomous Driving Simulator (RRADS) [1], with an interaction Wizard who provided verbal information of the waypoints during the trip [5]. Ranjar et al. also investigated the vibrotactile guidance in a WoZ FAV, providing real-time location information via vibrotactile code [18].

However, these studies lack BVI user interventions during trips, failing to discuss how WoZ FAVs can respond to BVI inputs while driving, which is essential for a "sense of control." Our evaluation method integrates assistive artifacts into WoZ FAVs, offering both output and input media for BVI users while ensuring safety, aiming to evaluate HMIs with reliability and provide in-the-field insights into the interactions in FAVs.

3 STUDY METHOD

3.1 Participants

BVI participants are recruited from the university's optometry research laboratory and local BVI community groups on social media platforms such as Facebook. By recruiting within a local organization or community, we anticipate familiarity among participants and increased willingness to disclose. Recruitment messages are sent to interested individuals via email or SMS.

As for the inclusion and exclusion criteria, participants must be over 18 years old and identified as visually impaired, including individuals with "blind" or "low vision." This study excludes individuals with reported tactile or hearing difficulties to ensure effective verbal communication during interviews and the usability of future audio or haptic HMIs. Participants' mobility is assessed prior to the study to determine if they need wheelchairs or require assistance from family members or guide dogs, ensuring their safety while reaching the study spots. Respecting BVI users' shopping preferences, each participant receives a $50 gift card as compensation based on their choice.

3.2 Route design

Our route design considers two main dimensions: geographic convenience to participants and the diverse composition of roads. We set a spacious room on the university campus as both studies' starting and ending points. The university, a recognizable landmark, provides ample space for staging, reception, and study preparation. The route includes a mix of city and suburban streets, featuring both civic and natural environments. Additionally, it traverses various functional areas, such as business and residential districts, to reflect the diverse transportation purposes of BVI users and includes numerous landmarks relevant to their daily lives. A range of traffic densities and intersections are incorporated to present BVI users with various orientation situations during the trip. Notably, the study schedule avoids wet roads and rush hour traffic to mitigate the risk of accidents and to maintain control over trip duration. The entire route is limited to 40 minutes to prevent fatigue and boredom. The trip should be terminated immediately if any participant feels uncomfortable or sick.

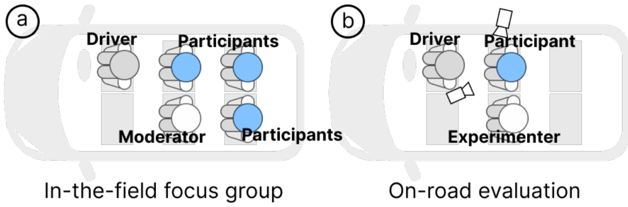

Figure 1: The Wizard of Oz FAV for two studies. a) The set-up of each focus group (N=3) in study 1; b) The set-up of per on-road experiment (N=1) in study 2.

Table 1: Scheduled agenda for the two-hour focus group in a WoZ FAV

Duration	Agenda
10 min	Study introduction and consent form signing
10 min	Guide participants to the start point and familiarize them with the car
20 min	Ice-breaking with self-introductions and discussions about personal transportation modes
40 min	In-ride discussion, participants think aloud about their experiences during the trip
30 min	Post-ride discussion, recap, and ideation of possible solutions
10 min	Summary and distribution of compensation

3.3 Study 1

This study employs an in-the-field focus group of BVI participants (N = 12) using a Wizard of Oz FAV. Each ride involves 3 participants. The study aims to investigate barriers, identify factors impacting BVI users' experience, and gather preferences for assistive solutions in a FAV. Following the above research purpose, the focus group is semi-structured with questions relating to particular topics and driving contexts. The topics move from general to specific: start from personal transportation mode to the UX during this ride, and end with possible solutions for UX issues. This study represents the discovery phase of our participatory method.

3.3.1 Set-up. A WoZ FAV is set up using a six-seat SUV operated by a sighted driver (Fig.1a). Three BVI participants are seated in the 2nd and 3rd rows, with a sighted moderator hosting the focus group from the 2nd-row seat. At the end of each session, the moderator checks in with participants to encourage relatively even participation. An audio recorder is placed on the center armrest to capture the discussions.

3.3.2 Procedure. The procedure of the focus group is scheduled as shown in Table1: Prior to the focus group, written information about this study has been sent to participants in an accessible way. On the day of the study, consent forms and project briefs are all read aloud to BVI participants (10 min) in the lab, with braille versions available as well. Then, the moderator guides three participants to the car and introduces them to the WoZ vehicle (10 min). Before the FAV starts, the research moderator conducts an initial interview to let participants introduce themselves as ice-breaking. Participants share their transportation habits and experiences by turn (20 min). During the ride, participants engage in a focus group discussion about their UX regarding the current ride and are encouraged to think aloud and express their feelings (40 min). The UX discussion focuses on accessibility, SA, and trust, especially regarding vehicle dynamics and surrounding information. The moderator here could probe and expand on issues in the discussion.

After parking, participants are led to discuss the topics raised during the journey in detail. Subsequent discussions focus on preferred assistive solutions within the FAV (30 min). Kits like clay are provided for participants to design artifacts to express their ideas tactilely. Participants could articulate their ideas through verbal expression and created artifacts, resulting in a series of design concepts for subsequent iteration and evaluation. After the debriefing, BVI participants can receive $50 compensation.

This participatory and in-the-field exploration can provide qualitative data on the UX of BVI users, identifying concerns and influential factors. Moreover, these focus groups generate early-stage design concepts with low-fidelity artifacts. All the above insights inform the design of assistive HMIs to address the needs of BVI users.

3.4 Study 2

To evaluate the HMI concerning its pragmatic (usability) and hedonic qualities (users' SA, trust, and enjoyment), study 2 is the on-road evaluation with BVI participants (N=12), one subject per ride. This user study represents the evaluation phase of our method.

3.4.1 Set-up. For study 2, we present a method to integrate proposed artifacts with an interaction WoZ. An information framework is designed to simulate the input and output during the autonomous driving:

(1) Data acquisition is conducted through sensors and cameras installed in the car, capturing vehicle dynamics, route-based information, and surrounding details.
(2) Necessary information is processed by the HMI and rendered with customization to BVI passengers.
(3) BVI participants interact with the HMI via voice, gestures, or tactile maneuvers.
(4) The HMI processes BVI participants' commends to the driver through the infotainment system.
(5) Driver performs responding driving behavior while ensuring safety.
(6) BVI participants perceive the vehicle dynamics.

Each user study involves a participant seated in the second row, with an experimenter sitting beside him/her (Fig.1b). In the above framework's step (5), while receiving input from BVI users, the driving wizard executes corresponding driving behaviors while ensuring safety. We incorporate a safety assurance method adapted from a prior "backseat driving" study [15]: if a participant issues a risky or off-track command, the driving wizard can decline to follow it and instead perform a predesigned maneuver. Simultaneously, the experimenter records the command as an issue for subsequent interviews. To capture participant behavior, two cameras are positioned behind the driver's seat and on the passenger side window.

Table 2: Scheduled agenda for the two-hour on-road evaluation

Duration	Agenda
10 min	Study introduction and sign the consent form
10 min	Pre-ride questionnaire on the autonomous technology acceptance
20 min	Training session with assistive HMI
40 min	In-ride evaluation with predefined tasks
10 min	Post-ride questionnaire on the usability and situation awareness
30 min	Post-ride interview towards the pragmatic and hedonic quality of HMIs

3.4.2 Procedure. The procedure of the user study is presented in Table2: In preparation for the on-road evaluation, Study 2 begins with an introduction (10 min) and an assessment of BVI participants' demographic characteristics and acceptance of autonomous technology (10 min). Following this, the experimenter helps BVI participants become familiar with the proposed HMI (20 min). During the primary track evaluation, participants are required to complete predefined tasks while interacting with the HMI, with their behavior recorded by cameras (40 min). After the ride, a questionnaire is set to evaluate users' perceived usability and SA (10 min). Finally, an interview delves into topics including SA, trust, and enjoyment, offering more profound insights into the interactions preferred by BVI users (30 min).

4 TAKEAWAYS AND FUTURE WORK

- Focus group in the field. As immersive experiences are crucial for provoking reflections, the in-the-field focus group is suggested to generate discussions among participants. When conducting studies with BVI users, rigorous recruitment and route design planning should respect participants' preferences and ensure accessibility.
- Evaluation with WoZ FAVs. For BVI users, on-road evaluation with WoZ is necessary due to the limitations of simulators. A WoZ FAV can drive response to users' inputs by aligning more closely with their need for "control" and providing a new level of immersion for experiments.
- Future case studies. This poster does not present the results of case studies. Future work will involve applying the proposed method to the HMI design for BVI users and reflecting on the methodology. Additionally, the adoption of the in-the-field method for various modalities should be discussed, offering future customization and diversity in designing with different modalities.

5 CONCLUSION

We present a participatory and in-the-field method for designing HMIs for BVI users in fully automated vehicles. This methodology aims to provide a more immersive in-situ experience, addressing the limited understanding of BVI users' real-world experience in FAVs. The method is detailed through a prospective case study design. We advocate for future studies to apply our method and offer guidance for researchers in their exploration and evaluation.

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