Transforming Transportation in the Pursuit of Barrier Free Mobility: The State-of-the-Art in Autonomous Vehicle Interaction Technologies for People with Disabilities

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Abstract

Fully autonomous or “self-driving” vehicles have been described as a significant and transformative mobility technology. The most advanced Autonomous Vehicles (AVs) may potentially eliminate deadly vehicle crashes thus reducing the associated loss of life and property. For people with disabilities, who may be unable to operate conventional motor vehicles, AVs may enhance personal mobility and independence. Despite the potential benefits of this technology, however, only recently have issues of accessibility been considered. Absent this emphasis, the potential of the self-driving vehicle as a democratizing mobility technology may go unrealized. This literature review is a synthesis of research that examines the design of vehicular automation technologies broadly, surveys the current state-of-the-art as it relates to evolving autonomous vehicle Human-Machine Interfaces and interaction, and discusses implications for AV accessibility.

Introduction

There is a significant and growing body of research related to Autonomous Vehicles (AVs) and automated driving systems. AVs have been described as a transformative technology with the potential to solve many driving-related problems. By minimizing the role of often error-prone and potentially impaired humans (e.g., intoxication, fatigue, etc.) from the manual manipulation of vehicle controls, it is anticipated that AVs may potentially save lives (Petrović et al., 2020), reduce property damage and loss (Marinik et al., 2014), and make for generally safer personal mobility (Douma & Palodichuk, 2012; Sparrow & Howard, 2017; Wiseman, 2022). It is argued that most of these potential benefits will not be realized until the most advanced of these systems, capable of full autonomy or "self-driving" (Lajunen & Sullman, 2021; Wang et al., 2021), become broadly commercially available. Despite the significant potential benefits of this technology, only relatively recently has the potential implications for people with disabilities (PWD) been explored. For people unable or unwilling to operate a conventional motor vehicle, AVs may potentially address a host of issues related to limited personal mobility. This reality may be significantly impactful for PWD given that many deal with economic, health and wellness, social, and employment challenges that are often related to the inability to drive (Bell & Mino, 2015; Harrabi et al., 2014). The inability to drive may limit a person's ability to pursue educational opportunities, for instance, thus limiting employment prospects and ultimately income. The inability to drive may also affect health and wellbeing by creating a transportation barrier that limits the ability of the PWD to travel to medical appointments for preventative care or treatment. AVs may potentially provide an ideal means of personal transportation that will enable people with a variety of disabilities to minimize the described drawbacks borne of the inability to drive by enabling travel with greater independence, autonomy, and privacy (Claypool et al., 2017). Despite the potential benefits for PWD there are growing concerns that many emerging automated driving systems are being designed without a significant emphasis on accessibility (Brinkley, Posadas, et al., 2017; Brinkley, Huff, Posadas, et al., 2020; Claypool et al., 2017; Gluck, Boateng, et al., 2020; Huff et al., 2019). It has been argued that much of this emerging technology is being designed around the *driver* of the present, who in all cases is physically and cognitively capable of manipulating a vehicle's manual controls, as opposed to the *operator* of the future who need not have this ability (Brinkley, Posadas, et al., 2017; Brinkley, Huff, Posadas, et al., 2020).

The problem of AV accessibility described within the present work is largely one that is focused on the most advanced level or highest capability automated driving systems currently imagined. The Society of Automotive Engineers (SAE) has defined six levels of automation for AVs (SAE International, n.d.). For the first three levels (Level 0 to Level 2), humans are drivers, and the automation features are mostly related to warnings and situational assistance (e.g., lane centering, adaptive cruise controls). Level 3 vehicles are capable of operating autonomously under prescribed conditions. In level 4 vehicles, when the automation features are activated, drivers are not required to manipulate the vehicle's manual controls but must monitor system operation and be prepared to take control if the vehicle encounters a situation beyond its capabilities. In level 5 automation, the vehicle is fully automated; there is typically no steering wheel, manual brakes, or gas pedal and it is anticipated that the vehicle is capable of handling even the most challenging driving scenarios. While "automated vehicles" encompasses a broad range of technologies, it is used in this paper to refer to the most advanced type of vehicle automation technologies, the fully autonomous or "self-driving", level 5 vehicle. In this paper we review current AV trends and synthesize research focused on AV accessibility and the use of this technology by persons with disabilities and older adults (65+). There are a small but growing number of literature reviews that survey AVs with a focus on policy (Fink et al., 2021), consumer sentiment (Othman, 2021), and technical characteristics (Campbell et al., 2018; Rosique et al., 2019). Missing, we argue, is a review of an aspect of the AV that if inaccessible may serve as a key barrier to the disabled user's ability to effectively use this technology: the Human-Machine Interface (HMI). We have identified three HMI-focused research questions to guide this literature review:

- **RQ1:** What are the existing approaches to AV design that may serve as accessibility barriers for persons with disabilities?
- **RQ2:** What is known about human-AV interactions from the perspective of persons with disabilities and older adults?
- **RQ3:** What is known about the opinions, preferences, and concerns of persons with disabilities and older adults as it relates to their interaction with autonomous vehicles?

In section 2 we discuss existing AV design and potential accessibility barriers (RQ1), in section 3 we explore human-AV interaction with a focus on persons with disabilities (RQ2), In section 4 we discuss literature focused on exploring the perspectives of persons with disabilities on AVs as it relates to human-AV interaction (RQ3). In section 5, we discuss the implications of our literature review and describe potential research directions. We conclude in section 6 with a discussion of the key takeaways from this work

Barriers to Accessibility in Emerging Automated Vehicles

Reports by advocacy organizations and initiatives like the U.S. Department of Transportation's Inclusive Design Challenge for Autonomous Vehicle Accessibility suggest that there are significant concerns with the accessibility of emerging vehicular automation technologies. Given the relatively nascent nature of the most advanced technologies of this type, the description of potential barriers to accessibility in the literature is limited. In this section we review what has been documented and what can be logically inferred related to the potential accessibility barriers that may be faced by persons with visual, auditory, cognitive, or mobility disabilities in their use of emerging AVs.

Touchscreen-Centric Environments

Modern vehicles increasingly come equipped with one or more visual displays that serve as the primary means of interacting with a vehicle's entertainment, navigation, and informational systems (Pitts et al., 2014). Many of these interfaces support tactile interaction which enables a user to select an item within the visual display using touch to initiate a corresponding response from the system/vehicle. A system might visually display a satellite radio station, for instance, which may be changed when the user presses a specific digital button. A system may present temperature or other controls within this visual display as well. Studies suggest that this approach may be helpful in supporting optimal interaction for both novice and experienced system users due the relatively simple and straightforward approach (Ahmad et al., 2015). For users with specific disabilities, however, interaction via a touchscreen may be anything but straightforward and effective. Touchscreens rely on a user's ability to recognize a digital control (e.g., button, slider, etc.) and take an appropriate action to manipulate it. Many Blind and Low Vision (BLV) users may face significant challenges in interacting with standard touchscreen devices given their largely visual nature. Users with little to no usable vision may face challenges in locating digital controls non visually and interacting with them absent associated cues like sound or haptic feedback. Touchscreens that lack audio narration like Apple's Voice Over (Apple, n.d.-b) or Google's Talk Back (Google, n.d.) may be inherently challenging for BLV users who 1) may not have the visual acuity necessary to identify where the control is located on the two-dimensional interface, and 2) if identified, may not have enough contextual information to manipulate or interact with it. The reliance on in-vehicle touchscreens may also pose challenges for persons with motor disabilities like cerebral palsy. Users with motor disabilities, unlike BLV users, may be able to easily recognize a digital control but may be challenged in physically manipulating it due to issues with fine motor control. This movement towards one or more touchscreens as a primary means of manipulating a vehicle's core functions may logically pose problems for BLV users and users with specific motor impairments in emerging AVs. While some existing work focuses on automotive display magnification (Apple, n.d.-b; Lee et al., 2021), there is limited research within the automotive domain specifically which describes an effective approach that a BLV user or user with a motor disability may utilize to interact with a traditional touchscreen interface. It is important to note that while the proliferation of touchscreens may be problematic for BLV users and users with motor disabilities specifically, some persons with disabilities and older adults have expressed a desire for touchscreens as a backup means of interaction (Brinkley, Huff, Boateng, et al., 2020).

Reliance on Visual Indicators

Manual driving of a conventional motor vehicle is an inherently visual task (Green, 1999) and vehicle designers have traditionally made significant use of the visual senses to inform the driver about the status of the vehicle or driving environment. Most modern vehicles for instance have visual indicators to alert the driver of emergency situations, vehicle failure, or system status like low fuel. This visually focused approach has carried over to emerging autonomous vehicles. Many emerging autonomous vehicles use a combination of visual and auditory indicators to alert the user of vehicle and environmental status. For users with vision loss, it may be difficult if not impossible to see a visual indicator, while any accompanying audio indicator may lack sufficient information to be useful in isolation. A system might, for instance, display a visual indicator to inform the users that the fuel is below a certain threshold but may indicate this with only a single audible tone; a tone that may be insufficient to relay necessary information non visually. For users with cognitive impairments visual indicators may also be problematic as the user may struggle with interpreting meaning. Many complex visual indicators in Advanced Driver Assistance Systems (ADAS), for instance may be difficult to interpret even for users without cognitive disabilities which may affect their ability to interpret this visual information (Brinkley, Dunbar, et al., 2017; Yoon et al., 2015). The use of visual indicators in emerging AVs may be significantly problematic for users with limited vision or cognitive impairments in that the type of information that the vehicle will likely convey is arguably more complex than the type of information that is conveyed within a conventional vehicle. Beyond conveying information regarding battery life or time to destination, a level 5 AV may also need to convey information regarding the operational status of environmental sensors, information regarding a vehicle's decision processes, or information regarding real time data collection. Given that much of what is being implemented in emerging AVs is based on what exists for conventional vehicles it is likely that designers, absent other considerations, will take a largely visual approach that may pose problems for PWD.

Accessible Human-AV Interaction for Persons with Disabilities

While challenges may exist regarding interaction with emerging Autonomous Vehicles (AVs) human-computer interaction literature suggests that Voice User Interfaces (VUIs), and gesture interaction, used in isolation or in combination, may address the accessibility challenges of persons with disabilities (PWD) in interacting with AVs.

Voice User Interfaces (VUIs)

Voice user interfaces (VUIs) have been described as one of the most efficient methods of human-vehicle interaction in the sense that it may reduce distractions while driving and thus decreases the likelihood of crashes (Large et al., 2016; Yan et al., 2007). As greater numbers of vehicles continue to be produced with relatively advanced Human-Machine Interfaces (HMIs) the ubiquity of VUIs grows. Many existing HMI are visually oriented with one or more displays (Section 2) that afford users the ability to access a variety of informational and entertainment applications such as navigation and satellite radio. However, with the steady advancement of technology, these visually oriented HMI integrate a growing array of features. While these feature-rich systems may be a key selling point for many manufacturers, users may find it difficult to find a specific feature or complete a specific task given the growing number of options available. VUIs can assist users in this regard by bypassing typically tactile interaction through the use of voice commands (Pfleging et al., 2012; Roider et al., 2017). Empirically, voice interaction has been shown to have several benefits over other forms of interaction in the automotive context. VUIs may be helpful for assisting drivers in remaining alert on the road, as suggested by Large et al. who studied how VUIs can help drivers combat driving fatigue (Large et al., 2018). Funk, Tobisch, and Emfield further explored VUI interactions by assessing non-verbal auditory input (NVAI); specifically exploring what NVAIs users would prefer for binary, discrete, and continuous input (Funk et al., 2020). Their findings suggest that beyond specific utterances (e.g., “Drive Home”), VUIs may be useful for non-speech-based interactions like the clapping of hands, snapping of fingers, and clicking of the tongue, as well as humming or whistling.

The relative flexibility of VUIs as a means of human-AV interaction are potentially significant when viewed within the context of the challenges that persons with disabilities (PWD) may experience with other interaction technologies. A Blind or Low Vision (BLV) user of a level 5 autonomous vehicle might, for instance, specify a route or destination using a voice command while a user with a disability that impacts fine motor control, or the use of the upper extremities might do the same using a tongue click. Despite the perceived benefits of VUIs, and perhaps due primarily to the limited availability of advanced vehicular automation technologies, the use of VUIs in AVs has been explored in only a small number of studies. Brinkley et al. demonstrated how an HMI with VUI support could facilitate the interaction between BLV persons and an AV

(Brinkley, Daily, et al., 2019; Brinkley, Posadas, et al., 2019). Their *Accessible Technology Leveraged for Autonomous vehicles System (ATLAS)* ATLAS supports users' ability to specify a route or destination using voice commands, remain situationally aware in transit, and verify arrival at a final destination without the use of the visual senses. Research has also explored how VUIs may be useful in allowing users with specific driving behavior preferences to customize their on-road experience (K. Kim et al., 2021); a capability that may prove beneficial for users who may be more sensitive to jarring or aggressive driving styles due to age or disability.

While several studies demonstrate the benefits of voice interaction in the automotive context, additional literature identifies key drawbacks that are relevant to any discussion of the use of VUIs as an accessible interaction technology for AVs. While VUIs may provide a hands-free option for human-AV interaction, VUIs may have issues of accessibility for persons with disabilities that impact speech or vocalization. The frequent use of "wake" words (e.g., words that alert the system to user input), limitations in translating continuous actions like adjusting music volume, and limitations in the accuracy of translating speech requests may all significantly impact individuals with speech-related impairments (Cui et al., 2021).

Gestural Interaction

Another means of interaction that may have promise in terms of supporting accessible human-AV interaction is the use of gestures. Gestural interaction may be generally defined as a human's interaction with a system using movements of the body. The use of gestures in human-vehicle interaction has been broadly studied (Fariman et al., 2016; Gable et al., 2014; May et al., 2017). Brand et al. designed a gesture-controlled Head Up Displays (HUD) and found that users responded favorably to gestures as a means of system interaction and overall vehicle control (Brand et al., 2016). Other researchers have explored the use of gestures as a standalone means of real time vehicle control (Zobl et al., 2003), or coupled with other technologies to function as multi-modal systems (Shakeri et al., 2017, 2018). Gestural interaction may be beneficial in supporting accessible human-AV interaction in circumstances where users have some degree of control of their extremities.

Perceptions of Autonomous Vehicles by Persons with Disabilities

While relatively small, there is a growing body of literature focused on understanding the perceptions of persons with disabilities (PWD) regarding autonomous vehicles (Othman, 2021). We discuss studies which explore trust, interaction preferences and transparency, given the relationship of each to AV Human-Machine Interfaces.

Trust

Trust is considered one of the most crucial factors when people firs consider the use of AVs (Raats et al., 2020). Several constructs positively affect people's trust: technically sound technology, transparency of systems, handling bad situations in an effective way, and perceived ease of use (Choi & Ji, 2015). Waung et al. (Waung et al., 2021) showed that trust is associated with a greater likelihood of AV use as they suggest that consumers believe a technically sound, and thus more trustworthy AV, is less likely to crash. Much of the existing literature on trust in AVs is focused on understanding the sentiments of Blind and Low Vision (BLV) individuals and older adults. Research by Bennett et al. (Bennett et al., 2020) suggests that BLV people, though they are hopeful regarding the future potential of AVs, are concerned about safety and generally have less trust in the technology than consumers generally. It has been suggested that the perception of risk regarding AVs may be at least partially attributable to the limited familiarity that consumers have with them. Brinkley et al. (Brinkley, Posadas, et al., 2019), for instance, found that when BLV persons interacted with even a simulated AV that their perception of risk decreased and sense of trust in the technology increased. Noor et al. (Kassens-Noor et al., 2021) similarly found some degree of distrust with BLV study participants related to automated driving technology. Gluck et al. explored the sentiment of older adults (65+), both with and without disabilities, as it relates to AVs (Gluck, Boateng, et al., 2020; Gluck, Huff, et al., 2020). While many of the concerns expressed by participants in both studies were related to privacy, participants expressed concerns regarding safety that were similar to those of other groups that have been studied (Hwang et al., 2020, 2021). A related issue to concerns regarding system failures and potential crashes is trust that the AV, when used in a ridesharing context, will deliver the user to the appropriate location. In a study by Brinkley et al. (Brinkley, Huff, Posadas, et al., 2020) participants were skeptical that the system could reliably deliver them to the correct location under all circumstances. The HMI within an AV may have a significant impact on a user's trust in the AV given that, at a minimum, the HMI may be able to relay information regarding system status that might support the user's belief in correct vehicle operation.

Interaction Preferences

The preferences of persons with disabilities as it relates to their interactions with AVs can be inferred both from existing studies on this topic, as well as from studies of related computing technologies. Azenkot and Lee (Azenkot & Lee, 2013), for instance, found that BLV users of computing technologies are more likely to use speech input than sighted users. As compared to the study by Schoettle and Shivak (Schoettle & Sivak, n.d.), Brinkley et al. found that most users wanted to have an accessible touchscreen with some form of narration as opposed to a VUI (Brinkley, Huff, Posadas, et al., 2020). This study was in contrast to an earlier study (Brinkley, Posadas, et al., 2017) which suggested that BLV users expect some form of VUI in an AV. The authors suggest that this difference may be at least partially attributable to the relative younger ages of participants in the later study; participants who it may be argued have a greater familiarity with more accessible "talking" touchscreen technologies like Apple's VoiceOver (Apple, n.d.-b) and Google's TalkBack (Google, n.d.). Much of the existing AV research focused on consumers without disabilities suggest that many want the ability to manually control an AV either for enjoyment (KPMG, 2013) or in an emergency (Schoettle & Sivak, 2015). Some studies suggest that small numbers of BLV persons are also interested in manual control capabilities though the means with which this control might be implemented are unclear (Brinkley, Huff, Posadas, et al., 2020).

Transparency

Lyons mentioned transparency as a medium between human and intelligent systems such as robots and smart devices to support communicative interaction (Lyons, 2013). Transparency may be generally defined as understanding why a machine executed a specific action (T. Kim &

Hinds, 2006). Huff et al. explored AV transparency using survey methodology (Huff Jr et al., 2021) to explore consumer perspectives on what constitutes transparency within an autonomous vehicle. Study findings suggest that older adults specifically (65+) have a greater affinity for AVs that provide information that is consistent with what may be understood as transparency, relative to AVs without this capability. The perspectives of persons with disabilities on transparency and how transparency would be achieved with an accessible Human-Machine Interface (HMI) have not been clearly defined in the literature.

Discussion

Our findings suggest that persons with disabilities (PWD) generally favor the use of speech-based interaction using accessible Voice User Interfaces (VUIs) within autonomous vehicles. Our findings further suggest that the Human-Machine Interfaces (HMIs) in these vehicles may need to do more than what has been described in much of the literature to address the need for situational awareness, spatial orientation, and generally accessible interaction.

Voice User Interfaces and Speech Interaction

The use of VUIs and other speech-based technology for older adults and people with disabilities is explored in many domains, such as voice assistants (Abdolrahmani et al., 2018), mobility aids (Guerrero et al., 2012; Kammoun et al., 2012), and assistive technologies (Aizawa & Watanabe, 2014). The body of literature on using speech in the automotive domain primarily focuses on areas such as navigation, in-vehicle voice assistants, and spatial audio. Few studies investigate the application of speech for the benefit of older adults and people with visual impairments (Brinkley, Huff, Posadas, et al., 2020). The existing literature suggests that the use of speech was the primary preference of interaction for both older adults and people with visual impairments. Concerns regarding the of speech as a method of interaction include the system inaccurately interpreting a person's commands and the prospect of the system listening and storing people's conversations. Related to the VUI though largely unexplored in the literature is the control of, and interaction with, autonomous vehicles using a smartphone.

Smartphone integrations are seeing more use in the automotive domain with technologies such as Android Auto (Google, Inc., n.d.) and Apple CarPlay (Apple, n.d.-a) allowing users to engage in hands-free activities with their favorite mobile applications. Certain luxury vehicles allow passengers to control specific functions like air conditioning and music using their mobile phones. Some manufacturers are using smartphones as an alternative 'key' to unlock and start their vehicles. With the increasing ubiquity of vehicle-related smartphone technologies, additional opportunities may be realized for hands-free interaction with autonomous vehicles. This may be a benefit for people who cannot otherwise manipulate the controls of a conventional vehicle. While largely unexplored in the accessible human-AV interaction context, smartphone integration may prove to be one of the most desirable means of accessible AV interaction.

Multi-Modal Interfaces

Many modern vehicles possess some form of in-vehicle infotainment system (IVIS) that allows passengers to perform various tasks like changing the temperature, choosing music, operating the navigation system, and accessing smartphone applications. Such Human-Machine Interfaces

(HMIs) provide one or more methods of control, typically via a physical control or touchscreen capability. The latter becomes a limitation for people with low vision or blindness and is considered a design anti-pattern because it may pose a barrier for full use of the vehicle. An acceptable form of an HMI may be one that enables multi-modal interaction with speech, gesture interaction, and or tactile input such as the one developed by Brinkley et al. (Brinkley, Daily, et al., 2019). Some studies examine the applicability of touchscreen interfaces with tactile and auditory feedback. Few studies to date, however, have explored this approach specifically within the autonomous vehicle context.

Spatial Assistance

Spatial assistance refers to designing features and systems to provide aide to passengers who may require help in understanding and navigating their environment before, during, and after traveling in an AV. Spatial assistance may prove especially beneficial to people with specific types of disabilities such as people with visual impairments. As Blind or Low Vision persons may face difficulties in non-visual orientation and mobility, they may benefit from additional support within an AV that may enable them to remain aware of their immediate environment more effectively.

Situational Awareness

Situational awareness is the level of knowledge a person needs to have about their surrounding environment to respond to an event. For some BLV persons their situational awareness within a vehicle may be limited depending on their degree of vision loss. The literature suggests that such limitations may contribute to distrust of AVs and a perception that the use of this technology is high risk. In studies involving BLV participants, situational awareness was a common concern and a critical factor in their trust of AVs. Having a feature or features that alert BLV users to key landmarks or places of interest during travel have been suggested within the related literature.

Location Verification

The ability to accurately confirm the correct destination upon arrival can be a major barrier, especially for those with limited usable vision. Such issues are especially concerning in situations where passengers utilize ridesharing services (e.g., Uber, Lyft, etc.) where their drop-off location may not coincide with the actual stated destination, such as at an airport. Additional research is required to understand how to establish verification procedures for a given location and how to support this ability to verify locations non visually.

Privacy

Within AV development, specifically shared AV fleet management, a topic of interest is information sharing. Studies suggest that older adults and persons with disabilities may be particularly concerned about what data is being collected and if AV systems are ‘listening’ to their conversations. On the one hand, study participants have expressed concerns about their privacy being invaded, and if state or federal regulations may enable such data collection from AVs. On the other hand, some participants have expressed an acceptance with certain information, such as medical history, being collected if used for a an acceptable reason (e.g., the

AV may know about a passenger's heart condition and may use that information to assess the passenger's condition if they suddenly fall ill). Privacy considerations are relevant to our discussion of autonomous vehicle HMI in that additional research is needed to fully understand the perspective of persons with disabilities on data collection with an AV, and how the information that is being collected should be communicated to the user.

Conclusion

In this paper, we have explored the existing literature as it relates to persons with disabilities (PWD) and their interactions with and use of autonomous vehicles (AVs). Within this work we have explored specifically: 1) what is known regarding existing approaches to AV design that may serve as accessibility barriers for persons with disabilities, 2) what is known about human-AV interactions from the perspective of persons with disabilities and older adults, and 3) what is known about the opinions, preferences, and concerns of persons with disabilities and older adults as it relates to their interaction with autonomous vehicles. Our findings suggest that while persons with disabilities may face challenges in interacting with autonomous vehicles as currently conceived, properly leveraging what is known about accessible human-machine interaction broadly may result in emerging AVs that are more accessible and fundamentally more usable by a brand range of people.

References

Abdolrahmani, A., Kuber, R., & Branham, S. M. (2018). "Siri Talks at You": An Empirical Investigation of Voice-Activated Personal Assistant (VAPA) Usage by Individuals Who Are Blind. *Proceedings of the 20th International ACM SIGACCESS Conference on Computers and Accessibility*, 249–258. https://doi.org/10.1145/3234695.3236344

Ahmad, B. I., Langdon, P. M., Godsill, S. J., Hardy, R., Skrypchuk, L., & Donkor, R. (2015). Touchscreen usability and input performance in vehicles under different road conditions: An evaluative study. *Proceedings of the 7th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*, 47–54. https://doi.org/10.1145/2799250.2799284

Aizawa, F., & Watanabe, T. (2014). A braille writing training device with voice feedback. *Proceedings of the 16th International ACM SIGACCESS Conference on Computers & Accessibility*, 243–244. https://doi.org/10.1145/2661334.2661390

Apple. (n.d.-a). *IOS - CarPlay*. Apple. Retrieved July 31, 2020, from https://www.apple.com/ios/carplay/

Apple. (n.d.-b). *Vision Accessibility—Mac*. Apple. Retrieved January 30, 2020, from https://www.apple.com/accessibility/mac/vision/

Azenkot, S., & Lee, N. B. (2013). Exploring the use of speech input by blind people on mobile devices. *Proceedings of the 15th International ACM SIGACCESS Conference on Computers and Accessibility*, 1–8. https://doi.org/10.1145/2513383.2513440

Bell, E. C., & Mino, N. M. (2015). Employment Outcomes for Blind and Visually Impaired Adults. *Journal of Blindness Innovation and Research*, *5*(2). https://www.nfb.org/images/nfb/publications/jbir/jbir15/jbir050202.html

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

Brinkley, J., Daily, S. B., & Gilbert, J. E. (2019). Implementing the ATLAS Self-Driving Vehicle Voice User Interface. *Journal on Technology and Persons with Disabilities*, *7*(16). http://dspace.calstate.edu/handle/10211.3/210396

Brinkley, J., Dunbar, J., Smith, J. D., & Gilbert, J. E. (2017). A Usability Evaluation of the BMW Active Cruise Control System With "Stop and Go" Function. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *61*(1), 1536–1540. https://doi.org/10.1177/1541931213601748

Brinkley, J., Huff, E. W., Boateng, K., & Ahire, S. (2020). Autonomous Vehicle Design Anti-Patterns: Making Emerging Transportation Technologies Inaccessible by Design. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *64*(1), 1038–1042. https://doi.org/10.1177/1071181320641249

Brinkley, J., Huff, E. W., Posadas, B., Woodward, J., Daily, S. B., & Gilbert, J. E. (2020). Exploring the Needs, Preferences, and Concerns of Persons with Visual Impairments Regarding Autonomous Vehicles. *ACM Transactions on Accessible Computing*, *13*(1), 1–34. https://doi.org/10.1145/3372280

Brinkley, J., Posadas, B., Sherman, I., Daily, S. B., & Gilbert, J. E. (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), 1018–1032. https://doi.org/10.1080/10447318.2018.1561787

Brinkley, J., Posadas, B., Woodward, J., & Gilbert, J. E. (2017). Opinions and Preferences of Blind and Low Vision Consumers Regarding Self-Driving Vehicles: Results of Focus Group Discussions. *Proceedings of the 19th International ACM SIGACCESS Conference on Computers and Accessibility - ASSETS '17*, 290–299. https://doi.org/10.1145/3132525.3132532

Campbell, S., O'Mahony, N., Krpalcova, L., Riordan, D., Walsh, J., Murphy, A., & Ryan, C. (2018). Sensor Technology in Autonomous Vehicles: A review. *2018 29th Irish Signals and Systems Conference (ISSC)*, 1–4. https://doi.org/10.1109/ISSC.2018.8585340

Choi, J. K., & Ji, Y. G. (2015). Investigating the Importance of Trust on Adopting an Autonomous Vehicle. *International Journal of Human–Computer Interaction*, *31*(10), 692–702. https://doi.org/10.1080/10447318.2015.1070549

Claypool, H., Bin-Nun, A., & Gerlach, J. (2017). *Self-Driving Cars: The Impact on People with Disabilities* (p. 35). Ruderman Family Foundation.

https://rudermanfoundation.org/white_papers/self-driving-cars-the-impact-on-people-with-disabilities/

Cui, Z., Gong, H., Wang, Y., Shen, C., Zou, W., & Luo, S. (2021). Enhancing Interactions for In-Car Voice User Interface with Gestural Input on the Steering Wheel. *13th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*, 59–68. https://doi.org/10.1145/3409118.3475126

Douma, F., & Palodichuk, S. A. (2012). Criminal Liability Issues Created by Autonomous Vehicles Symposium Article. *Santa Clara Law Review*, *52*(4), 1157–1170.

Fariman, H. J., Alyamani, H. J., Kavakli, M., & Hamey, L. (2016). Designing a user-defined gesture vocabulary for an in-vehicle climate control system. *Proceedings of the 28th Australian Conference on Computer-Human Interaction*, 391–395. https://doi.org/10.1145/3010915.3010955

Fink, P. D. S., Holz, J. A., & Giudice, N. A. (2021). Fully Autonomous Vehicles for People with Visual Impairment: Policy, Accessibility, and Future Directions. *ACM Transactions on Accessible Computing*, *14*(3), 15:1-15:17. https://doi.org/10.1145/3471934

Funk, M., Tobisch, V., & Emfield, A. (2020). Non-Verbal Auditory Input for Controlling Binary, Discrete, and Continuous Input in Automotive User Interfaces. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems* (pp. 1–13). Association for Computing Machinery. https://doi.org/10.1145/3313831.3376816

Gable, T. M., May, K. R., & Walker, B. N. (2014). Applying Popular Usability Heuristics to Gesture Interaction in the Vehicle. *Adjunct Proceedings of the 6th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*, 1–7. https://doi.org/10.1145/2667239.2667298

Gluck, A., Boateng, K., Huff Jr., E. W., & Brinkley, J. (2020). Putting Older Adults in the Driver Seat: Using User Enactment to Explore the Design of a Shared Autonomous Vehicle. *12th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*, 291–300. https://doi.org/10.1145/3409120.3410645

Gluck, A., Huff, E. W., Zhang, M., & Brinkley, J. (2020). Lights, Camera, Autonomy! Exploring the Opinions of Older Adults Regarding Autonomous Vehicles Through Enactment. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *64*(1), 1971–1975. https://doi.org/10.1177/1071181320641475

Google. (n.d.). *Get started on Android with TalkBack—Android Accessibility Help*. Retrieved April 26, 2022, from https://support.google.com/accessibility/android/answer/6283677?hl=en

Google, Inc. (n.d.). *Android Auto*. Android. Retrieved July 31, 2020, from https://www.android.com/auto/

Green, P. (1999). *Visual and Task Demands of Driver Information Systems* (No. 98–16; p. 199). University of Michigan Transportation Research Institute.

Guerrero, L. A., Vasquez, F., & Ochoa, S. F. (2012). An Indoor Navigation System for the Visually Impaired. *Sensors*, *12*(6), 8236–8258. https://doi.org/10.3390/s120608236

Harrabi, H., Aubin, M.-J., Zunzunegui, M. V., Haddad, S., & Freeman, E. E. (2014). Visual Difficulty and Employment Status in the World. *PLOS ONE*, *9*(2), e88306. https://doi.org/10.1371/journal.pone.0088306

Huff, E. W., DellaMaria, N., Posadas, B., & Brinkley, J. (2019). Am I Too Old to Drive? Opinions of Older Adults on Self-Driving Vehicles. *The 21st International ACM SIGACCESS Conference on Computers and Accessibility*, 500–509. https://doi.org/10.1145/3308561.3353801

Huff Jr, E. W., Day Grady, S., & Brinnkley, J. (2021). Tell Me What I Need To Know: Consumers' Desire for Information Transparency in Self-Driving Vehicles. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *65*(1), 327–331. https://doi.org/10.1177/1071181321651240

Hwang, J., Li, W., Stough, L., Lee, C., & Turnbull, K. (2020). A focus group study on the potential of autonomous vehicles as a viable transportation option: Perspectives from people with disabilities and public transit agencies. *Transportation Research Part F: Traffic Psychology and Behaviour*, *70*, 260–274. https://doi.org/10.1016/j.trf.2020.03.007

Hwang, J., Li, W., Stough, L. M., Lee, C., & Turnbull, K. (2021). People with disabilities' perceptions of autonomous vehicles as a viable transportation option to improve mobility: An exploratory study using mixed methods. *International Journal of Sustainable Transportation*, *15*(12), 924–942. https://doi.org/10.1080/15568318.2020.1833115

Kammoun, S., Parseihian, G., Gutierrez, O., Brilhault, A., Serpa, A., Raynal, M., Oriola, B., Macé, M. J.-M., Auvray, M., Denis, M., Thorpe, S. J., Truillet, P., Katz, B. F. G., & Jouffrais, C. (2012). Navigation and space perception assistance for the visually impaired: The NAVIG project. *IRBM*, *33*(2), 182–189. https://doi.org/10.1016/j.irbm.2012.01.009

Kassens-Noor, E., Cai, M., Kotval-Karamchandani, Z., & Decaminada, T. (2021). Autonomous vehicles and mobility for people with special needs. *Transportation Research Part A: Policy and Practice*, *150*, 385–397. https://doi.org/10.1016/j.tra.2021.06.014

Kim, K., Park, M., & Lim, Y. (2021). Guiding Preferred Driving Style Using Voice in Autonomous Vehicles: An On-Road Wizard-of-Oz Study. *Designing Interactive Systems Conference 2021*, 352–364. https://doi.org/10.1145/3461778.3462056

Kim, T., & Hinds, P. (2006). Who Should I Blame? Effects of Autonomy and Transparency on Attributions in Human-Robot Interaction. *ROMAN 2006 - The 15th IEEE International Symposium on Robot and Human Interactive Communication*, 80–85. https://doi.org/10.1109/ROMAN.2006.314398

KPMG. (2013). *Self-driving cars: Are we ready?* https://institutes.kpmg.us/manufacturing-institute/articles/2017/self-driving-cars-are-we-ready.html

Lajunen, T., & Sullman, M. J. M. (2021). Attitudes Toward Four Levels of Self-Driving Technology Among Elderly Drivers. *Frontiers in Psychology*, *12*, 682973. https://doi.org/10.3389/fpsyg.2021.682973

Large, D. R., Burnett, G., Antrobus, V., & Skrypchuk, L. (2018). Driven to discussion: Engaging drivers in conversation with a digital assistant as a countermeasure to passive task-related fatigue. *IET Intelligent Transport Systems*.

Large, D. R., Burnett, G., Anyasodo, B., & Skrypchuk, L. (2016). Assessing Cognitive Demand During Natural Language Interactions with a Digital Driving Assistant. *Proceedings of the 8th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*, 67–74. https://doi.org/10.1145/3003715.3005408

Lee, H.-N., Ashok, V., & Ramakrishnan, I. (2021). Bringing Things Closer: Enhancing Low-Vision Interaction Experience with Office Productivity Applications. *Proceedings of the ACM on Human-Computer Interaction*, *5*(EICS), 197:1-197:18. https://doi.org/10.1145/3457144

Lyons, J. B. (2013, March 15). Being Transparent about Transparency: A Model for Human-Robot Interaction. *2013 AAAI Spring Symposium Series*. 2013 AAAI Spring Symposium Series. https://www.aaai.org/ocs/index.php/SSS/SSS13/paper/view/5712

Marinik, A., Bishop, R., Fitchett, V., Morgan, J., Trimble, T. E., & Blanco, M. (2014). *Human Factors Evaluation of Level 2 And Level 3 Automated Driving Concepts: Concepts of operation* (DOT HS 812 044). National Highway Traffic Safety Administration. https://vtechworks.lib.vt.edu/bitstream/handle/10919/55082/812044_HF-Evaluation-Levels-2-3-Automated.pdf?sequence=1&isAllowed=y

May, K. R., Gable, T. M., & Walker, B. N. (2017). Designing an In-Vehicle Air Gesture Set Using Elicitation Methods. *Proceedings of the 9th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*, 74–83. https://doi.org/10.1145/3122986.3123015

Othman, K. (2021). Public acceptance and perception of autonomous vehicles: A comprehensive review. *AI and Ethics*, *1*(3), 355–387. https://doi.org/10.1007/s43681-021-00041-8

Petrović, Đ., Mijailović, R., & Pešić, D. (2020). Traffic Accidents with Autonomous Vehicles: Type of Collisions, Manoeuvres and Errors of Conventional Vehicles' Drivers. *Transportation Research Procedia*, *45*, 161–168. https://doi.org/10.1016/j.trpro.2020.03.003

Pfleging, B., Schneegass, S., & Schmidt, A. (2012). Multimodal interaction in the car: Combining speech and gestures on the steering wheel. *Proceedings of the 4th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*, 155–162. https://doi.org/10.1145/2390256.2390282

Pitts, M. J., Skrypchuk, L., Attridge, A., & Williams, M. A. (2014). Comparing the User Experience of Touchscreen Technologies in an Automotive Application. *Proceedings of the 6th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*, 1–8. https://doi.org/10.1145/2667317.2667418

Raats, K., Fors, V., & Pink, S. (2020). Trusting autonomous vehicles: An interdisciplinary approach. *Transportation Research Interdisciplinary Perspectives*, *7*, 100201. https://doi.org/10.1016/j.trip.2020.100201

Roider, F., Rümelin, S., Pfleging, B., & Gross, T. (2017). The Effects of Situational Demands on Gaze, Speech and Gesture Input in the Vehicle. *Proceedings of the 9th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*, 94–102. https://doi.org/10.1145/3122986.3122999

Rosique, F., Navarro, P. J., Fernández, C., & Padilla, A. (2019). A Systematic Review of Perception System and Simulators for Autonomous Vehicles Research. *Sensors*, *19*(3), 648. https://doi.org/10.3390/s19030648

SAE International. (n.d.). *J3016B: Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles*. Retrieved November 1, 2019, from https://www.sae.org/standards/content/j3016_201806/

Schoettle, B., & Sivak, M. (n.d.). *Public opinion about self-driving vehicles in China, India, Japan, the U.S., the U.K., and Australia*. 35.

Schoettle, B., & Sivak, M. (2015). *Motorists' preferences for different levels of vehicle automation*. University of Michigan Transportation Research Institute. https://deepblue.lib.umich.edu/handle/2027.42/114386

Shakeri, G., Williamson, J. H., & Brewster, S. (2017). Novel Multimodal Feedback Techniques for In-Car Mid-Air Gesture Interaction. *Proceedings of the 9th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*, 84–93. https://doi.org/10.1145/3122986.3123011

Shakeri, G., Williamson, J. H., & Brewster, S. (2018). May the Force Be with You: Ultrasound Haptic Feedback for Mid-Air Gesture Interaction in Cars. *Proceedings of the 10th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*, 1–10. https://doi.org/10.1145/3239060.3239081

Sparrow, R., & Howard, M. (2017). When human beings are like drunk robots: Driverless vehicles, ethics, and the future of transport. *Transportation Research Part C: Emerging Technologies*, *80*, 206–215. https://doi.org/10.1016/j.trc.2017.04.014

Wang, J., Huang, H., Li, K., & Li, J. (2021). Towards the Unified Principles for Level 5 Autonomous Vehicles. *Engineering*, *7*(9), 1313–1325. https://doi.org/10.1016/j.eng.2020.10.018

Waung, M., McAuslan, P., & Lakshmanan, S. (2021). Trust and intention to use autonomous vehicles: Manufacturer focus andpassenger control. *Transportation Research Part F: Traffic Psychology and Behaviour*, *80*, 328–340. https://doi.org/10.1016/j.trf.2021.05.004

Wiseman, Y. (2022). *Autonomous Vehicles* [Chapter]. Research Anthology on Cross-Disciplinary Designs and Applications of Automation; IGI Global. https://doi.org/10.4018/978-1-6684-3694-3.ch043

Yan, B., Weng, F., Feng, Z., Ratiu, F., Raya, M., Meng, Y., Varges, S., Purver, M., Lien, A., Scheideck, T., Raghunathan, B., Lin, F., Mishra, R., Lathrop, B., Zhang, Z., Bratt, H., & Peters, S. (2007). A conversational in-car dialog system. *Proceedings of Human Language Technologies: The Annual Conference of the North American Chapter of the Association for Computational Linguistics: Demonstrations*, 23–24.

Yoon, S. H., Lim, J., & Ji, Y. G. (2015). Assessment model for perceived visual complexity of automotive instrument cluster. *Applied Ergonomics*, *46*, 76–83. https://doi.org/10.1016/j.apergo.2014.07.005

Zobl, M., Geiger, M., Schuller, B., Lang, M., & Rigoll, G. (2003). A real-time system for hand gesture controlled operation of in-car devices. *2003 International Conference on Multimedia and Expo. ICME '03. Proceedings (Cat. No.03TH8698)*, *3*, III–541. https://doi.org/10.1109/ICME.2003.1221368

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