Light My Way: Developing and Exploring a Multimodal Interface to Assist People With Visual Impairments to Exit Highly Automated Vehicles

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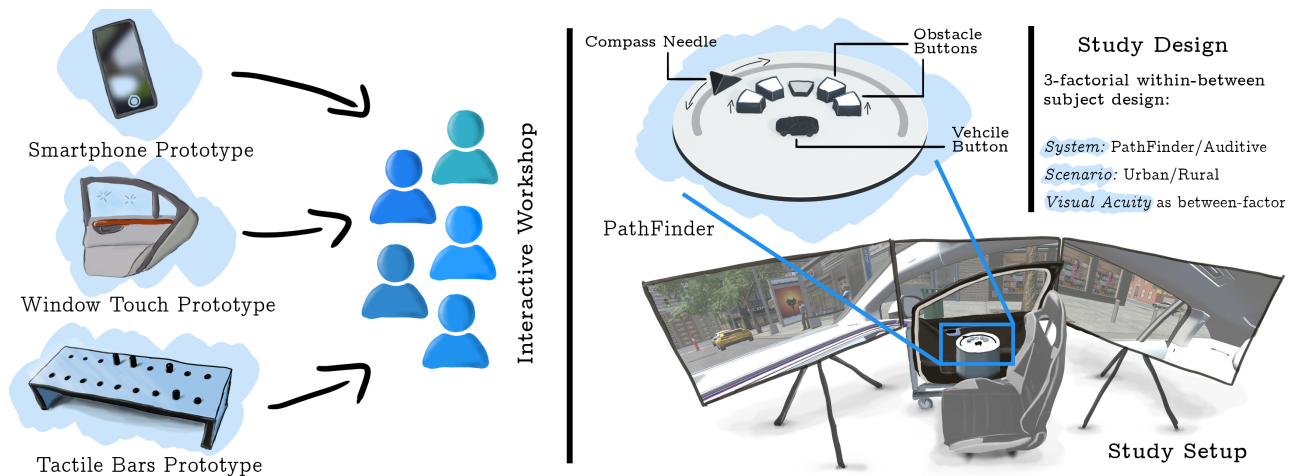
Figure 1: (Left) Interactive workshop (N=5) exploring the information needs of blind and visually impaired people when exiting future highly automated vehicles. Participants engaged with three initial low-fidelity prototypes: a smartphone, a window touch prototype, and tactile bars. (Right) Study setup featuring three monitors and a real car door with PathFinder–a multimodal interface–attached to simulate a ride with an HAV. The top section explains PathFinder's functionalities, including the compass needle, five extendable obstacle buttons, and the vehicle button. We used this setup to conduct a three-factorial within-between-subject study, using system and scenarios as our two within factors and participants' visual acuity as the between factor

Abstract

The introduction of Highly Automated Vehicles (HAVs) has the potential to increase the independence of blind and visually impaired people (BVIPs). However, ensuring safety and situation awareness when exiting these vehicles in unfamiliar environments remains challenging. To address this, we conducted an interactive workshop with N=5 BVIPs to identify their information needs when

exiting an HAV and evaluated three prior-developed low-fidelity prototypes. The insights from this workshop guided the development of PathFinder, a multimodal interface combining visual, auditory, and tactile modalities tailored to BVIP's unique needs. In a three-factorial within-between-subject study with N=16 BVIPs, we evaluated PathFinder against an auditory-only baseline in urban and rural scenarios. PathFinder significantly reduced mental demand and maintained high perceived safety in both scenarios, while the auditory baseline led to lower perceived safety in the urban scenario compared to the rural one. Qualitative feedback further supported PathFinder's effectiveness in providing spatial orientation during exiting.

CCS Concepts

• **Hardware** → **Sensors and actuators**; • **Human-centered computing** → **User studies**; *Laboratory experiments*; **Haptic devices**; *Sound-based input / output*; **Accessibility design and evaluation methods**; *Empirical studies in accessibility*; **Accessibility technologies**; **Accessibility systems and tools**.

Keywords

people with visual impairments, multimodal interfaces, situation awareness, highly automated vehicles

1 Introduction

Over 270 million people worldwide live with vision impairments [2, 69], and this number is expected to rise as the population ages [11]. These impairments can limit daily activities such as driving [56], making independent mobility a significant challenge. Hence, the introduction of Highly Automated Vehicles (HAVs) in the near future has the potential to improve transportation for people who are blind or have visual impairments (BVIPs) [19]. Studies indicate that sighted individuals barely expect increased independence using HAVs, but this expectation is significantly higher among BVIPs [52]. Hence, by enabling independent and safe mobility among this demographic, HAVs represent a crucial step toward achieving greater equality in transportation [10]. However, ensuring safety and situation awareness when exiting these vehicles in unfamiliar environments remains a critical challenge as in today's manually driven vehicles, BVIPs often rely on drivers to drop them off at convenient locations that make it easier to navigate their surroundings [15]. With the introduction of HAVs, BVIPs may gain more independence [52] but are likely to face situations alone without human assistance. This is where situation awareness will be particularly important as BVIP. This situation awareness involves "*the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future*"[26, p. 5]. In exciting situations,

specific assistance—like detailed information about the vehicle's surroundings while parked—can benefit BVIPs [15, 30]. However, situation awareness is not exclusive to BVIPs. Research shows that it also significantly enhances trust and perceived safety for sighted passengers in HAVs [23, 29, 45, 73, 87, 90].

Related research has already been conducted on parts of the trip via HAVs to enhance BVIPs' situation awareness, including locating ride-sharing vehicles with a smartphone application [31] and enhancing situation awareness during rides by conveying traffic-relevant information [35, 37, 60, 61]. However, enhancing situation awareness and safety while exiting the HAV remains underexplored. Yet this part of the trip is crucial as it requires immediate awareness of potential hazards like moving cyclists [15] or obstacles that could cause trips or falls, posing significant safety risks. Unlike typical pedestrian navigation, where BVIPs rely on tools like canes or guide dogs, exiting an HAV involves rapidly adapting to a potentially unfamiliar and more hazardous environment. This situation requires new solutions to complement traditional navigation aids.

A notable attempt to address this research gap is the prototype ATLAS developed by Brinkley et al. [18], which utilizes computer vision to articulate the surroundings upon arrival at the destination [18]. Despite its advancements, such as increased trust towards the HAV, this solution is limited to auditory feedback only. However, incorporating additional modalities, such as tactile feedback [88], might be even more helpful by providing a multimodal approach [35]. In fact, research suggests that integrating multiple modalities enriches the quality of information conveyed and significantly enhances situation awareness for BVIPs, offering advantages over single-modality feedback [89]. Specifically, the combination of voice-based and tactile feedback is particularly effective for navigation tasks [57].

This paper explores a new interface designed to support BVIPs in such situations. Recognizing the advantages of multimodal interfaces in conveying information to BVIPs [35, 61], we developed three initial prototypes (a smartphone, a window touch prototype, and tactile bars prototype) based on related work (e.g. [43, 47, 55, 61]). Each prototype featured various modalities, including tactile, auditory, and visual cues, as well as different interaction strategies like pointing and sensing. This enabled us to conduct a focused evaluation of each modality and interaction strategy during an interactive workshop with N=5 BVIPs. In addition to evaluating the initial prototypes, the workshop explored the information needs of BVIPs when exiting a future HAV and possible methods to convey this information.

The workshop results highlight the need for a multimodal approach to provide information about the vehicle's surroundings. In response, we developed PathFinder, a system designed to help BVIPs safely exit HAVs. By integrating visual, tactile, and auditory modalities into its design, PathFinder adapts to BVIPs with different degrees of visual impairments. This approach ensures that PathFinder effectively supports each passenger's individual needs in HAVs.

We evaluated PathFinder in a subsequent three-factorial, within-between-subject user study with N=16 BVIPs. This study compared PathFinder to an auditory-only baseline, the current standard in accessible navigation technology, across two scenarios: a complex

urban environment and a simpler rural setting. Quantitative results demonstrated that PATHFINDER significantly reduced mental demand compared to the baseline. Additionally, the multimodal system consistently maintained high perceived safety in both scenarios, whereas the auditory baseline resulted in lower perceived safety in the urban scenario compared to the rural one. Additionally, qualitative feedback revealed a preference for multimodal information of conveyance of PATHFINDER, which improved participant's spatial orientation.

Contribution Statements [86]

- **Empirical study that tells us about people.** We developed three low-fidelity prototypes with different interaction strategies and modalities to assist BVIPs in exiting HAVs, which were used as inspirational input for the interactive workshop with N=5 BVIPs. We found that participants preferred tactile cues as the basic modality to gain an overview of the surrounding HAVs, with auditory cues used for critical information, highlighting the need for multimodal accessible interfaces.
- **Artifact or System.** Based on insights from the interactive workshop, we designed and developed PATHFINDER, a multimodal interface including tactile, auditory, and visual modalities to assist BVIPs in exiting HAVs. This artifact demonstrates how the findings of the interactive workshop are applied to a concrete interface design that can be reproduced in future studies, as we provided all construction files as open source.
- **Empirical study that tells us about how people use a system.** In the following user study with N=16 BVIPs, we found that PATHFINDER significantly reduced mental demand compared to an auditory-only baseline and maintained high perceived safety in both urban and rural scenarios. These results provide empirical evidence that multimodal interfaces can outperform unimodal systems in the HAV context, especially in complex environments, and highlight the need to tailor the interface to the user's visual acuity and the situation at hand.

2 Related Work

This research is grounded in current research on BVIPs and HAVs. We present navigation aids for BVIPs primarily designed to support pedestrians. Following this, we dive into the context of HAVs by describing current research on the needs of BVIPs within these vehicles.

2.1 Navigation Aids for Visually Impaired People

Giudice and Legge [40] explored how technological aids assist with navigation for people with visual impairments, identifying four key considerations: (1) The conveyance of visual information into auditory or tactile modalities should be defined clearly, accommodating the cognitive demands and learning curve of users. (2) The presented information should be minimized to the essentials. (3) Given that each system has unique advantages and disadvantages depending on the context, combining various aids might be necessary for effective navigation across different scenarios. (4) Devices should be designed to be non-intrusive and aesthetically pleasing.

Building on these guidelines, several navigation aids have been developed and assessed to support BVIPs. For this, Ducasse et al. [25] reviewed various dynamic tactile maps for BVIPs, classifying them into *Digital Interactive Maps* displayed on flat surfaces like screens and *Hybrid Interactive Maps* that incorporate both digital and physical elements. These dynamic tactile maps have demonstrated higher performance compared to touchscreen and swell paper maps (a type of tactile paper that raises printed images or text) regarding map reading speed and the ability to create a mental map of the route [91]. Further research by Holloway et al. [48] demonstrated that tactile maps *[...] support orientation and mobility through identification of landmarks, route planning and creation of a mental map [...]* [48, p.184].

In general, multimodal approaches to conveying information seem to outperform those that rely on a single modality, as supported in *multiple-resource theory* by Wickens et al. [84], which states that distributing information across modalities such as auditory and visual reduces competition for attention and processing resources, leading to better task performance, and reduced mental demands as task difficulty increases [70]. Neuroimaging studies further support this, showing that the occipital cortex in blind individuals represents spatial information similarly across different sensory inputs [6], facilitating sensory-independent spatial representations [59]. Therefore, multimodal interfaces leverage cognitive advantages and neural adaptability, potentially leading to more effective navigation aids for BVIPs. This argument is in line with finding from Kuriakose et al. [54], who reviewed multiple tools and technologies that support BVIPs in their navigation task, recommending that "*if there is an option for multiple feedback modalities, the user will get the flexibility to choose one based on a situation or environment*" [54, p. 12]. This aligns with Yatani et al. [89], who found that handheld tactile maps combining tactile feedback with audio instructions offer superior spatial orientation compared to audio-only feedback. Additionally, the study revealed differences in the effectiveness of verbal audio vs. auditory icons, aligning with the findings of Glatz et al. [41], who found auditory icons to be more effective for conveying contextual information, while verbal audio was better for urgent requests. Further, by comparing the effectiveness of auditory, visual, and combined audio-visual feedback, the combination of audio and visual feedback improved participants' situation awareness more than visual feedback alone [66]. Additionally, multimodal maps with tactile elements, augmented by audio feedback when touched, enhanced navigation skill improvement for BVIPs. Participants especially valued the combination of audio and tactile cues, highlighting the importance of designing such tools in line with users' preferences and needs [4].

Given the advantages of multimodal systems for navigation tasks and following the guidelines of Giudice and Legge [40], this work investigates the potential of multimodal interfaces for BVIPs in the automotive domain. The following sections will explore the specific needs of BVIPs inside HAVs, providing a foundation for developing new systems tailored to their requirements.

2.2 Needs and Opinions of Visually Impaired People in the Context of Highly Automated Vehicles

While the aforementioned studies primarily focused on pedestrian navigation, the introduction of HAVs presents new opportunities and challenges for BVIPs. Most BVIPs are enthusiastic about the autonomy HAVs promise, potentially granting access to previously challenging locations [52]. Despite this, initial qualitative research showed that BVIPs raised concerns regarding whether HAVs will be truly designed to meet BVIPs needs [10, 17, 19]. To envision these needs, current rideshare services have been used as a proxy for future HAV scenarios [15, 30] and workshops have been conducted to identify passengers' needs and imagine accessible interfaces for HAVs [16]. Results have demonstrated the need for non-visual support for BVIPs throughout the complete transportation trip via HAVs, from locating an HAV [32] to conveying traffic information, such as the reason for the HAV stopping during the ride [35, 61]. The following sections review the small but emerging field of literature on nonvisual interfaces across the complete trip via HAVs.

2.3 Non-visual Interface Development Across the Entire Journey

Initial research has sought to design and test accessible interfaces in HAVs. For instance, researchers have evaluated mid-air haptics and tactile interfaces to enhance situation awareness during the ride [33, 61]. Additionally, gestural interactions have been explored for in-vehicle control by BVIPs [30]. While these in-vehicle studies have shown promising results, they have primarily focused on the on-road part of the trip. Only a few studies have investigated other parts of the trip, such as pre-journey mapping [36] and vehicle localization [31, 74]. While the ATLAS system by Brinkley et al. [18] explored supporting BVIPs in gaining situation awareness when exiting the vehicle, it solely utilized the auditory modality, missing the benefits of multimodal interfaces that can support BVIPs inside HAVs [35, 61].

To address this research gap, this work will examine BVIPs' information needs for exiting HAVs and investigate the potential of a multimodal interface to assist them during this phase. To achieve this, we hosted an interactive workshop with BVIPs and created three initial low-fidality prototypes, which will be described in the following section.

3 Initial Low-Fidelity Prototypes

Prior to hosting the interactive workshop with N=5 BVIPs, we developed three initial low-fidelity prototypes (smartphone, window touch, and tactile bars) based on existing research [43, 47, 55, 61] and state-of-the-art smartphone applications for BVIPs [9, 35, 43, 63]. This section will detail each prototype and explain the related work from which they were derived. The three prototypes were designed to serve as concrete examples to inspire and facilitate discussion during the workshop, providing participants with tangible prototypes to interact with rather than relying solely on conceptual discussions about potential interaction strategies and modalities. Hence, each prototype employs different modalities and interaction strategies. This approach enabled us to evaluate each modality and strategy independently in a focused manner during the subsequent workshop. Below, we describe each prototype in detail, along with the rationale for their design choices. Additionally, we provided the construction files for each initial prototype for reconstruction in a git repository (see section Open Science).

Scenario Design for the Prototypes. For the prototypes, we designed a simulated suburban scene using Unity [82] version 2023.2.1f1 and the Suburb Neighborhood House Pack asset [38]. This scene, which was used in both the smartphone prototype and the window touch prototype, depicted an HAV parked on the side of the road, with a pedestrian/cyclist path next to it and a house (the final destination) behind the path. The scene included static obstacles such as a tree and a street sign near the HAV's door, as well as dynamic obstacles like pedestrians and cyclists moving in front of the door.

3.1 Smartphone Prototype

Smartphones are prevalent among BVIPs, especially among young BVIPs (19-34); 76% of them own a smartphone [1]. Building on this familiarity, we developed a smartphone prototype inspired by previous work, such as the object detection application by Zhong et al. [92] and more recent smartphone-based navigation aids in the automotive context for BVIPs [31]. Research has indicated that BVIPs prefer to move the smartphone to scan their surroundings when exploring their environment, compared to other interaction strategies via smartphone [43]. Therefore, our smartphone prototype (Figure 2a) allows users to scan their surroundings using the smartphone's camera, triggering auditory descriptions of static objects and dynamic obstacles within the simulated suburban scene. A button on the screen allows participants to cast a ray within the Unity environment, identifying objects like "Tree" via verbal auditory feedback. Vibration feedback confirms successful button activation, enhancing interaction [71]. Dynamic obstacles, such as approaching cyclists, are automatically announced in real-time to ensure immediate awareness.

The interaction strategy combines verbal and auditory modalities, supported by visual feedback through the smartphone's scanning and pointing mechanism.

3.2 Window Touch Prototype

Our window touch prototype (Figure 2b) draws inspiration from Ford's "Feel the View" system [42], which allows users to receive tactile feedback about the outlines of the environment on the vehicle's side window. Our prototype extends this concept, but instead of using vibration, we employed verbal auditory feedback of the obstacles when the participants touch the window, as based on touch-exploration of images [55, 63].

To demonstrate this prototype, we created a setup with a car door and a 75" monitor displaying the same suburban scene used in the smartphone prototype. This setup was designed as a Wizard-of-Oz prototype, where one of the workshop moderators manually triggered the corresponding verbal output upon participants' pointing. For example, if a participant pointed toward a tree, the verbal sound "Tree" was played. Like the smartphone prototype, information about dynamic obstacles, including their direction, was communicated automatically upon the HAV reaching its destination.

(a) Smartphone Prototype   (b) Window Touch Prototype   (c) Tactile Bars Prototype

Figure 2: Initial low-fidelity prototypes that where used during the interactive workshop

This prototype focuses on a verbal, auditory modality, enhanced by touch-based interaction, allowing participants to receive detailed information about their surroundings directly through the car window.

3.3 Tactile Bars Prototype

Related work showed that tactile cues can help gain situation awareness for BVIPs inside HAVs [21, 33, 35, 60, 61, 78]. Hence, we designed a tactile bar prototype (see Figure 2c) to convey potential obstacles when exiting the vehicle. Unlike the smartphone and window touch prototypes, this one does not rely on a visual Unity scene; instead, it solely uses tactile feedback to convey information about obstacles.

The tactile bars prototype features two rows of nine movable bars. The first row (from the perspective of the participants) represents static obstacles, such as trees or street signs, while the second row represents dynamic obstacles, like cyclists or pedestrians. We rounded the edges of the bars to ensure a smooth surface to avoid discomfort when touching them, as recommended by Holloway et al. [47]. The rationale for having two distinct rows is to separate the types of obstacles, assuming to make it easier for participants to understand the environment. Static obstacles are presented as constant and unchanging, while dynamic obstacles are represented with motion, created by manipulating the bars in the second row to simulate movement.

In the first row, each bar is controlled by one of nine levers, operated by one of the workshop moderators, allowing individual movement up and down. A slider at the prototype's bottom manipulates the dynamic obstacle bars. Moving this slider creates a wave-like effect on the bars, creating a tactile illusion of motion. The decision to convey motion via bars that move up and down was inspired by Holloway et al. [46], who noted that using height differences is a perceivable method to convey tactile motion for BVIPs.

The prototype's design prioritizes simplicity and tactile feedback, offering BVIPs to gather information about their surroundings without relying on visual or auditory cues.

4 Interactive Workshop

In this section, we describe the interactive workshop we conducted with N=5 BVIPs (three female, two male and no non-binary) aged between 44 to 67 (M = 57.80, M = 8.61). The female participants reported being completely blind, with one having light perception. The male participants had impaired vision, with visual acuity between 3-5% (see Appendix B for more details).

The workshop was conducted to identify BVIPs' specific information needs to improve their situation awareness and assist in safe exit of HAVs. Further, we explored preferred interaction strategies to convey the necessary information for these tasks. To provide prior inspiration and a starting point for discussion, the three initial low-fidelity prototypes (see section 3) were presented to the participants in individual sessions during the workshop.

The following section details the interactive workshop procedure and the implications of the results, which eventually led to the final design of PATHFINDER. By including the participants from the beginning of the design phase, we adopted the Participatory Design approach from Muller and Kuhn [65].

4.1 Procedure

The workshop, moderated by five of the authors, was scheduled to last three hours and divided into four phases. The detailed agenda for the session is outlined in Table 1. Before the start, we ensured that all participants had consented to share their data, which allowed us to proceed with audio and video recordings during the study.

During the first phase, we started with brief introductions, where each participant shared their visual abilities. This was followed by a concise overview of the capabilities of HAVs, which can reach their destination without any intervention, as defined by SAE levels 4 and 5 [75].

Transitioning into the workshop's core discussion in the second phase, we opened the floor to conversations about the participants' personal experiences with exiting traditional vehicles, such as taxis. Following this, we asked participants about their specific information needs to gain situation awareness of the surrounding environment. Next, we invited participants to generate ideas on how to convey these information needs to them.

Table 1: Scheduled agenda for the three hours interactive workshop

phase	scheduled duration	agenda
1	15 min	Introduction of the Participants and Moderators (4 authors). Overview of HAVs capabilities
2	45 min	Open Group Discussion about Information Needs and Information Conveyance to Exit the Vehicle
3	75 min	Individual Interactive Prototype Sessions (15 min per Participant and Prototype)
4	45 min	Open Group Discussion about the Prototype Interaction

After collecting their unbiased ideas, we moved to the third phase: the interactive prototype sessions. Here, we presented the three initial prototypes to each participant individually in a counterbalanced order. This approach ensured that the participants' initial ideas remained independent of our prototypes, thus avoiding bias in their creativity. During each individual interactive prototype session, we prompted the participants with an initial story to envision themselves in an HAV, traveling alone to a friend's house for the first time, simulating their unfamiliarity with the area. While interacting with the prototypes, we asked the participants to perform the Thinking-Aloud method [50]. Hence, we asked participants to explain their thoughts about each part of the prototype, describing what they thought it represented and what aspects of the information conveyance they liked or found difficult, including their reasons. Given that the prototypes were set up in three separate rooms, we arranged for three participants to interact with the prototypes simultaneously while the remaining two participants waited. Each prototype was operated by one of the moderators. During the sessions, we briefly explained the prototype's interaction strategies and let the participants interact with the prototype while thinking aloud.

After the prototype sessions, we gathered the participants again in a group discussion to ask them about their positive and negative experiences with the prototypes and their interaction strategies (phase four). By first collecting individual impressions during the prototype sessions, we ensured that the feedback remained honest and unbiased from the other participants, facilitating diverse viewpoints from the group. The participants were compensated with 30 Euros for their time during the three-hour workshop.

4.2 Analysis

Four authors conducted a reflexive, inductive thematic analysis, following the approach of Braun and Clarke [13, 14]. We analyzed audio and video recordings from the workshop, focusing on both group discussions and think-aloud sessions of the prototypes. The codes generated from this analysis were organized on a digital whiteboard, sorted by feedback for each prototype and the group discussions. We then grouped these codes into thematic clusters before moving to the third phase of thematic analysis: searching for themes. This was done in a group meeting among the authors. In cases of disagreement, we engaged in discussions to resolve any discrepancies. In total, we generated 396 codes from the interactive workshop, which were clustered into 8 subclusters and three main themes.

4.3 Results and Implications

Our findings are divided into three main sections based on the identified themes: (1) current situations to exit a vehicle, (2) the

information needs of participants when exiting HAVs, and (3) methods for effectively conveying this information. The first section mainly derives from the open group discussion about information needs. The second section derives from the individual interactive prototype sessions and the subsequent group discussion (see Table 1). However, before we dive into these two key areas, we first provide an overview of the participants' current experiences when exiting a vehicle.

To correlate participants' visual acuity with our findings, we used blue highlighting with different levels of transparency. The transparency level reflects each participant's visual acuity: participants with lower visual acuity, like P3 and P4 (0%), had more transparent highlighting, while those with higher visual acuity, like P2 (1%), P5 (3%), and P1 (5%), had darker, less transparent highlighting. For more detailed demographic information, please refer to Appendix B.

4.3.1 Current Situation to Exit a Vehicle. All participants consistently mentioned their reliance on the assistance of others, such as taxi drivers, when exiting the vehicle. For example, P2 shared, "*I rely on the taxi driver to guide me until I am familiar with my surroundings again*". P4 agreed, adding that she also asks if it is safe to open the car door before exiting. During the exit, she holds the cane with her right hand while using her left hand for support. The participants generally relied on more assistance to exit the vehicle in an unfamiliar environment, as mentioned by P1. Further, P5 emphasized the value of communicating his visual impairment in an unfamiliar vehicle. He explained that sharing information about his condition enhances his perceived safety and ensures that others are mindful of his needs. Likewise, both P5 and P3 mentioned that being in the company of acquaintances increases their perceived safety, as these people are already familiar with their needs. Many of the insights align with Brewer and Ellison [15] whose participants stated that "*they asked drivers to drop them off at convenient locations that made it easier to find doors*" [15, p. 3].

Recognizing the current need for assistance in exiting the vehicle to gain situation awareness of the environment is essential. The potential increasing independence of BVIPs with the introduction of HAVs [52] highlights the need for interfaces that support BVIPs in exiting future HAVs. By exploring and understanding the specific information needs when exiting HAVs, we can contribute to the design of future HAVs that promote not only accessibility but also independence and perceived safety.

4.3.2 Information Needs When Exiting HAVs. P5 summarized that when exiting a potential HAV "*it is important to find out immediately what [obstacle] it is, and then I can decide whether it is relevant for me*". Echoing this statement, P1 and P3 acknowledged that while technology can aid them in gaining situation awareness, they still feel responsible for their actions and strive to maintain their sense

of control, as already suggested by Brewer and Kameswaran [16]. However, they highlighted the critical need for direct communication in potentially dangerous situations, such as cyclists passing in front of the HAV before exiting. Once their situation awareness needs are met, participants noted no further information requirements after leaving the vehicle. P1 clarified, "*As soon as I leave the car, that's my concern, but I know which way I'm going.*" Reflecting a similar sentiment, P4 and P2 mentioned their preferred reliance on traditional mobility aids, such as canes or guide dogs, immediately after exiting the HAV. Diving into the concrete information needs, we categorized the participants' needs into five categories: (1) static obstacles, (2) dynamic obstacles, (3) the condition of the ground, (4) information needs about the final destination, and (5) the spatial orientation.

Static Obstacles. Our workshop participants mentioned multiple static objects they would need to be informed about when exiting HAVs, such as trees in front of the pedestrian path, road signs, garbage cans on the road, road bollards, or parking vehicles. Further, for P3 and P1, the information about a safe pedestrian path is crucial. Opinions on the need for information about the distances to these obstacles were mixed. P1, who has relatively high visual acuity among the group, expressed that he could independently estimate these distances and did not require explicit information. Conversely, P5, despite having similar visual acuity, preferred to have distances explicitly communicated, aligning with the other participants' preferences.

Dynamic Obstacles. All participants agreed that information about dynamic obstacles, such as cyclists passing in front of the vehicle, is crucial. P1 specifically noted, "*Very fast cyclists are frightening; they don't take any care of me*". P3 added that knowing the direction of these dynamic obstacles is essential. She would also appreciate information about when an obstacle has passed. Further, P4 emphasized the importance of receiving updates about dynamic obstacles just before exiting the vehicle, as this timing is most critical for her situation awareness.

Terrain Perturbations. In addition to static and dynamic obstacles, participants highlighted the importance of understanding the ground conditions around the vehicle. In particular, they noted that awareness of potentially dangerous surfaces, such as slippery ice or wet grass, is critical given the increased risk of injury from such conditions. However, P5 mentioned that while this information might be important for people with total blindness, he would not require this kind of information.

Information Needs About the Final Destination. All participants expressed the need for detailed information about their final walking destination. P3 specified the importance of knowing the approximate distance and direction to the final destination. P1 expanded on this, highlighting its particular significance in unfamiliar environments. He stressed that understanding which side of the vehicle to exit from and the route to the final destination are his highest priorities among all information needs.

Spatial Orientation. All participants emphasized acquiring spatial orientation before exiting the vehicle to improve their situation awareness. In this context, P3 pointed out that "*if you become blind later in life, your spatial perception differs from someone who has been blind since birth*". This aligns with the deficiency model by

Von Senden [83] arguing that visual experience is critical for accurate spatial orientation. Accordingly, the lack of visual experience slows down and reduces the accuracy of situation awareness for BVIPs, leading to less spatial orientation compared to sighted individuals [83]. More recent studies however indicate that BVIPs are able to gain the same spatial orientation as sighted people when enough information is provided [58, 59]. Thus, to increase the amount of information to gain spatial orientation, P4, P3, and P5 all agreed on the importance of using the ego vehicle as a reference point to contextualize other objects in the environment. Additionally, P3 suggested that information should be organized in a structured manner (e.g., arranged in a circle) to support her spatial orientation.

4.3.3 Information Conveyance. The insights on how to convey the information needs discussed previously were mainly derived from individual and group feedback on the initial low-fidelity prototypes (see Figure 2).

Active and Passive Interaction. In general, participants preferred receiving crucial information passively rather than seeking it out actively, as with the smartphone prototype. For instance, P5 noted his discomfort with actively scanning the surroundings. He also pointed out that relying solely on auditory feedback would be insufficient in scenarios where other passengers are talking within the HAV, thus expressing a preference for the tactile bars prototype in this situation.

Feedback on the auditory and tactile modalities varied among participants. P5 found the tactile bars prototype helpful for gaining a broad initial overview of the environment, though he noted it was insufficient for detailed information. He explained, "*I often drive with noisy children. Tactile output would let me [actively] sort out important details like necessary precautions by myself,*" supporting the findings of Di Campli San Vito et al. [24] that tactile feedback is less distracting and bothersome than other interfaces. P2 and P3 suggested integrating voice output similar to the window touch and smartphone prototype to enhance the tactile bars prototype. This suggestion echoes the ISANA system from Li et al. [57] to enhance BVIPs' navigation tasks. Nevertheless, there was a consensus among all participants that critical information, such as cyclists should primarily be conveyed passively through voice. Additionally, P4 preferred that voice output be as concise as possible. This requirement underscores the importance of delivering clear and succinct information to avoid overwhelming the passengers with excessive details. Further, many found the smartphone prototype cumbersome and inconvenient. For example, P4 mentioned, "*I found that a bit stupid with the smartphone; I don't have enough hands for it when I get out of the car.*" Most participants (4 of 5) shared this sentiment, indicating discomfort with not having their hands free.

Completeness of Information. All participants emphasized the importance of being informed when all relevant information were conveyed to them. This requirement was well met by the tactile prototype, as P2 and P3 could physically sense when they had explored all available information with their hands. However, the smartphone prototype presented some challenges; for example, P2 criticized the absence of a physical boundary or frame to guide the smartphone's movement. Similarly, P3 expressed difficulties in effectively scanning the environment, remarking, "*I have to scan the*

environment, but I'm imperfect." These issues were also reflected in using the window touch prototype, where P4 was uncertain about whether she had touched all relevant objects on the window. To overcome these challenges, P5 suggested implementing a standardized output of information to ensure passengers are consistently aware when all relevant data has been communicated.

Variations in Different Visual Acuities Participants' responses to the initial prototypes varied significantly based on their visual acuity. P1, who retains 5% visual acuity, expressed discomfort with being overwhelmed by excessive information. In contrast, P2 (1% acuity) advocated for providing more information rather than less, allowing passengers the autonomy to determine which details are relevant to their needs. Furthermore, she proposed that the amount of information should be adjustable by the participants themselves, allowing for a customized experience based on individual needs and preferences.

5 PATHFINDER

Based on the insights of the interactive workshop, we developed PATHFINDER, a multimodal interface that considers the individual needs of BVIPs and assists them in exiting HAVs (see Figure 3). This section will describe the design rationale and features of PATHFINDER.

5.1 General Design

In general, our participants preferred combining tactile feedback with auditory cues. Consequently, tactile feedback should provide a broad overview of the surrounding environment, serving as a foundational layer of information, while verbal feedback adds detailed information. Additionally, PATHFINDER employs a clean and simple interface design to prevent users from becoming overwhelmed and used high contrasts in color (black and white) to enhance visibility for those with residual vision, as suggested in prior work exploring accessible technology for BVIPs [40, 48, 61]. As described below, PATHFINDER consists of four main components positioned on an oval-shaped plate (30x24cm): the *initial audio announcement*, the *compass needle*, the *five obstacle buttons*, and the *vehicle button*. All electronic components of PATHFINDER were controlled by an Arduino Mega microcontroller [8] and powered by an external power source. The following subsection gives a brief overview of the construction of each component. In addition, to reproduce PATHFINDER, we have provided all the construction files, including blueprints, 3D files, and laser-cut files, in a git repository (see section: Open Science).

5.2 Initial Audio Announcement

To clearly distinguish between the HAV stopping at a traffic light [61] and the destination, we created an initial audio announcement that indicates that the HAV has parked at the destination. This announcement also provides directions and distances for the passengers to reach their final destination (e.g., a coffee shop) and informs them if pedestrians or cyclists are expected to pass by. A detailed description of the audio announcements can be found in Appendix A. This verbal audio is played automatically once the HAV stops. According to the participant's feedback, this audio announcement is as concise as possible.

5.3 Five Obstacle Buttons

To represent the vehicle's surroundings, we divided the area into five sectors corresponding to the direction of exit. These sectors are represented by five buttons that can extend following the initial audio announcement. If a static obstacle is detected in a particular sector, the corresponding button extends; otherwise, it remains retracted. For blind participants, this difference in height can be sensed by touch. For those with residual vision, the extended buttons also blink to attract attention, as Holloway et al. [46] recommended to "*use blinking pins to direct attention to important areas [...]*"[46, p. 12]. This approach was also supported by Ivanchev et al. [49], who discovered that blinking interactive elements were beneficial for navigation tasks among BVIPs.

Based on participants' feedback, we enhanced the tactile feedback system by adding audio announcements. We made all five buttons pressable, regardless of whether they were extended or retracted. Due to the resistance in our design, pressing a button does not cause it to move; instead, it maintains its current state. A short press provides concise information, while a long press delivers detailed information, including distances to the respective obstacles. This dual approach was implemented to meet the participants' ambiguity in the need for comprehensive but concise information. It also ensures that participants, including those with no remaining vision, have access to detailed information.

Our participants preferred a structured and organized approach that ensured they received all relevant information, giving them confidence that nothing was missed. This aligns with the findings of Brewer and Kameswaran [16], whose participants emphasized the importance of an interface that provides feedback in a clear and organized manner. Thus, by pressing each button, they can gain a complete understanding of the vehicle's surroundings. Additionally, embedding audio announcements for sector-specific obstacles into the button allows participants to actively seek out information rather than passively receive it, as already highlighted by Arditi and Tian [7]. Nevertheless, crucial information, such as passing dynamic obstacles (e.g., cyclists or pedestrians), is automatically announced as they approach the HAV, as mentioned in our workshop.

The mechanism enabling the buttons to be extendable was achieved using a camshaft system powered by a servo motor for each button, which raises the button. At the tip of each button, a white LED was embedded beneath a frosted acrylic glass plate, providing the flashing.

5.4 The Compass Needle

The compass needle provides directional guidance toward the final destination both during the ride and once the HAV has stopped. This concept was inspired by feedback from participants in a workshop conducted by Brewer and Kameswaran [16] and was further validated by our participants, who emphasized the importance of knowing the direction of the final destination and the side of the vehicle to exit.

We constructed the compass needle using a stepper motor that moves a timing belt and a metal sled. The 3D-printed compass needle is mounted on this sled, allowing it to traverse an oval-shaped rail covering approximately 180°. If the final destination is
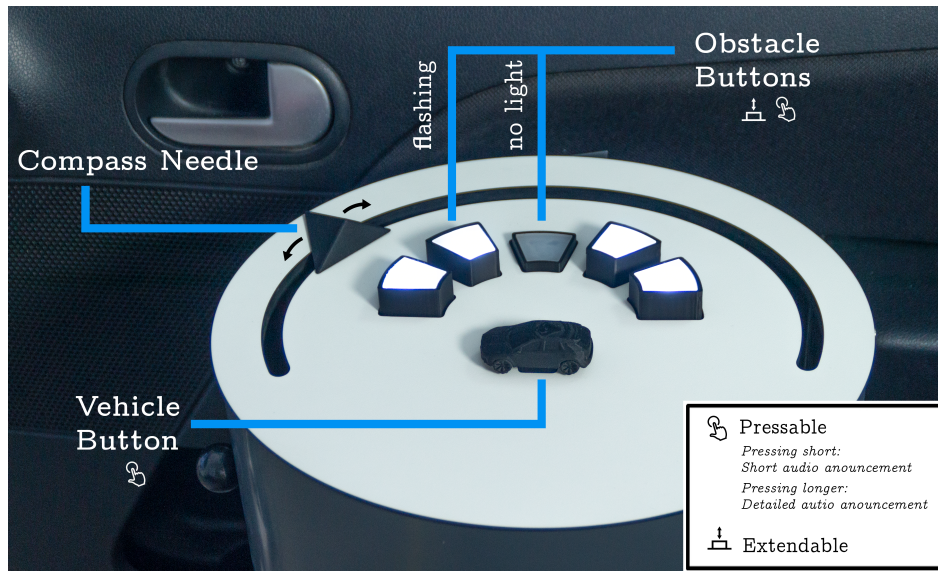
Figure 3: Interface design of PathFinder, featuring a compass needle, five obstacle buttons, and a vehicle button. Each obstacle button can extend to indicate an obstacle in the corresponding section, and pressing it triggers additional details via audio announcements. The extended buttons also flash to enhance visibility. The compass needle moves along a rail to continuously point toward the final destination.

to the vehicle's left during the ride, the needle will point as far left as possible within its limited range of motion.

5.5 Vehicle Button

Meinhardt et al. [61] noted that participants required a reference point, such as the ego vehicle, to contextualize all other information and gain spatial orientation. Hence, we constructed a button shaped like a vehicle as a reference point to the five obstacle buttons and the compass needle. Further, by pressing this button, the initial audio announcement (see subsection 5.2) could be repeated to ensure participants could actively seek the information [7]. Like the obstacle buttons, a detailed announcement would be played if pressed longer, including information about the terrain perturbations.

6 User Study

To investigate the capabilities of PathFinder in assisting BVIPs to exit HAVs, we conducted a user study with N=16 BVIPs. We compared this multimodal interface with an auditory baseline inspired by the ATLAS system from Brinkley et al. [18], chosen because the auditory output is currently the predominant modality used in interfaces for BVIPs [20]. The auditory cues provided comprehensive environmental information equivalent to that offered by PathFinder, ensuring a fair comparison by delivering all detailed information upon the vehicle's arrival at its intended destination. The detailed description of the audio announcement of PathFinder and the auditory baseline, including their durations, can be found in Appendix A.

To enhance the generalizability of our study, we assessed both the auditory baseline and PathFinder systems in two distinct scenarios: a complex urban environment and a simpler rural one. Based

on findings by Meinhardt et al. [61], which indicate that visual acuity affects how BVIPs engage with a system, we included visual acuity as a factor in our analysis. This led to a three-factor design in our study: *System* (auditory/PathFinder) and *Scenario* (urban/rural) were the within-subject factors, while visual acuity was the between-subject factor.

The participants of the user study partly overlapped with the participants of the prior interactive workshop, as all workshop participants also took part in the user study (indicated in Appendix B). Their average age was $M = 59.06$, $SD = 15.00$ (nine female, seven male and no non-binary). Their visual accuracy varied from total blindness (0%) to 14% with $M = 4.88$, $SD = 4.67$. Detailed information about the visual impairment of each participant can be found in Appendix B.

6.1 Study Setup

Aiming for high realism in our study, we utilized three 55" monitors positioned side by side to simulate the surroundings of the HAV, as illustrated in Figure 1. For participants with residual vision, this setup provided a 180° view of the right side of the HAV's surroundings. The scenarios were created using Unity [82] version 2020.3.15f2, incorporating various Unity assets (e.g., [3, 5, 67]).

Both scenarios featured simulated pedestrians and cyclists passing by the vehicle, with different complexities reflecting typical environmental variations. Hence, dynamic obstacles were more frequent in the urban scenario, averaging four pedestrians and two cyclists per minute. In contrast, the rural scenario averaged two pedestrians and one cyclist per minute. Additionally, obstacles in the urban scenario were distributed across four sections, while the rural scenario had them in two sections. The atmospheric audio also differed: the urban scenario featured bustling city sounds, including

passing vehicles and people talking, while the rural scenario had a quieter ambiance with forest sounds, such as birds singing. The vehicle's surroundings for the urban and rural scenarios can be seen in Figure 4. Further, the corresponding audio announcements for each obstacle button can be found in Appendix A.

We reused the car door and seat used in the workshop (see subsection 3.2) and positioned this setup in front of the center monitor. We ensured alignment with the virtual car window in the simulation from the passenger's point of view. Further, we mounted PATHFINDER between the car seat and the window, speculating a plausible position for this kind of future interface. The study setup also included a camera facing the participant and a microphone to record qualitative feedback.

6.2 Procedure

For each participant, we described the study setup in the room and sought the participants' consent to record the session. We ensured they comprehended all aspects and encouraged them to ask questions. We then read the consent form aloud, adhering to the research institute's ethical guidelines, highlighting their right to withdraw from the study at any time. The procedure also guaranteed privacy protection, anonymity, fair compensation, and risk aversion. Acknowledging the unique needs of our participants, we went beyond standard ethical practices by offering personalized support, such as assistance with transportation, to maintaining high ethical standards in accessibility research.

After obtaining their consent, the BVIPs were seated next to the car door and asked to imagine themselves as passengers in an HAV traveling to their desired destination without any need for intervention (SAE level 4 to 5) [75]. Before starting the four main conditions (i.e., urban and rural scenario, auditory baseline, and PATHFINDER), participants were introduced to the study procedure through an introductory suburban scenario, where the vehicle drove for 10 seconds before reaching its destination. During this scene, we explained the functionalities of PATHFINDER and the auditory cues while asking them to understand the surroundings of the surroundings. Participants were encouraged to repeat this introductory scenario as often as necessary to explore the interfaces until they felt comfortable with their features. While most participants completed the introductory scenario once, four participants requested to repeat it a second time. This introductory scenario was entirely different from the main scenarios to prevent any overlap of information and bias towards the main scenarios.

The four main conditions were then presented in a counterbalanced order. Each scenario included a 30-second ride before the HAV reached its destination, after which participants were told they had as much time as they needed to explore the vehicle's surroundings as best as they could using either PATHFINDER or the auditory-only baseline. For the auditory condition, PATHFINDER was covered with a wooden lid to prevent interaction with the system. Participants were also allowed to repeat the audio announcements as often as they wished. The simulation concluded once participants indicated they had obtained sufficient information to exit the vehicle. Notably, participants did not physically open the car door during the simulation.

For the urban scenario, participants were informed that the HAV would take them to a coffee shop in an unfamiliar area. In the rural scenario, they were told that the HAV would transport them to a friend's house, also in an unfamiliar area. After completing the four conditions, we collected demographic information, including age, gender, and visual acuity. We then engaged in a qualitative conversation asking the participants to compare both interfaces in relation to the insights from the workshop (see subsubsection 4.3.2 and subsubsection 4.3.3). Specifically, we asked about the clarity in conveying dynamic and static obstacles, the conveyance of terrain perturbations, the information provided about the final destination, the spatial orientation, and the overall completeness of information necessary for a comprehensive understanding of the HAV's surroundings.

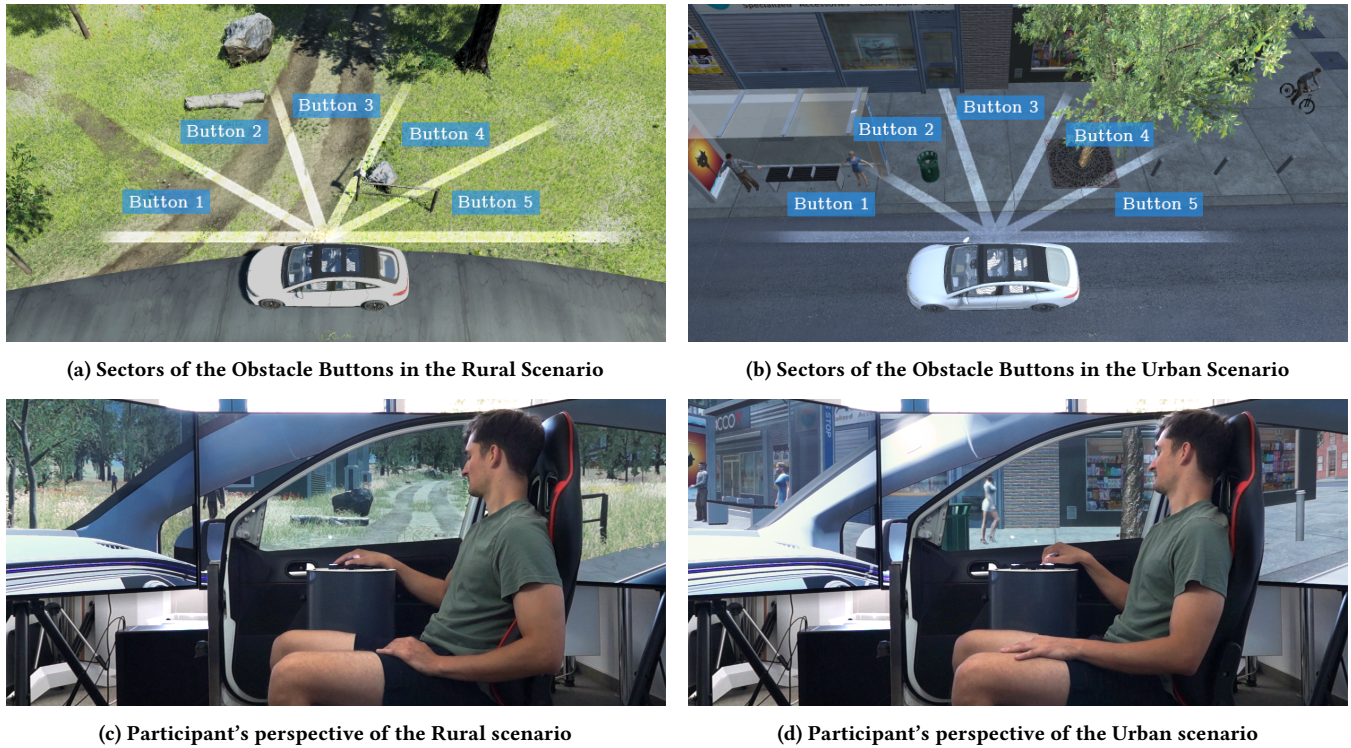The participants were compensated for the 1.5h session with 18 Euros.

6.3 Measurements

After each condition, participants were asked to rate both PATHFINDER and the auditory baseline as experienced within the respective scenario. We utilized the System Usability Scale (SUS) [51] to assess usability. Additionally, we measured the participants' mental demand using the NASA-TLX scale [44]. To assess perceived situation awareness [26, 27], we employed the Situation Awareness Rating Technique (SART) [79]. We also evaluated the participants' perceived safety through a set of four 7-point semantic differential scales, ranging from -3 (anxious/agitated/unsafe/timid) to +3 (relaxed/calm/safe/confident) [29].

Finally, we used the Immersion subscale of the Technology Usage Inventory (TUI) [53] to ensure that participants were sufficiently immersed during the study. This measurement helps us determine if the study's findings are comparable to those in a potential real-world scenario. All questionnaires were read aloud to ensure they were accessible to all participants.

6.4 Results

During our user study, we collected qualitative and quantitative results, which will be reported in the following two sections. After all conditions of the user study, participants rated their perceived immersion via the TUI [53] during the simulation as medium-high $M = 17.06$, $SD = 6.16$ (minimum: 4, maximum: 28), indicating a reasonable approximation to potential real-world scenarios. On average, the time between the HAV stopping at the destination and participants indicating that they had sufficient information to exit the vehicle was 1 min 46 sec (SD = 59 sec) for PATHFINDER and 1 min 57 sec (SD = 55 sec) for the auditory baseline. Refer to Appendix C for detailed descriptive data.

6.4.1 Quantitative Data. To ensure our quantitative data met the assumptions necessary for statistical analysis, we first used the Shapiro-Wilk test [77] to check for normality. For data that followed a normal distribution, we performed a repeated measures ANOVA. When the data did not meet the normality assumption, we applied the aligned rank transformation (ART) method, which is suited for non-parametric factorial analysis of repeated measures [85]. The WHO categorizes visually impaired individuals into two groups: *legally blind* and *visually impaired*, with visual acuity of 5% or

(a) Sectors of the Obstacle Buttons in the Rural Scenario

(b) Sectors of the Obstacle Buttons in the Urban Scenario

(c) Participant's perspective of the Rural scenario


(d) Participant's perspective of the Urban scenario

Figure 4: Sectors for the five Obstacle Buttons of PATHFINDER for the Urban and Rural Scenario and the Participants' Perspective of the Study Setup. See Appendix A for the concrete audio announcements

less classified as *legally blind* [39]. Following this approach, we categorized participants into these two groups due to the limited data range available for participants' visual acuity. In our analysis, the system and scenario were treated as within-subject factors, while BVIPs' visual acuity was treated as the between-subject factor. This categorization resulted in ten participants being classified as *legally blind*, while the other six participants were categorized as *visually impaired*. We conducted our analyses using R software version 4.4.1.

Mental Demand. The ART found a large significant main effect on mental demand [44] for *System* (F(1) = 11.03, p = 0.005; η^2 = 0.44, 95% CI [0.11, 1.00]). Hence, PATHFINDER (M = 7.75, SD = 5.16) yielded a significantly lower mental demand than the auditory Baseline (M = 11.09, SD = 5.63). Refer to Figure 5a for the plotting. Further, the ART found a trend towards significance, suggesting an interaction between *Scenario* and *Visual Acuity* (p=0.063). While not significant, the interaction's η^2 = 0.23 effect size is defined as large [22].

Usability. The ART did not identify any significant main or interaction effects on Usability [51]. The usability ratings for PATHFINDER (M = 64.84, SD = 16.30) were similar to those for the Auditory Baseline (M = 62.42, SD = 14.07).

Situation Awareness. An ANOVA did not find significant differences in situation awareness [79]. Yet, the rated situation awareness
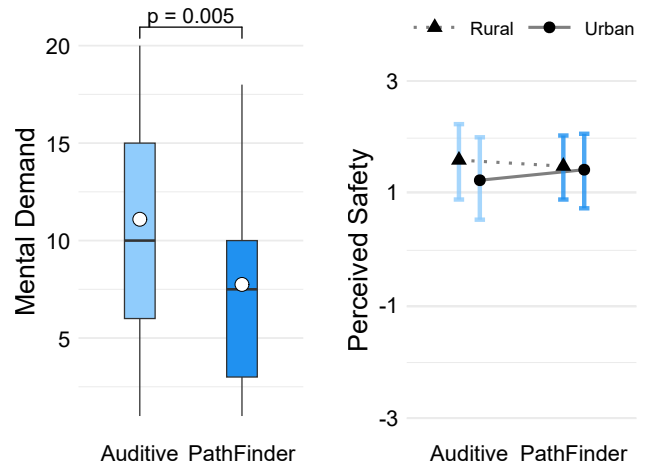
(a) Significant main effect on mental demand [44] for *System*

(b) Significant interaction effect on perceived safety [29]

Figure 5: Significant effects of the quantitative data for mental demand and perceived safety

for both PATHFINDER (M = 19.09, SD = 5.51) and the auditory baseline (M = 17.91, SD = 6.25) was rated medium to high on a scale from -20 to 40.

Perceived Safety. The ART found a large significant interaction effect between *System* and *Scenario* (F(1) = 6.47, p = 0.023; η^2 = 0.32, 95% CI [0.03, 1.00]). Hence, Perceived Safety ratings for PATHFINDER were consistent across the Urban (*M* = 1.44, *SD* = 1.86) and Rural scenarios (*M* = 1.50, *SD* = 2.00). In contrast, the ratings for the auditory baseline showed a divergence between the urban (*M* = 1.25, *SD* = 1.25) and rural (*M* = 1.61, *SD* = 2.13) scenario. No main effects were found for either *System*, *Scenario*, or *Visual Acuity*. Refer to Figure 5b for the plotting.

6.4.2   Qualitative Feedback. After completing all four conditions, we conducted brief interviews with participants, focusing on their experiences with both interfaces in relation to the findings from the previous workshop (see subsubsection 4.3.2 and subsubsection 4.3.3). Unlike the workshop, we did not perform a thematic analysis of this feedback. Instead, we present anecdotal feedback and participants' opinions, organized by the specific questions asked during the interviews. Therefore, the clusters presented below are based directly on the specific questions (see subsection 6.2) asked during the interviews rather than being the result of a formal thematic analysis.

Spatial Orientation. The feedback on spatial orientation varied across participants, but the majority of participants were satisfied with the conveyed information of PATHFINDER with regards to the spatial orientation. P1 found the PATHFINDER particularly compelling, stating, "*I was impressed because I could get an overview by pressing different symbols*". This opinion was echoed by P5, who also preferred the multimodal interface, noting that it allowed her to "*create a mental map*", whereas listening to the auditory feedback led to higher mental demand. However, P3 expressed some confusion, stating that "*using 'left' and 'right' instead of 'in the direction of travel' was disorienting*". P15 indicated that he was able to achieve sufficient spatial orientation through the auditory baseline, whereas the tactile components of PATHFINDER proved particularly distracting, necessitating concentration on the individual elements, which in turn impeded his ability to listen to the audio announcements carefully.

Navigation to the Final Destination Four participants stated that the information how to navigate to the final destination was very similar between both interfaces. Particularly, P8 mentioned that "*the information was the same but the method was different*". P2 appreciated the tactile compass needle of PATHFINDER to navigate to the final destination, stating, "*The triangle [compass needle] in the multimodal interface was better for me. I knew where I was and where I needed to go*". Conversely, P15 stated that the compass needle was not needed as the initial audio announcement was already sufficient to navigate to the final destination. However, P5 found the navigation through touch more intuitive than listening to the auditory baseline. But she appreciated the combination of both interfaces, saying, "*Both should be combined, but I prefer touch for navigation*".

Terrain Perturbations. Most participants felt that the information about the terrain perturbations was clear and sufficient across both interfaces. For instance, P4 mentioned that "*it was clear whether the ground was paved or not*". However, P15 criticized that with PATHFINDER, he had to search for terrain information, whereas the auditory baseline provided it automatically. Further, P11 noted

that some information was excessive, such as the grass on the sidewalk.

Dynamic and Static Obstacles. Participants generally agreed that the identification of dynamic and static objects was essential but differed in their preferred modality of receiving this information. P1 preferred PATHFINDER for recalling details of the static obstacles. P2 and P3 emphasized the importance of combining both interfaces, with P2 suggesting, "*A pin that rises when a pedestrian is present would be helpful*." This suggestion is particularly notable, as the workshop's findings indicated that dynamic obstacle information was preferred to be conveyed verbally for quicker understanding.

P8 and P10 highlighted the challenge of predicting the presence of dynamic objects like pedestrians or cyclists. They noted the absence of information indicating when these obstacles had passed, which would signal that it is safe to exit the HAV. However, P16 appreciated that both interfaces announced the presence of these obstacles, stating that knowing they are nearby is more important to her than precisely when they pass by the vehicle. P7 also voiced concern about the lack of continuous updates on dynamic objects, expressing a desire for a system that "*always informs me when the situation changes*."

Completeness of Information. Overall, participants felt that both systems provided comprehensive information, though seven participants, including P6, P8, and P9, mentioned that the auditory information was overwhelming, with P9 specifically stating, "*It says too much, and I have to concentrate hard*". P7 criticized that both interfaces only covered the area immediately around the HAV, leaving users without further guidance once they moved beyond a few meters. However, this concern contrasts with insights from the prior workshop, where participants preferred using traditional mobility aids, such as canes or guide dogs, after their immediate situation awareness needs were satisfied (see subsubsection 4.3.2).

7   Discussion

This research was driven by the need for BVIPs to gain assistance when exiting HAVs in unfamiliar environments [15]. In an interactive workshop (N=5), we found that BVIPs currently rely on acquaintances to gain situation awareness of the vehicle's surroundings. However, with the introduction of HAVs, BVIPs may gain more independence [52], but they likely face situations alone without human assistance. To investigate the information needs of BVIPs when exiting HAVs, we presented three low-fidelity prototypes to the participants. Feedback from the workshop indicated a preference for a multimodal approach to convey information about the environment in an organized and structured manner. Based on this feedback, we developed PATHFINDER, which integrates visual, tactile, and auditory cues to assist BVIPs. Using the Participatory Design approach [65], we involved BVIPs from the outset, ensuring that PATHFINDER's final design met the diverse needs of users with varying degrees of visual impairment. This approach aligns with the recommendations of Bradley and Dunlop [12] and Albouys-Perrois et al. [4], who emphasized the importance of designing audio and tactile cues based on specific user needs and preferences for navigational tools for BVIPs. We subsequently conducted a three-factorial within-between-subject user study (N=16), simulating an HAV ride. Our study assessed PATHFINDER against an auditory-only baseline

in both complex urban and simpler rural scenarios. PATHFINDER yielded a significantly lower mental demand than the auditory baseline and maintained high perceived safety in both scenarios, while the auditory baseline led to lower perceived safety in urban scenarios compared to rural ones.

7.1 Multimodal Approaches to Convey Environmental Information

Our findings indicate that the multimodal PATHFINDER interface is effective in conveying information about the HAV's surroundings, enabling participants to create "mental maps" and gain situation awareness. This finding is important because developing accurate cognitive maps of the transportation environment is essential for BVIP independence and mobility [34, 35, 71] and aligns with broader evidence supporting the effectiveness of multimodal interfaces; for instance, Papadopoulos et al. [72] highlighted that audio-tactile maps enhance BVIP's spatial orientation, especially in unfamiliar environments. Further, the reduced mental demand found for PATHFINDER supports the *multiple-resource theory* [84], which posits that cross-modal distribution of information reduces competition for cognitive resources, thereby reducing mental demand. This aligns with participants' statements, appreciating the combination of the modalities, especially the auditory and tactile ones. The broad implications of our multimodal approach to improving mental mapping and reducing mental demands can be realized in efforts to increase independent mobility for BVIP passengers. Just as our workshop participants reported that they often rely on drivers or acquaintances to help them understand the environment and exit safely, it stands to reason that interfaces like PATHFINDER can help improve safety and independent travel for BVIPs in future HAV.

Interestingly, while our qualitative results clearly prefer PATHFINDER over the auditory baseline concerning spatial orientation, the quantitative analysis revealed no significant differences in situation awareness between the two systems. This discrepancy may arise from participants' challenges in accurately self-reporting their situation awareness, as suggested by Endsley et al. [28], or because both systems convey the same information, resulting in similar situation awareness ratings. The latter aligns with the fact that both systems received medium to high ratings for situation awareness, suggesting that they are generally effective in this regard. These findings, however, diverge from those of Meinhardt et al. [61] and Md. Yusof et al. [60], who reported low ratings for situation awareness with their tactile interfaces. Yet, it is important to note that their studies focused on conveying traffic information during the HAV ride, whereas our study centered on the HAV's surroundings when exiting the vehicle. This difference in the journey's parts is interesting, as understanding the HAV's surroundings when exiting into an unfamiliar area is likely more critical for BVIPs than being immediately aware of the traffic situation during the ride. While situation awareness during the journey is also important [35, 61], it becomes essential when navigating a new environment after exiting the vehicle. This difference in context might explain the variation in situation awareness ratings across different studies.

7.2 Inconsistency in Diverse Scenario's Complexities

Our study revealed a significant interaction effect between the scenarios and the two systems on perceived safety (see Figure 5b). While we expected that the more complex urban scenario would lead to differing ratings, PATHFINDER consistently maintained high perceived safety across both urban and rural settings. In contrast, the auditory baseline showed divergence, with lower perceived safety in the urban scenario compared to the rural one. This indicates that while the auditory baseline may meet BVIPs' safety needs in simpler environments, it becomes less reliable in more complex settings. These findings underscore the limitations of single-modality approaches [35, 89] and suggest that multimodal systems like PATHFINDER offer greater robustness across varying levels of environmental complexity. Therefore, these results support the recommendations of Kuriakose et al. [54], who highlight that multimodal cues enable BVIPs to adjust their information intake according to situation demands. This robustness is essential for ensuring safety in demanding scenarios where situation awareness is critical. However, it is important to recognize that our study was limited to only two scenarios. While these scenarios were designed to reflect typical environments BVIPs might encounter, they do not capture the full range of possible conditions that could affect information conveyance. For instance, extreme weather conditions such as heavy rain, snow, or fog could introduce new challenges that neither the multimodal nor the auditory-only system might handle effectively. Further, we used simple scenarios, implying that after the initial obstacles, the path to the final destination is straight. While this might not reflect real-world scenarios, we based this decision on the participants' statement that after exiting the vehicle, they would rely on traditional mobility aids such as canes or guide dogs (see subsection 4.3.2). This decision reflects the interface's primary purpose: providing essential initial information conveyance before users switch to their customary navigation methods. However, in scenarios with no obstacles, the auditory-only system might suffice and even be preferred due to its simplicity.

7.3 One System to Rule the Entire Journey

This research contributes to the growing body of work on exploring accessible interfaces for each part of a journey using HAVs, such as finding the vehicle [37] or conveying information during the ride [35, 60, 61]. We extend this work by focusing specifically on the crucial exiting phase. Previous studies [31, 40] have highlighted BVIP frustration with using multiple apps and systems for different navigation tasks. To address this problem, Giudice and Legge [40] suggested that integrating systems could enhance effectiveness across different scenarios.

Therefore, it seems desirable to combine the PATHFINDER system with other tactile or multimodal systems (e.g., [35, 61]) to ensure comprehensive accessibility throughout the entire journey. However, integrating multiple functionalities into a single system requires careful consideration of the form factor to maintain ease of use. For example, simplifying PATHFINDER by removing the compass needle—-considered unnecessary by participants--can help reduce its size. Additionally, leveraging existing devices like smartphones [31, 36] and tablets [18] can extend the system's capabilities

without increasing its size. For instance, smartphones could provide additional vibrotactile feedback on the HAV's location on a map [36]. Our workshop findings indicate that BVIPs prefer systems that deliver essential information upfront, allowing them to keep their hands free for tasks such as using canes or guide dogs. Therefore, expanding PathFinder with the tactile elements on OnBoard [61], like the rotating vehicle representation and the reason-for-stopping button, could enhance the user's understanding of the ongoing traffic during the ride.

7.4 Practical Implications and Future Work

While the quantitative data from our user study shows significant effects on mental demand and perceived safety, there are no significant differences between PathFinder and the auditory-only baseline regarding usability and situation awareness. This suggests that an auditory-only solution may be sufficient for enhancing the exiting phase for BVIPs, potentially reducing the cost and complexity of adding tactile modality to the system. However, qualitative feedback from participants highlights that for optimal effectiveness, information should be conveyed through all available modalities. For example, PathFinder communicated dynamic obstacles only via audio. Yet, to enhance redundancy across modalities, these obstacles could also be conveyed using a tactile approach, such as bars that rise to indicate the presence of cyclists or pedestrians. This would further improve the system's robustness, providing that critical information is reliably understood by all potential passengers, regardless of their sensory preferences or extent, etiology, or onset of visual impairment. Furthermore, the significantly reduced mental demand observed with PathFinder, along with its consistently high perceived safety in complex and simple scenarios, highlights its potential as a valuable add-on feature for vehicle manufacturers committed to accessibility. Additionally, future research should look into a more seamless integration of the tactile elements of PathFinder into vehicles, such as using textile buttons and sliders integrated directly into the vehicle's fabrics [68, 76] or the armrest close to the door handle. The other modalities of PathFinder could also provide more detailed information, such as whether a dynamic obstacle is moving fast or slow, via audio or blinking the obstacle buttons in different colors to distinguish between different types of obstacles for those with residual vision.

Finally, conducting real-world testing in actual vehicle environments would be essential to validate the system's effectiveness outside of controlled settings, ensuring that PathFinder meets the practical needs of BVIPs in everyday use.

7.5 Limitations

Our interactive workshop included only five BVIPs. While small sample sizes can still provide valuable insights [80], there is a potential for response bias [64]. Thus, it is important to recognize that the views expressed by these participants may not fully represent the broader target group. Additionally, the design of PathFinder was partly influenced by the subjective opinions of these five participants. While related work informed the development of both the auditory interface and PathFinder, these interfaces should be considered with caution. Another limitation is the lack of external

validity in our study, as participants did not physically exit an actual vehicle, which may affect the applicability of our findings to real-world scenarios. The actual process of exiting can introduce additional challenges, such as maintaining orientation, managing personal belongings or guide dogs, and navigating immediate hazards outside the vehicle. Additionally, testing the interfaces in a controlled environment rather than a real vehicle may have reduced the perceived risk and mental demand associated with exiting in real traffic conditions. These factors might have influenced participants' feedback and limit the generalizability of our results. Despite this, our study setup achieved a high level of perceived immersion, suggesting that the simulated experimental conditions were well-designed and effective.

Additionally, due to the specialized nature of our target group, the user study was conducted with a relatively small sample size of N=16 for quantitative analysis. This sample size may limit the findings' applicability to a wider population. Moreover, fewer participants increase the risk of Type II errors, where true effects may not reach statistical significance. Therefore, it is important not only to consider statistical significance but also to examine the effect sizes. For example, although not statistically significant, the interaction between the *Scenario* and *Visual Acuity* on mental demand showed a large effect size. This suggests that there could be meaningful differences that warrant further investigation. Further, it is worth noting that while we attempted to provide a more nuanced perspective based on visual impairment (by highlighting qualitative responses with acuity information from Appendix C) than the typical approach of collapsing BVIPs into a single group [30], a larger sample size would have also enabled comparisons for the quantitative data. Additionally, whether participants were congenitally blind or acquired their impairment later in life could influence their specific information needs and should be explored in future studies.

It is also crucial to account for potential novelty effects [81] in our user study as the participants experience both interfaces for the first time. Hence, we anticipate that, as users become familiar with the interfaces over time [62], these novelty effects may diminish. Specifically, the auditory baseline featured longer audio announcements compared to PathFinder, which could have biased participants towards preferring PathFinder. However, the similar time required for participants to gather sufficient information to exit the vehicle (see Appendix C) suggests that the length of the auditory announcements did not impact the overall task performance.

Additionally, we were unable to counterbalance the between-factor of visual acuity, meaning that participants with similar visual acuity levels might have experienced the same order of conditions. This lack of counterbalancing could introduce slight learning effects, where participants become more accustomed to the tasks, potentially influencing the study's results.

8 Conclusion

This paper introduces PathFinder, a multimodal interface designed to assist BVIPs in safely exiting HAVs by providing information about the vehicle's surroundings. PathFinder integrates visual,

tactile, and auditory cues, making it accessible to users regardless of their visual impairment.

We conducted an interactive workshop with N=5 visually impaired participants to identify their information needs for safely exiting a vehicle. The workshop revealed that BVIPs currently rely heavily on acquaintances for assistance. However, as HAVs offer greater mobility independence, BVIPs may increasingly face these situations without human assistance. During the workshop, we presented three low-fidelity prototypes (a smartphone, a window touch prototype, and tactile bars), each employing different modalities and interaction strategies to assist with vehicle exit. Participants expressed a strong preference for a multimodal interface, favoring tactile cues as a foundation, supplemented by auditory cues for critical information, such as the presence of dynamic obstacles like cyclists. Based on these insights, we developed PathFinder, a multimodal interface tailored to the unique needs of BVIPs. The system includes a compass needle that points to the final destination, five extendable, flashing obstacle buttons that represent different sections of the vehicle's surroundings and provide audio announcements for additional information, and a vehicle button that serves as a reference point.

In a subsequent three-factorial, within-between-subject user study (N=16), we evaluated PathFinder against an auditory-only baseline in both complex urban and simpler rural scenarios. The results showed that PathFinder significantly reduced mental demand compared to the baseline and consistently maintained high perceived safety in both scenarios. In contrast, the auditory baseline resulted in lower perceived safety in the urban scenario compared to the rural one. Further, the qualitative feedback indicated a clear preference for multimodal information conveyance to enhance spatial orientation and situation awareness. However, to increase robustness and ensure that critical information is reliably understood by all passengers, regardless of their sensory preferences or visual impairments, it is recommended that all information be conveyed across all modalities.

Open Science

The source code and construction files, including blueprints, 3D-printing files, and laser-cutting files for both the three initial low-fidelity prototypes and PathFinder have been made publicly available. These resources can be accessed at the following link: https://anonymous.4open.science/r/light_my_way-2CC3/.

Acknowledgments

References

[1] Carl Halladay Abraham, Bert Boadi-Kusi, Enyam Komla Amewuho Morny, and Prince Agyekum. 2022. Smartphone usage among people living with severe visual impairment and blindness. *Assistive Technology* 34, 5 (Sept. 2022), 611–618. doi:10.1080/10400435.2021.1907485

[2] Peter Ackland, Serge Resnikoff, and Rupert Bourne. 2017. World blindness and visual impairment: despite many successes, the problem is growing. *Community eye health* 30, 100 (2017), 71. http://www.ncbi.nlm.nih.gov/pmc/articles/pmc5820628/

[3] AGLOBEX. 2023. *Urban Traffic System*. AGLOBEX. https://assetstore.unity.com/packages/templates/systems/urban-traffic-system-89133

[4] Jérémy Albouys-Perrois, Jérémy Laviole, Carine Briant, and Anke M. Brock. 2018. Towards a Multisensory Augmented Reality Map for Blind and Low Vision People: a Participatory Design Approach. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*. ACM, Montreal QC Canada, 1–14. doi:10.1145/3173574.3174203

[5] ALP. 2024. *Nature Package - Forest Environment*. ALP. https://assetstore.unity.com/packages/3d/vegetation/nature-package-forest-environment-165645

[6] Amir Amedi, Lotfi B. Merabet, Felix Bermpohl, and Alvaro Pascual-Leone. 2005. The Occipital Cortex in the Blind: Lessons About Plasticity and Vision. *Current Directions in Psychological Science* 14, 6 (Dec. 2005), 306–311. doi:10.1111/j.0963-7214.2005.00387.x

[7] Aries Arditi and YingLi Tian. 2013. User interface preferences in the design of a camera-based navigation and wayfinding aid. *Journal of Visual Impairment & Blindness* 107, 2 (2013), 118–129. doi:10.1177/0145482X1310700205

[8] Arduino. 2019. *Arduino*. https://www.arduino.cc/

[9] Be My Eyes. 2024. *Be My Eyes - See the world together*. Retrieved Mar 15, 2024 from https://www.bemyeyes.com/

[10] Roger Bennett, Rohini Vijaygopal, and Rita Kottasz. 2020. Willingness of people who are blind to accept autonomous vehicles: An empirical investigation. *Transportation Research Part F: Traffic Psychology and Behaviour* 69 (2020), 13–27. doi:10.1016/j.trf.2019.12.012

[11] Rupert R. A. Bourne, Jaimie Adelson, Seth Flaxman, Paul Briant, Michele Bottone, Theo Vos, Kovin Naidoo, Tasanee Braithwaite, Maria Cicinelli, Jost Jonas, Hans Limburg, Serge Resnikoff, Alex Silvester, Vinay Nangia, and Hugh R. Taylor. 2020. Global Prevalence of Blindness and Distance and Near Vision Impairment in 2020: progress towards the Vision 2020 targets and what the future holds. *Investigative Ophthalmology & Visual Science* 61, 7 (2020), 2317. doi:10.1016/S2214-109X(20)30425-3

[12] Nicholas A. Bradley and Mark D. Dunlop. 2005. An Experimental Investigation into Wayfinding Directions for Visually Impaired People. *Personal and Ubiquitous Computing* 9, 6 (Nov. 2005), 395–403. doi:10.1007/s00779-005-0350-y

[13] Virginia Braun and Victoria Clarke. 2006. Using thematic analysis in psychology. *Qualitative Research in Psychology* 3, 2 (2006), 77–101. doi:10.1191/1478088706qp063oa

[14] Virginia Braun and Victoria Clarke. 2021. One size fits all? What counts as quality practice in (reflexive) thematic analysis? *Qualitative Research in Psychology* 18, 3 (2021), 328–352. doi:10.1080/14780887.2020.1769238

[15] Robin Brewer and Nicole Ellison. 2020. *Supporting people with vision impairments in automated vehicles: Challenge and opportunities*. Technical Report. University of Michigan, Ann Arbor, Transportation Research Institute. https://rosap.ntl.bts.gov/view/dot/56391

[16] Robin N. Brewer and Vaishnav Kameswaran. 2018. Understanding the Power of Control in Autonomous Vehicles for People with Vision Impairment. In *Proceedings of the 20th International ACM SIGACCESS Conference on Computers and Accessibility* (Galway, Ireland) *(ASSETS '18)*. Association for Computing Machinery, New York, NY, USA, 185–197. doi:10.1145/3234695.3236347

[17] Julian Brinkley, Earl W. Huff, Briana Posadas, Julia Woodward, Shaundra B. Daily, and Juan E. Gilbert. 2020. Exploring the Needs, Preferences, and Concerns of Persons with Visual Impairments Regarding Autonomous Vehicles. *ACM Transactions on Accessible Computing* 13, 1 (2020), 1–34. doi:10.1145/3372280

[18] Julian Brinkley, Brianna Posadas, Imani Sherman, Shaundra B. Daily, and Juan E. Gilbert. 2019. An Open Road Evaluation of a Self-Driving Vehicle Human–Machine Interface Designed for Visually Impaired Users. *International Journal of Human–Computer Interaction* 35, 11 (2019), 1018–1032. doi:10.1080/10447318.2018.1561787

[19] Julian Brinkley, Brianna Posadas, Julia Woodward, and Juan E. Gilbert. 2017. Opinions and Preferences of Blind and Low Vision Consumers Regarding Self-Driving Vehicles. In *Proceedings of the 19th International ACM SIGACCESS Conference on Computers and Accessibility*, Amy Hurst, Leah Findlater, and Meredith Ringel Morris (Eds.). ACM, New York, NY, USA, 290–299. doi:10.1145/3132525.3132532

[20] Piyush Chanana, Rohan Paul, M. Balakrishnan, and Pvm Rao. 2017. Assistive technology solutions for aiding travel of pedestrians with visual impairment. *Journal of rehabilitation and assistive technologies engineering* 4 (2017), 2055668317725993. doi:10.1177/2055668317725993

[21] Francesco Chiossi, Steven Villa, Melanie Hauser, Robin Welsch, and Lewis Chuang. 2022. Design of On-body Tactile Displays to Enhance Situation Awareness in Automated Vehicles. In *2022 IEEE 9th International Conference on Computational Intelligence and Virtual Environments for Measurement Systems and Applications (CIVEMSA)*. IEEE, New York, NY, USA, 1–6. doi:10.1109/CIVEMSA53371.2022.9853690

[22] Jacob Cohen. 1988. *Statistical Power Analysis for the Behavioral Sciences* (0 ed.). Routledge. doi:10.4324/9780203771587

[23] Mark Colley, Benjamin Eder, Jan Ole Rixen, and Enrico Rukzio. 2021. Effects of Semantic Segmentation Visualization on Trust, Situation Awareness, and Cognitive Load in Highly Automated Vehicles. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*, Yoshifumi Kitamura, Aaron Quigley, Katherine Isbister, Takeo Igarashi, Pernille Bjørn, and Steven Drucker (Eds.). ACM, New York, NY, USA, 1–11. doi:10.1145/3411764.3445351

[24] Patrizia Di Campli San Vito, Gözel Shakeri, Stephen Brewster, Frank Pollick, Edward Brown, Lee Skrypchuk, and Alexandros Mouzakitis. 2019. Haptic Navigation Cues on the Steering Wheel. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*, Stephen Brewster, Geraldine Fitzpatrick, Anna Cox, and Vassilis Kostakos (Eds.). ACM, New York, NY, USA, 1–11. doi:10.1145/3290605.3300440

[25] Julie Ducasse, Anke M. Brock, and Christophe Jouffrais. 2018. Accessible Interactive Maps for Visually Impaired Users. In *Mobility of Visually Impaired People*, Edwige Pissaloux and Ramiro Velazquez (Eds.). Springer International Publishing, Cham, 537–584. doi:10.1007/978-3-319-54446-5_17

[26] Mica R. Endsley. 1995. Toward a Theory of Situation Awareness in Dynamic Systems. *Human Factors: The Journal of the Human Factors and Ergonomics Society* 37, 1 (1995). https://doi.org/10.1518/001872095779049543.

[27] Mica R Endsley, Stephen J Selcon, Thomas D Hardiman, and Darryl G Croft. 1998. A comparative analysis of SAGAT and SART for evaluations of situation awareness. In *Proceedings of the human factors and ergonomics society annual meeting*, Vol. 42. SAGE Publications Sage CA: Los Angeles, CA, SAGE Publications, Los Angeles, CA, USA, 82–86.

[28] Mica R. Endsley, Stephen J. Selcon, Thomas D. Hardiman, and Darryl G. Croft. 1998. A Comparative Analysis of Sagat and Sart for Evaluations of Situation Awareness. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* 42, 1 (1998), 82–86. doi:10.1177/154193129804200119

[29] Stefanie M. Faas, Andrea C. Kao, and Martin Baumann. 2020. A Longitudinal Video Study on Communicating Status and Intent for Self-Driving Vehicle – Pedestrian Interaction. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA). Association for Computing Machinery, New York, NY, USA, 1–14. doi:10.1145/3313831.3376484

[30] Paul D.S. Fink, Maher Alsamsam, Justin R. Brown, Henry D. Kindler, and Nicholas A. Giudice. 2023. Give us something to chauffeur it: Exploring user needs in traditional and fully autonomous ridesharing for people who are blind or visually impaired. *Transportation Research Part F: Traffic Psychology and Behaviour* 98 (2023), 91–103. doi:10.1016/j.trf.2023.09.004

[31] Paul D.S. Fink, Stacy A. Doore, Xue (Shelley) Lin, Matthew Maring, Pu Zhao, Aubree Nygaard, Grant Beals, Richard R. Corey, Raymond J. Perry, Katherine Freund, Velin Dimitrov, and Nicholas A. Giudice. 2023. The Autonomous Vehicle Assistant (AVA): Emerging Technology Design Supporting Blind and Visually Impaired Travelers in Autonomous Transportation. *International Journal of Human-Computer Studies* (2023). doi:10.1016/j.ijhcs.2023.103125

[32] Paul D. S. Fink. 2023. *Accessible Autonomy: Exploring Inclusive Autonomous Vehicle Design and Interaction for People Who Are Blind and Visually Impaired.* Ph. D. Dissertation. University of Maine. https://digitalcommons.library.umaine.edu/etd/3817

[33] Paul D. S. Fink, Anas Abou Allaban, Omoruyi E. Atekha, Raymond J. Perry, Emily S. Sumner, Richard R. Corey, Velin Dimitrov, and Nicholas A. Giudice. 2023. Expanded Situational Awareness Without Vision. In *Proceedings of the 2023 ACM/IEEE International Conference on Human-Robot Interaction*, Ginevra Castellano, Laurel Riek, Maya Cakmak, and Iolanda Leite (Eds.). ACM, New York, NY, USA, 54–62. doi:10.1145/3568162.3576975

[34] Paul D. S. Fink, Anas Abou Allaban, Omoruyi E. Atekha, Raymond J. Perry, Emily S. Sumner, Richard R. Corey, Velin Dimitrov, and Nicholas A. Giudice. 2023. Expanded Situational Awareness Without Vision: A Novel Haptic Interface for Use in Fully Autonomous Vehicles. In *Proceedings of the 2023 ACM/IEEE International Conference on Human-Robot Interaction*. ACM, Stockholm Sweden, 54–62. doi:10.1145/3568162.3576975

[35] Paul D. S. Fink, Velin Dimitrov, Hiroshi Yasuda, Tiffany L. Chen, Richard R. Corey, Nicholas A. Giudice, and Emily S. Sumner. 2023. Autonomous is Not Enough: Designing Multisensory Mid-Air Gestures for Vehicle Interactions Among People with Visual Impairments. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems* (Hamburg, Germany) (CHI '23). Association for Computing Machinery, New York, NY, USA, Article 74, 13 pages. doi:10.1145/3544548.3580762

[36] Paul D. S. Fink, H. Milne, A. Caccese, M. Alsamsam, J. Loranger, Mark Colley, and Nicholas A Giudice. 2024. Accessible Maps for the Future of Inclusive Ridesharing. In *16th International Conference on Automotive User Interfaces and Interactive Vehicular Applications* (AutomotiveUI '24). ACM, New York, NY, USA. doi:10.1145/3640792.3675736

[37] Paul D. S. Fink, Emily Sarah Sumner, and Velin Dimitrov. 2024. Multisensory gestural-audio interface to promote situational awareness for improved autonomous vehicle control. https://patents.google.com/patent/US20240217539A1/en

[38] Finward Studio. 2024. *Suburb Neighborhood House Pack (Modular)*. Finward Studio. https://assetstore.unity.com/packages/3d/environments/urban/suburb-neighborhood-house-pack-modular-72712

[39] WHO Programme for the Prevention of Blindness and Deafness. 2003. Consultation on development of standards for characterization of vision loss and visual functioning : Genveva, 4-5 September 2003. WHO/PBL/03.91 pages. https://apps.who.int/iris/handle/10665/68601

[40] Nicholas A Giudice and Gordon E Legge. 2008. Blind navigation and the role of technology. *The engineering handbook of smart technology for aging, disability, and independence* (2008), 479–500. doi:10.1002/9780470379424.ch25

[41] Christiane Glatz, Stas S. Krupenia, Heinrich H. Bülthoff, and Lewis L. Chuang. 2018. Use the Right Sound for the Right Job: Verbal Commands and Auditory Icons for a Task-Management System Favor Different Information Processes in the Brain. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (Montreal QC, Canada) (CHI '18). Association for Computing Machinery, New York, NY, USA, 1–13. doi:10.1145/3173574.3174046

[42] GTB - Italy. 2018. *Feel the View*. Retrieved Jul 19, 2024 from https://sites.wpp.com/wppedcream/2018/healthcare/consumer-digital/feel-the-view

[43] Anhong Guo, Saige McVea, Xu Wang, Patrick Clary, Ken Goldman, Yang Li, Yu Zhong, and Jeffrey P. Bigham. 2018. Investigating Cursor-based Interactions to Support Non-Visual Exploration in the Real World. In *Proceedings of the 20th International ACM SIGACCESS Conference on Computers and Accessibility*. ACM, Galway Ireland, 3–14. doi:10.1145/3234695.3236339

[44] Sandra G Hart and Lowell E Staveland. 1988. Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In *Advances in psychology*. Vol. 52. Elsevier, Amsterdam, The Netherlands, 139–183. doi:10.1016/S0166-4115(08)62386-9

[45] Kevin Anthony Hoff and Masooda Bashir. 2015. Trust in automation: integrating empirical evidence on factors that influence trust. *Human factors* 57, 3 (2015), 407–434. doi:10.1177/0018720814547570

[46] Leona Holloway, Swamy Ananthanarayan, Matthew Butler, Madhuka Thisuri De Silva, Kirsten Ellis, Cagatay Goncu, Kate Stephens, and Kim Marriott. 2022. Animations at Your Fingertips: Using a Refreshable Tactile Display to Convey Motion Graphics for People who are Blind or have Low Vision. In *Proceedings of the 24th International ACM SIGACCESS Conference on Computers and Accessibility*. ACM, Athens Greece, 1–16. doi:10.1145/3517428.3544797

[47] Leona Holloway, Kim Marriott, and Matthew Butler. 2018. Accessible Maps for the Blind: Comparing 3D Printed Models with Tactile Graphics. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*. ACM, Montreal QC Canada, 1–13. doi:10.1145/3173574.3173772

[48] Leona Holloway, Kim Marriott, Matthew Butler, and Samuel Reinders. 2019. 3D Printed Maps and Icons for Inclusion. In *The 21st International ACM SIGACCESS Conference on Computers and Accessibility*, Jeffrey P. Bigham, Shiri Azenkot, and Shaun K. Kane (Eds.). ACM, New York, NY, USA, 183–195. doi:10.1145/3308561.3353790

[49] Mihail Ivanchev, Francis Zinke, and Ulrike Lucke. 2014. Pre-journey Visualization of Travel Routes for the Blind on Refreshable Interactive Tactile Displays. In *Computers Helping People with Special Needs*, Klaus Miesenberger, Deborah Fels, Dominique Archambault, Petr Peňáz, and Wolfgang Zagler (Eds.). Vol. 8548. Springer International Publishing, Cham, 81–88. doi:10.1007/978-3-319-08599-9_13 Series Title: Lecture Notes in Computer Science.

[50] M Jaspers, T Steen, C Bos, and M Geenen. 2004. The think aloud method: a guide to user interface design. *International Journal of Medical Informatics* 73, 11-12 (Nov. 2004), 781–795. doi:10.1016/j.ijmedinf.2004.08.003

[51] Patrick W. Jordan, Ian Lyall McClelland, B. Thomas, and Bernard A. Weerdmeester (Eds.). 1996. *Usability evaluation in industry* (first edition ed.). CRC Press, an imprint of Taylor and Francis, Boca Raton, FL. https://permalink.obvsg.at/

[52] Celina Kacperski, Florian Kutzner, and Tobias Vogel. 2024. Comparing autonomous vehicle acceptance of German residents with and without visual impairments. *Disability and rehabilitation. Assistive technology* (2024), 1–11. doi:10.1080/17483107.2024.2317930

[53] Oswald Kothgassner, A Felnhofer, N Hauk, E Kastenhofer, J Gomm, and I Krysprin-Exner. 2013. Technology Usage Inventory. https://www.ffg.at/sites/default/files/allgemeine_downloads/thematische%20programme/programmdokumente/tui_manual.pdf. *Manual. Wien: ICARUS* 17, 04 (2013), 90. [Online; accessed: 05-JULY-2024].

[54] Bineeth Kuriakose, Raju Shrestha, and Frode Eika Sandnes. 2022. Tools and Technologies for Blind and Visually Impaired Navigation Support: A Review. *IETE Technical Review* 39, 1 (Jan. 2022), 3–18. doi:10.1080/02564602.2020.1819893

[55] Jaewook Lee, Jaylin Herskovitz, Yi-Hao Peng, and Anhong Guo. 2022. ImageExplorer: Multi-Layered Touch Exploration to Encourage Skepticism Towards Imperfect AI-Generated Image Captions. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems (CHI '22)*. Association for Computing Machinery, New York, NY, USA, Article 462, 15 pages. doi:10.1145/3491102.3501966

[56] So Yeon Lee, B Gurnani, and Fassil B Mesfin. 2024. *Blindness*. https://www.ncbi.nlm.nih.gov/books/NBK448182/ Updated 2024 Feb 27. In: StatPearls. Treasure Island (FL): StatPearls Publishing; 2024 Jan..

[57] Bing Li, Juan Pablo Munoz, Xuejian Rong, Qingtian Chen, Jizhong Xiao, Yingli Tian, Aries Arditi, and Mohammed Yousuf. 2019. Vision-Based Mobile Indoor Assistive Navigation Aid for Blind People. *IEEE Transactions on Mobile Computing*

18, 3 (March 2019), 702–714. doi:10.1109/TMC.2018.2842751

[58] Jack M. Loomis, Roberta L. Klatzky, and Nicholas A. Giudice. 2013. Representing 3D Space in Working Memory: Spatial Images from Vision, Hearing, Touch, and Language. In *Multisensory Imagery*, Simon Lacey and Rebecca Lawson (Eds.). Springer New York, New York, NY, 131–155. doi:10.1007/978-1-4614-5879-1_8

[59] Jack M. Loomis, Yvonne Lippa, Roberta L. Klatzky, and Reginald G. Golledge. 2002. Spatial updating of locations specified by 3-D sound and spatial language. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 28, 2 (March 2002), 335–345. doi:10.1037/0278-7393.28.2.335

[60] Nidzamuddin Md. Yusof, J. Karjanto, J. M. B. Terken, F. L. M. Delbressine, and G. W. M. Rauterberg. 2020. Gaining Situation Awareness through a Vibrotactile Display to Mitigate Motion Sickness in Fully-Automated Driving Cars. *International Journal of Automotive and Mechanical Engineering* 17, 1 (2020), 7771–7783. doi:10.15282/ijame.17.1.2020.23.0578

[61] Luca-Maxim Meinhardt, Maximilian Rück, Julian Zähnle, Maryam Elhaidary, Mark Colley, Michael Rietzler, and Enrico Rukzio. 2024. Hey, What's Going On? Conveying Traffic Information to People with Visual Impairments in Highly Automated Vehicles: Introducing OnBoard. *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol.* 8, 2, Article 67, 24 pages. doi:10.1145/3659618

[62] Valerie Mendoza and David G. Novick. 2005. Usability over time. In *Proceedings of the 23rd Annual International Conference on Design of Communication: Documenting & Designing for Pervasive Information* (Coventry, United Kingdom) (*SIGDOC '05*). Association for Computing Machinery, New York, NY, USA, 151–158. doi:10.1145/1085313.1085348

[63] Microsoft Seeing AI. 2017. *Seeing AI - Talking Camera for the Blind.* Microsoft Seeing AI. Retrieved Aug 19, 2024 from https://www.seeingai.com/

[64] Joy Ming, Sharon Heung, Shiri Azenkot, and Aditya Vashistha. 2021. Accept or Address? Researchers' Perspectives on Response Bias in Accessibility Research. In *Proceedings of the 23rd International ACM SIGACCESS Conference on Computers and Accessibility*. ACM, Virtual Event USA, 1–13. doi:10.1145/3441852.3471216

[65] Michael J. Muller and Sarah Kuhn. 1993. Participatory Design. *Commun. ACM* 36, 6 (jun 1993), 24–28. doi:10.1145/153571.255960

[66] Chihab Nadri, Sangjin Ko, Colin Diggs, Michael Winters, V. K. Sreehari, and Myounghoon Jeon. 2021. Novel Auditory Displays in Highly Automated Vehicles: Sonification Improves Driver Situation Awareness, Perceived Workload, and Overall Experience. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* 65, 1 (2021), 586–590. doi:10.1177/1071181321651071

[67] noirfx. 2028. *Modern City Pack.* noirfx. https://assetstore.unity.com/packages/3d/environments/urban/modern-city-pack-18005

[68] Oliver Nowak, René Schäfer, Anke Brocker, Philipp Wacker, and Jan Borchers. 2022. Shaping Textile Sliders: An Evaluation of Form Factors and Tick Marks for Textile Sliders. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems (CHI '22)*. Association for Computing Machinery, New York, NY, USA, Article 214, 14 pages. doi:10.1145/3491102.3517473

[69] World Health Organization. 2022. *Blindness and vision impairment.* WHO. Retrieved Jun 15, 2024 from https://www.who.int/news-room/fact-sheets/detail/blindness-and-visual-impairment

[70] Sharon Oviatt, Rachel Coulston, and Rebecca Lunsford. 2004. When do we interact multimodally?: cognitive load and multimodal communication patterns. In *Proceedings of the 6th international conference on Multimodal interfaces*. ACM, State College PA USA, 129–136. doi:10.1145/1027933.1027957

[71] Hari P. Palani, Paul D. S. Fink, and Nicholas A. Giudice. 2020. Design Guidelines for Schematizing and Rendering Haptically Perceivable Graphical Elements on Touchscreen Devices. *International Journal of Human–Computer Interaction* 36, 15 (Sept. 2020), 1393–1414. doi:10.1080/10447318.2020.1752464

[72] Konstantinos Papadopoulos, Eleni Koustriava, and Marialena Barouti. 2017. Cognitive maps of individuals with blindness for familiar and unfamiliar spaces: Construction through audio-tactile maps and walked experience. *Computers in Human Behavior* 75 (Oct. 2017), 376–384. doi:10.1016/j.chb.2017.04.057

[73] Bastian Pfleging, Shadan Sadeghian, and Debargha Dey. 2021. User interfaces for automated vehicles. *it - Information Technology* 63, 2 (2021), 73–75. doi:10.1515/itit-2021-0020

[74] Parivash Ranjbar, Pournami Krishnan Krishnakumari, Jonas Andersson, and Maria Klingegård. 2022. Vibrotactile guidance for trips with autonomous vehicles for persons with blindness, deafblindness, and deafness. *Transportation Research Interdisciplinary Perspectives* 15 (2022), 100630. doi:10.1016/j.trip.2022.100630

[75] SAE International. 2021. *SAE Levels of Driving Automation™ Refined for Clarity and International Audience.* SAE. Retrieved Jul 29, 2023 from https://www.sae.org/blog/sae-j3016-update

[76] René Schäfer, Oliver Nowak, Lovis Bero Suchmann, Sören Schröder, and Jan Borchers. 2023. What's That Shape? Investigating Eyes-Free Recognition of Textile Icons. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems (CHI '23)*. Association for Computing Machinery, New York, NY, USA, Article 580, 12 pages. doi:10.1145/3544548.3580920

[77] S. S. Shapiro and M. B. Wilk. 1965. An Analysis of Variance Test for Normality (Complete Samples). *Biometrika* 52, 3/4 (1965), 591–611. http://www.jstor.org/stable/2333709

[78] Kohei Sonoda and Takahiro Wada. 2017. Displaying System Situation Awareness Increases Driver Trust in Automated Driving. *IEEE Transactions on Intelligent Vehicles* 2, 3 (2017), 185–193. doi:10.1109/TIV.2017.2749178

[79] R.M. Taylor. 2017. Situational Awareness Rating Technique (Sart): The Development of a Tool for Aircrew Systems Design. In *Situational Awareness* (1 ed.), Eduardo Salas (Ed.). Routledge, 111–128. doi:10.4324/9781315087924-8

[80] Jean Toner. 2009. Small is not too small: Reflections concerning the validity of very small focus groups (VSFGs). *Qualitative Social Work* 8, 2 (2009), 179–192. doi:10.1177/1473325009103374

[81] Endel Tulving and Neal Kroll. 1995. Novelty assessment in the brain and long-term memory encoding. *Psychonomic Bulletin & Review* 2, 3 (1995), 387–390. doi:10.3758/BF03210977

[82] Unity Technologies. 2023. *Unity.* Unity Technologies. https://unity.com/

[83] Marius Von Senden. 1960. Space and sight: the perception of space and shape in the congenitally blind before and after operation. (1960).

[84] Christopher D. Wickens, Diane L. Sandry, and Michael Vidulich. 1983. Compatibility and Resource Competition between Modalities of Input, Central Processing, and Output. *Human Factors: The Journal of the Human Factors and Ergonomics Society* 25, 2 (April 1983), 227–248. doi:10.1177/001872088302500209

[85] Jacob O. Wobbrock, Leah Findlater, Darren Gergle, and James J. Higgins. 2011. The aligned rank transform for nonparametric factorial analyses using only anova procedures. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, Vancouver BC Canada, 143–146. doi:10.1145/1978942.1978963

[86] Jacob O. Wobbrock and Julie A. Kientz. 2016. Research Contributions in Human-Computer Interaction. *Interactions* 23, 3 (apr 2016), 38–44. doi:10.1145/2907069

[87] Marcel Woide, Mark Colley, Nicole Damm, and Martin Baumann. 2022. Effect of System Capability Verification on Conflict, Trust, and Behavior in Automated Vehicles. In *Proceedings of the 14th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*, Yong Gu Ji and Myounghoon Jeon (Eds.). ACM, New York, NY, USA, 119–130. doi:10.1145/3543174.3545253

[88] Jiawei Yang, Xinyue Yu, Mengge Wang, Zhenhao Chen, and Hao Tan. 2022. Novel Tactile Feedback Research for Situation Awareness in Autonomous Vehicles. In *With Design: Reinventing Design Modes*, Gerhard Bruyns and Huaxin Wei (Eds.). Springer Nature Singapore, Singapore, 2874–2887. doi:10.1007/978-981-19-4472-7_186

[89] Koji Yatani, Nikola Banovic, and Khai Truong. 2012. SpaceSense: Representing Geographical Information to Visually Impaired People Using Spatial Tactile Feedback. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, Joseph A. Konstan, Ed H. Chi, and Kristina Höök (Eds.). ACM, New York, NY, USA, 415–424. doi:10.1145/2207676.2207734

[90] Fang You, Xu Yan, Jun Zhang, and Wei Cui. 2022. Design Factors of Shared Situation Awareness Interface in Human–Machine Co-Driving. *Information* 13, 9 (2022), 437. doi:10.3390/info13090437

[91] Limin Zeng, Mei Miao, and Gerhard Weber. 2015. Interactive Audio-haptic Map Explorer on a Tactile Display. *Interacting with Computers* 27, 4 (2015), 413–429. doi:10.1093/iwc/iwu006

[92] Yu Zhong, Pierre J. Garrigues, and Jeffrey P. Bigham. 2013. Real time object scanning using a mobile phone and cloud-based visual search engine. In *Proceedings of the 15th International ACM SIGACCESS Conference on Computers and Accessibility*. ACM, Bellevue Washington, 1–8. doi:10.1145/2513383.2513443

A Audio Announcements of PathFinder and the Auditory Baseline

Due to the participant's mother tongue, the audio announcements were in German. For this appendix, we translated the audio announcements via Deepl.com.

A.1 Urban Scene

A.1.1 PathFinder. **Upon Reaching the Destination,** the following audio announcement was played automatically:
"We have reached the end of the journey. The destination, Café Good Times, can be reached via the pavement next to the road. The entrance to the café is 70 meters away on the right-hand side."
Duration: 0:14 min

Vehicle Button Short. "The destination, Café Good Times, can be reached via the pavement next to the road. The entrance to the café is 70 meters away on the right."

Vehicle Button Detailed. "The destination, Café Good Times, can be reached via the pavement next to the road. The entrance to the

café is 70 meters away on the right. The curb is one meter away from the vehicle. The pavement is 3 meters wide, paved, and level. There are many pedestrians and cyclists in front of the vehicle."

Obstacle Buttons

- **Button 1: Raised**
  - *Short*. "Bus stop."
  - *Detailed*. "Bus stop on the pavement five meters away."
- **Button 2: Raised**
  - *Short*. "Rubbish bin."
  - *Detailed*. "Rubbish bin on the pavement three meters away."
- **Button 3**
  - *Short*. "The pavement is clear."
  - *Detailed*. "The pavement is clear. The curb is one meter away."
- **Button 4: Raised**
  - *Short*. "Tree."
  - *Detailed*. "Tree on the pavement three meters away. No danger from low-hanging branches."
- **Button 5: Raised**
  - *Short*. "Three bollards."
  - *Detailed*. "Three bollards in a row on the pavement three meters away."

A.1.2 Auditory Baseline. **Upon Reaching the Destination,** the following audio announcement was played automatically:
"We have reached the end of the journey. The destination, Café Good Times, can be reached via the pavement next to the road. The entrance to the café is 70 meters away on the right-hand side. The curb is one meter away from the vehicle. The pavement is three meters wide, paved, and level. There are many pedestrians and cyclists in front of the vehicle. There is a bus stop five meters to the left of the vehicle. A rubbish bin is three meters away from the bus stop. The pavement in front of the car door does not have obstacles. A tree is on the pavement three meters away to the right behind the vehicle. No danger from low-hanging branches. To the right of the tree, there are 3 bollards in a row on the pavement at a distance of 3 meters." **Duration:** 0:57 min

A.2 Rural Scene

A.2.1 PathFinder. **Upon Reaching the Destination,** the following audio announcement was played automatically:
"We have reached the end of the journey. The destination, Carmen's House, can be reached via the dirt track right next to the road. The entrance is 15 meters straight ahead on the left-hand side."
Duration: 0:13 min

Vehicle Button Short. "The destination, Carmen's House, can be reached via the field path directly next to the road. The entrance is 15 meters straight ahead on the left-hand side."

Vehicle Button Detailed. "The destination, Carmen's House, can be reached via the field path directly next to the road. The entrance is 15 meters straight ahead on the left-hand side. The edge of the road is one meter from the vehicle. The field path is 2 meters wide, and the surface is unpaved and uneven. There are pedestrians and cyclists in front of the vehicle."

Obstacle Buttons

- **Button 1: Raised**
  - *Short*. "Trees"

  - *Detailed*. "Several trees next to the road on the grass five meters away."
- **Button 2**
  - *Short*. "The area is clear."
  - *Detailed*. "The area is clear. A footpath crosses the field path three meters away."
- **Button 3**
  - *Short*. "The field path is clear."
  - *Detailed*. "The field path is clear and consists of two channels. A branch and a stone lie on the grass next to the field path at a distance of seven meters."
- **Button 4: Raised**
  - *Short*. "A fence and a stone behind it."
  - *Detailed*. "There is a fence on the grass next to the road two meters away. Behind it is a large stone three meters away."
- **Button 5**
  - *Short*. "The area is clear."
  - *Detailed*. "The area is clear. The ground is a meadow."

A.2.2 Auditory Baseline. **Upon Reaching the Destination,** the following audio announcement was played automatically:
"We have reached the end of the journey. The destination, Carmen's House, can be reached via the dirt track right next to the road. The entrance is 15 meters straight ahead on the left-hand side. The edge of the road is one meter away from the vehicle. The dirt track is 2 meters wide and the surface is unpaved and uneven. There are pedestrians and cyclists in front of the vehicle. There are several trees five meters to the left in front of the vehicle. Behind the trees is a path that crosses the dirt track 3 meters from the vehicle. The country lane begins straight ahead. The track is clear and consists of two channels. A branch and a stone lie on the grass next to the field path at a distance of seven meters. To the right behind the vehicle is a fence next to the road on the grass two meters away. Behind it is a large stone three meters away."
Duration: 1:01 min

B   Participants' Demographic Data

The alpha level of blue highlighting of the participant IDs indicates their visual acuity in the tables below.

Table 2: Table of participants' demographic data for the interactive workshop

ID	Age	Gender	Visual Acuity	Impairment
P1	61	M	5%	total blindness on the left eye, right eye blurry vision
P2	44	F	1.5%	only contours visible
P3	52	F	0%	total blindness
P4	67	F	0%	total blindness
P5	65	M	3.5%	blurry vision

Table 3: Table of participants' demographic data from the user study and their overlapping participation with the workshop

ID	Age	Gender	Visual Acuity	Impairment	Workshop Part.
P1	67	F	0%	total blindness	×
P2	53	F	0%	total blindness	×
P3	60	M	10%	vision becomes gray when in distance	
P4	72	F	0%	total blindness	
P5	45	F	1.5%	only contours visible	×
P6	62	M	5%	total blindness on the left eye, right eye blurry vision	×
P7	65	M	3%	blurry vision, black spots in the fovea	
P8	29	M	14%	tunnel vision	
P9	53	F	2%	red. vision in the left eye, only close objects are visible	
P10	68	F	10%	blind spots in the fovea	
P11	23	F	6%	blind spots in the fovea	
P12	71	M	0%	total blindness	
P13	62	M	10%	blurry vision	
P14	76	F	3.5%	colors visible but blurry	×
P15	77	M	12%	total blindness in fovea but limited vision in periphery	
P16	62	F	1%	perception of brightness/darkness	

C Descriptive Data of the User Study

Table 4: Table of the descriptive data of the user study

Variable	System	Scenario	n	Min	Max	Mean	Median	SD
Mental Demand [44]	PATHFINDER	Urban	16	1.00	18.00	7.56	7.50	5.15
	PATHFINDER	Rural	16	2.00	15.00	7.94	7.50	5.34
	Auditory	Urban	16	4.00	20.00	11.25	10.00	5.08
	Auditory	Rural	16	1.00	20.00	10.94	10.00	6.29
Usability (SUS) [51]	PATHFINDER	Urban	16	20.00	80.00	64.36	67.50	16.42
	PATHFINDER	Rural	16	20.00	87.50	65.31	67.50	16.71
	Auditory	Urban	16	32.50	80.00	62.34	62.50	13.21
	Auditory	Rural	16	27.50	80.00	62.50	65.00	15.33
Situation Awareness (SART) [79]	PATHFINDER	Urban	16	15.00	29.00	19.69	17.00	4.76
	PATHFINDER	Rural	16	7.00	35.00	18.50	18.00	6.27
	Auditory	Urban	16	10.00	30.00	19.06	19.00	5.30
	Auditory	Rural	16	3.00	28.00	16.75	18.00	7.06
Perceived Safety [29]	PATHFINDER	Urban	16	-1.75	3.00	1.44	1.86	1.42
	PATHFINDER	Rural	16	-0.50	3.00	1.50	2.00	1.21
	Auditory	Urban	16	-1.50	3.00	1.25	1.25	1.47
	Auditory	Rural	16	-1.50	3.00	1.61	2.13	1.50
Completion Time (in min:sec)	PATHFINDER	Urban	16	0:50	4:57	1:52	1:29	1:06
	PATHFINDER	Rural	16	0:35	4:37	1:41	1:32	0:51
	Auditory	Urban	16	1:02	3:55	1:56	1:59	0:45
	Auditory	Rural	16	1:03	4:09	1:57	1:18	1:03