AUTONOMOUS VEHICLES AND VISUALLY IMPAIRED OPERATORS

By

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To Nathalie, Jaden, Christopher, Quentin and Lillie

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LIST OF ABBREVIATIONS

ACB	American Council of the Blind.
ACC	Active/adaptive cruise control.
ADAS	Advanced Driver Assistance System.
ASA	AV Start Act.
ATLAS	Accessible Technology Leveraged for Autonomous vehicles System.
CCC	Conventional Cruise Control.
DOT	Department of Transportation.
GUI	Graphical User Interface.
HMI	Human-Machine Interface.
NFB	National Federation of the Blind.
NHTSA	National Highway Transportation Safety Administration.
SDA	Self-Drive Act.
VUI	Voice User Interface.

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The emergence of fully autonomous or self-driving vehicles may prove to be the most significant change in personal mobility in more than a century. Recent reports have suggested however that most self-driving vehicle technology is being developed in a manner that will render it largely inaccessible to many users with disabilities. This is especially problematic for individuals who are blind or significantly visually impaired who, due to the nature of their disability, are unable to operate conventional motor vehicles. Within this dissertation, I have explored the issue of self-driving vehicle accessibility from the perspective of visually impaired operators. I conducted two formative research studies to investigate this issue: a survey intended to investigate opinions and perspectives on the technology, preferences and concerns of visually impaired consumers related to vehicle automation, and a series of focus groups intended to investigate the anticipated accessibility challenges of interacting with self-driving vehicle technology. Using what was learned in these activities, I conducted a series of participatory design sessions with visually impaired participants with an accessible self-driving vehicle human-machine interface that was designed and prototyped. The resulting Accessible Technology Leveraged for Autonomous vehicles System (ATLAS) combines natural language processing, affective computing, and spatial audio to enable visually impaired operators to

accessibly interact with a self-driving vehicle. Using a quasi-naturalistic study, I show that the ATLAS system is effective in satisfying the usability and experiential needs of visually impaired self-driving vehicle users. This dissertation presents a comprehensive approach to the design of accessible self-driving vehicle systems that supports visually impaired users' needs and abilities.

CHAPTER 1
INTRODUCTION

Autonomous vehicle (AV) technology, in its many manifestations and incarnations, has captured the attention of academia, industry, and perhaps most importantly, the masses. This technology, which broadly includes partially, highly and fully automated vehicle systems, allows a human driver to relinquish various aspects of vehicle control to automated systems. Only recently has the potential for fully autonomous or "self-driving" vehicles transcended the confines of the science fiction and academic literature and began to emerge as a practical technology. Due largely to its potential impact, the emergence of AV technology has been met with significant fanfare by both the scientific and mainstream media. It has been argued that vehicles capable of driving themselves could potentially lead to the end of personal vehicle ownership [1]; upending a host of industries from automotive manufacturing to insurance [2]. This consumption of Transportation as a Service (TaaS) [3] may also prove to be a boon for both the fight against man-made climate change and the movement towards environmentally friendly cities [4], [5]. The aforementioned benefits may pale in comparison to the life and property saving benefits of AV technology, however [6], [7]. Vehicles capable of driving themselves by definition minimize the impact of error-prone human beings on vehicle operation and may, as some studies suggest, reduce automobile accidents by as much as 90% [8]. This may have the net effect of saving thousands of lives and millions of dollars worth of property in the process [7]. While these world and society-changing benefits are being broadly discussed from many angles, the question of universal access to AV technology has been insufficiently addressed. Though largely piecemeal, AV accessibility efforts on the part of industry [9], academia [10], interest groups [11], [12] and government entities [13] exist. Little apparent action is being taken; however, to directly address issues of AV accessibility. It is, therefore, questionable whether

these disjointed activities are capable of ensuring that all individuals, regardless of physical ability, will have equitable access to this revolutionary technology and comparable user experiences with it. Unfortunately, it is within this existing paradigm that the self-driving vehicle is being developed. Several companies in the automotive and technology industry are attempting to move the masses from human-operated vehicles to semi-autonomous and ultimately fully autonomous technologies. In the process, the self-driving vehicles of the near future are being designed around the needs of the *driver* of the present who, in all cases, is sighted as opposed to the *user/operator* of the future who needs not necessarily be. According to the National Federation of the Blind, under the current paradigm, self-driving vehicles are being developed that will ultimately prove inaccessible to many persons with disabilities and especially those who are significantly visually impaired [14].

Within this dissertation, I investigate the needs, preferences, and concerns of visually impaired persons regarding self-driving vehicles, design and develop an accessible human-machine interface and evaluate this system under quasi-naturalistic conditions. I present an approach to improving the accessibility of the self-driving vehicle human-machine interface that capitalizes on the spatial abilities of visually impaired persons while utilizing natural language processing, affective computing principles, and spatial audio to satisfy users' experiential needs.

Motivation

The present research has been primarily motivated by recognition of the impact of a lack of personal mobility on the lives of many individuals who are blind, coupled with a recognition that self-driving vehicle technology is still in its infancy. In the case of the former, the economic and social benefits of the type of personal mobility that may be introduced to the visually impaired community by self-driving vehicle technology are potentially tremendous. In the case of the latter, an opportunity exists to break with recent tradition by incorporating universal

design principles during the advent of a critical technology as opposed to essentially retrofitting it to accommodate a range of user needs.

Visually Impaired Persons and Personal Mobility

The economic and social impact of limited mobility for individuals who are blind or significantly visually impaired cannot be overstated. A number of studies suggest that individuals with significant visual impairments like blindness are more likely to have difficulty finding work and are less likely to participate in the workforce relative to sighted individuals when all other factors are eliminated [15]. The National Federation of the Blind's most recent data [16], indicates that fewer than 41% of working-age adults who reported significant vision loss were employed in 2014 as compared to nearly 60% of the population generally during this period [17].

A number of factors have been cited for this disparity but personal mobility has been identified as a key concern [18]. While it is important to avoid generalizations, it is a reality that it is often difficult for persons who are blind to travel to receive the requisite education and training required for many positions. In circumstances where education is not an issue, securing travel to job interviews and to jobs themselves often is very difficult [18], [19]. In many circumstances, persons who are blind must rely on public transportation, which has its own costs and complexities, or they rely on the assistance of friends and relatives [19]. In either case, the lack of personal mobility severely disadvantages persons who are blind in a competitive job market. The self-driving vehicle, properly implemented, could, therefore, prove to be life-changing for many persons who are significantly visually impaired. With this technology, the type of personal mobility that may be taken for granted by sighted individuals with personal transportation would be equally available to those with visual impairments.

Incorporating Accessibility in the Design of New Technologies

The importance of incorporating principles of universal design at the advent of a new technology cannot be understated. This dissertation uses the accessibility "retrofits" of the World Wide Web as a counterexample; proposing that accessibility should be introduced before self-driving vehicle technology is commercially available as opposed to after issues have been identified. Given that the World Wide Web is a largely visual medium it is the visually impaired who have been most greatly impacted by the web's inaccessibility. While the web is almost thirty years old, only in the past twenty years that formal steps have been taken to make web-based information accessible for persons with disabilities, with much of this activity occurring in the past decade [20]. Recommendations like the Web Content Accessibility Guidelines (WCAG) [21], [22] have encouraged content designers to make structural changes to web-based content with the aim of making web-based information more accessible through non-visual means (e.g. screen reading technology). Federal and state legal statutes relating to the access of electronic information have existed for much longer than the WCAG but by their nature have only been enforced after an issue has been identified, which is often times too late from a practical perspective. Legal statutes like Section 508 of the Rehabilitation Act of 1973 (amended in 1998) [23, p. 508], the American with Disabilities Act (ADA) [24] and the California Application Development Accessibility Statute [25] are only a handful of the many laws relating to the accessibility of electronic information [26].

In the case of many of society's most critical web-based applications, it has been suggested that the accommodations made as a result of these recommendations and requirements often results in a degree of technical accessibility while falling short of providing equal usability [27]. Relatively low rates of social networking site (SNS) usage by persons who are blind exemplify this problem [28]. While SNS usage has exploded amongst the general public over the

past decade the usage by persons who are blind has been reported as a relatively low 67% as compared to 95% usage by sighted individuals [28]. Studies investigating this issue have cited usability issues as a key impediment to broader SNS use [29].

Facebook for instance, the world's largest SNS, has been generally regarded as being technically accessible but with a number of core usability issues that serve as impediments to functional use by blind screen reader users [27], [29], [30]. Fundamental changes to systems like Facebook and to the web generally may, at this stage of the web's existence, financially infeasible. This dissertation advocates for a deviation from this trend as it pertains to self-driving vehicle technology by proposing to address the basic interaction needs of visually impaired users while the technology is still being refined.

Scope

Through research conducted collaboratively with visually impaired persons and related organizations in North Central Florida and nationally, this research focuses on self-driving vehicles and visually impaired users/operators. Specifically addressed are the opinions, preferences and concerns of visually impaired persons as it relates to self-driving vehicles, their experiential needs with respect to vehicle operation and the policy environment of the technology's development. By addressing usability and accessibility before the technology is broadly commercially available, it is hoped that best practices for accessibility may be adopted by industry and incorporated into the relevant legal and regulatory framework for autonomous vehicles.

Research Approach

This research utilizes a user-centered approach to investigate the perceptions of visually impaired consumers regarding self-driving vehicle technology, the anticipated needs of visually impaired persons in interacting with this technology, and a technical solution designed to satisfy

some of the identified needs in a practical context. I conducted an online survey (discussed in Chapter 3) to understand the opinions and preferences of visually impaired consumers as it relates to self-driving vehicle technology, the legal and regulatory environment of its use, and perceptions regarding the technology's potential benefits and liabilities. Following the survey, I conducted a series of focus groups and interviews with visually impaired persons (discussed in Chapter 4) to further investigate these issues in a format designed to encourage dialogue and debate. Through a process of categorization and grouping of focus group data, personas were developed (discussed in Chapter 5) to reflect the interpreted user characteristics. Participatory design sessions were then conducted (discussed in Chapter 6) that utilized the described personas, explored specific use cases of visually impaired persons and self-driving vehicles, investigated the specific challenges that might be faced by visually impaired persons when interacting with this technology, and included the collaborative design of prototypes intended to address these challenges. A final prototype was developed, discussed in Chapter 7, which combined what was learned from the participatory design sessions into a single system. I conducted a formal study on a public road course of the prototype (discussed in Chapter 8) to collect data on participants' perceptions of the usability of this system, its effectiveness in satisfying the experiential needs of visually impaired users, and the impact of its use on participants' perception of self-driving vehicle generally.

Structure of this Dissertation

This dissertation is structured as follows: Chapter 2 discusses work related to vehicle automation, AV-oriented driver assistance systems, computer-based navigational aides for visually impaired persons, and research related to visually impaired persons' interaction with conventional motor vehicles. Chapters 3 and 4 describe exploratory research (a survey, focus groups, and interviews), conducted to understand the needs, preferences and concerns of visually

impaired persons regarding self-driving vehicles. Chapter 5 describes the development of personas with disabilities to support participatory design sessions involving disabled persons, while Chapter 6 describes the use of these personas in participatory design sessions with visually impaired participants. Chapter 7 introduces and describes the implementation of the *Accessible Technology Leveraged for Autonomous vehicles System* or ATLAS; a system designed to satisfy some of the experiential needs of visually impaired persons as they interact with self-driving vehicles. Chapter 8 describes a formal study of the ATLAS system conducted on public roads with visually impaired participants. Chapter 9 examines the legal and regulatory environment of the development and use of self-driving vehicles, and provides a policy recommendation intended to improve the accessibility of this technology. Finally, Chapter 10 discusses the contributions of this research, opportunities for future research and concludes the dissertation.

CHAPTER 2
RELATED WORK

Although research that directly and specifically addresses the issues pertaining to enabling persons who are blind to fully operate self-driving vehicles is scarce in the academic literature, three bodies of literature primarily inform this dissertation. This chapter begins with a review of vehicle automation, proceeds with a discussion of computer-based navigational aides for visually impaired persons, and concludes with a review of the literature focused on enabling visually impaired drivers to operate vehicles under non-naturalistic conditions.

Vehicle Automation

Levels of Vehicle Automation

In May of 2013, The National Highway Traffic Safety Administration (NHTSA) identified five levels of vehicle automation that encompassed the varying degrees of automation found in advanced driver assistance systems (ADAS) [6]. This categorization was supplanted in October 2016 by the SAE International categorization of vehicle automation that has since been adopted by NHTSA [31]. The SAE / NHTSA definition identifies six level of vehicle automation from level 0 to level 5. An explanation of this vehicle automation taxonomy is important as it has bearing on the discussion of the technology discussed in this dissertation and has specific implications on the understanding of any discussion of the legal, regulatory and policy environment for an accessible self-driving vehicle system (discussed in Chapter 9).

Level 0 (L0, no-automation)

In Level 0 (L0) automation the driver maintains complete control of the primary vehicle systems: powertrain, brake, steering and throttle [6]. The driver is responsible for monitoring the roadway and safely operating the vehicle. Technologies that provide varying levels of driver support and convenience but lack primary system control capabilities are characteristic of L0

systems. Systems that produce only warnings (e.g. forward collision warning or lane departure warning) and systems that automate secondary controls (e.g. wipers, headlights or turn signals) would be considered L0 systems.

Level 1 (L1, function-specific automation)

In Level 1 (L1) automation, one or more specific control functions are automated independently [6]. In L1, the driver has overall control and is solely responsible for safe operation, but he/she may choose to relinquish control over a primary vehicle system (such as with active cruise control [32]), the vehicle may automatically assume limited control (e.g. electronic stability control [32]) or the system may augment the driver's ability to control a system (e.g. dynamic brake support). In L1 systems, there may be multiple support systems that function, to some degree, in concert, but at no point does the vehicle assume driving responsibility.

The vehicle's automated system(s) may assist the driver in operating one of the primary controls, typically either steering or braking, but does not provide assistance for more than one system. So while there may be some degree of system coordination, this coordination is limited and not to the level where the driver can be safely disengaged from the physical driving task. In an L1 vehicle, the driver may operate the vehicle with his or her hands off of the steering wheel or feet off of the brake and accelerator pedals, but not both at the same time (e.g. conventional cruise control [32]).

Level 2 (L2, combined function automation)

In Level 2 (L2) automation, at least two primary control functions are designed to work in unison, and the driver relinquishes responsibility over those functions [6]. In L2 vehicles, the driver retains responsibility for monitoring the roadway and safe operation and is expected to be available to resume primary control at all times; the system may release control with little to no

warning at any time. The primary control of select systems is ceded however in limited driving situations. Active cruise control coupled with active lane centering capabilities is an example of combined functions (powertrain, brake and steering) found in an L2 system. L1 and L2 systems are primarily differentiated by the fact that, in specific situations in L2 systems, the driver can safely remove his or her hands off the steering wheel and feet off of the brake and accelerator pedals at the same time.

Level 3 (L3, limited self-driving automation)

In Level 3 (L3) automation, the driver is able to fully relinquish control of all safety-critical functions under specific traffic and environmental conditions [6]. The driver is also able to heavily rely on the vehicle to actively monitor changes in traffic and environmental conditions for the purposes of alerting the driver when the change in those conditions requires that control be transferred back to the driver. L3 systems expect that the driver is available to resume occasional control, but in non-emergency circumstances. Control, when transferred back to the driver, occurs with sufficient time to make the transition smooth and comfortable. A vehicle equipped with an L3 system (or systems that would facilitate L3 capabilities) would be designed to operate safely when in automated driving mode but would detect when environmental or traffic conditions were ill-suited for automated driving. The system would the notify the driver, and a graceful transition to manual control would follow. L2 and L3 systems are primarily differentiated by the fact that the driver is not expected to constantly monitor the roadway while driving in an L3 system.

Level 4 (L4, conditional full self-driving automation)

In Level 4 (L4) automation, the vehicle is designed to fully control all safety-critical functions while monitoring roadway conditions for the duration of the trip under prescribed conditions [6]. In L4 systems, the driver's chief responsibility is to provide navigational input in

the form of a final or series of destinations. Provided the vehicle is being operated under the prescribed conditions, is not expected that the driver will need to take over control in exigent circumstances. The key-differentiating factor between L4 and unconditional vehicle automation (L5) is that, in an L4 vehicle, full automation is available under prescribed circumstances (e.g. in an urban environment, on prescribed roadways, etc.).

Level 5 (L5, unconditional full self-driving automation)

In Level 5 (L5) automation, the vehicle is designed to fully control all safety-critical functions while monitoring roadway conditions for the duration of the trip n all conditions [6] . In L5 systems, the driver's chief responsibility is to provide navigational input in the form of a final or series of destination. The driver is expected to behave like a passenger, without any expectation that he/she will be available for control. The entire responsibility for safe vehicle, then, operation rests with the vehicle.

Manufacturer Implementations of Vehicle Automation

Manufacturers have utilized a variety of ADAS to implement L1, L2, and L3 levels of automation (e.g. conventional cruise control, active cruise control, lane keeping assistance, etc.) [32]. Tesla's Model S and Model X vehicles have features that most closely resemble the expectation s of an L4 vehicle; however, in practice, the autonomous features on both vehicles most likely render them closer to L3 automation given the widely discussed accidents [32][33]. Finally, no manufacturer has commercially produced a L5 vehicle.

Computer-Based Navigational Aides for Visually Impaired Persons

Wide ranging consumer technologies and research efforts have been aimed at supporting the situational awareness and spatial navigation of visually impaired persons. A review of these technologies is relevant given the potential overlap between effective approaches to satisfying the spatial orientation and navigational needs of visually impaired pedestrians and approaches

that might prove effective in satisfying similar needs of visually impaired users of self-driving vehicles. Generally, the rise of navigational systems for visually impaired persons has largely paralleled the availability of relatively inexpensive commercially available GPS technologies and the growing ubiquity of GPS enabled mobile devices. Figure 2-1 illustrates the core features of the reviewed technologies.

Mobile Applications		**Experimental / Research Systems**	
System	Core Features	System	Core Features
Blind Square (N.D.) Apple iOS	Vocalized pedestrian directions, Points of Inter - est, Open Street Map data & FourSquare	Bousbia-Salah & Fezari (2007)	Wearable, GPS-based navigation with turn-by-turn directional cues, synthe - sized speech and ultrasonic sensor-based obstacle detection
Loadstone GPS (2004) Symbian OS / Apple iOS	Vocalized pedestrian directions, GPS tracking, screen reading capabilities, Open Street Map data	Chaudary, Paajala, Keino & Pulli (2017)	Wearable teleguidance navigation with directions from a remote caregivier
LoroDux (2009) JAVA OS / Android	Vocalized pedestrian directions, Points of Inter - est, vibrotactile directional cues	Koley & Mishra (2012)	Wearable, GPS-based navigation with turn-by-turn directional cues, synthe - sized speech and ultrasonic sensor-based obstacle detection
Mobile Geo GPS (N.D.) Windows Mobile OS	Vocalized pedestrian directions, Points of Inter - est, morse code-based vibrotactile directional cues	Marston, Loomis, Klatzk y, Golledge & Smith (2006)	Wearable, GPS-based navigation with remote infrared audible signage
Not Nav (N.D.) Android	Vocalized pedestrian directions, Points of Interest	Toyota BLAID (2016)	Wearable, navigation aide with turn-by-turn directions, vibrotactile directional cues and bone conducting headphones
Seeing Eye GPS (N.D.) Apple iOS	Vocalized pedestrian directions, Points of Inter - est, morse code-based vibrotactile directional cues, verbal description of imme - diate surroundings		

Figure 2-1. Surveyed computer-based navigational aides for visually impaired persons.

In 2004, Loadstone GPS was introduced as an open source navigational aide for visually impaired persons [33]. Originally designed to run on the Symbian operating system on Nokia devices, the application combines GPS tracking with a screen reader application and data from the Open Street Map project [34]. The system has been updated for Apple's iOS and implements Apple VoiceOver capabilities to improve accessibility [35]. LoroDux [36], introduced in 2009, is an open source, multi-platform navigational aide for visually impaired persons that also uses data from the Open Street Map project. LoroDux provides real time walking directions, distance to points of interest, street crossing alerts and vibrotactile directional cues. Mobile Geo GPS [37] is a Windows Mobile product that allows users to learn about their present location and nearby points of interest and plan routes. Mobile Geo GPS uses Morse code-based vibrotactile feedback to alert the user to nearby places of interest or as a cue for directional change. The system is reportedly capable of operation at speeds up to 101 miles per hour for potential use in vehicles. The makers of Mobile Geo GPS have also developed another product for iOS called Seeing Eye GPS [38]. The Seeing Eye GPS product functions similarly to Mobile Geo GPS, but contains a feature called the "Look Around Wand" that is capable of providing a rudimentary vocal description of a user's immediate surroundings. Seeing Eye GPS uses Foursquare [39] and the Google Places API [40] for points of interest and Google Maps [41] for street information. BlindSquare [42] from MIPSoft functions in a manner similar to the Seeing Eye GPS product but incorporates crowd-sourced data, uses Open Street Map Project data for street information and Foursquare for points of interest. NotNav [43]is similar to both Seeing Eye GPS and BlindSquare but lacks many of these apps' more advanced features. NotNav primarily uses synthesized speech to communicate information to the user regarding their immediate environment (e.g. places of interest and street crossings) and their specified route.

Beyond these commercial, mobile device-based navigational aides, there are a wide range of largely experimental wearable navigation technologies for visually impaired persons. Chaudary et al. [44] have proposed a tele-guidance navigation system that is based on the idea that a blind pedestrian can be assisted by spoken instructions from a remote caregiver. The caregiver is aware of the pedestrian's immediate surroundings via a live video stream received from a small camera carried by the visually impaired person. Marston et al. [45] have investigated the use of wearable, GPS-based navigation for visually impaired persons incorporating remote infrared audible signage. Koley and Mishra [46], and Bousbia-Salah and Fezari [47] have proposed wearable systems that provide turn-by-turn directional cues to a visually impaired user using synthesized speech to communicate and ultrasonic sensors for obstacle detection. Toyota's project BLAID [48], originally intended as an indoor navigational aide, uses Bluetooth capabilities to provide turn-by-turn directions to a bone conducting headphone, and uses vibrations to provide directional cues to the visually impaired user.

The respective hardware, architecture, services used and features generally differentiate each of the described commercial and research-oriented technologies. Each of these systems, however, incorporates some combination of audible tones, synthesized speech, and vibrotactile feedback to communicate information about the visually impaired person's environment. These systems also share the common goal of improving the user's situational awareness and spatial orientation.

Motor Vehicle Operation by Visually Impaired Persons

Very limited, research exists that focuses specifically on enabling the operation of autonomous and non-autonomous vehicles, under non-naturalistic conditions, by blind drivers. One example is the National Federation of the Blind (NFB)'s 2004 commissioned project, called the "Blind Driver Initiative," which had the high-level goal of supporting the development of

technology that would enable a blind driver to operate a conventional motor vehicle [11]. A small body of literature has emerged from this research that has experimentally focused on enabling blind drivers to operate motor vehicles under non-naturalistic, and often simulated conditions. The NFB's study has also furthered research around nonvisual automotive interfaces generally. In another example, Hong et al. modified a self-driving vehicle designed for the Defense Advanced Research Projects Agency's (DARPA) Urban Challenge [49] to allow a blind driver to operate the vehicle with directional cues provided through the use of audible tones [50]. This is similar to the research of Sucu and Folmer that explored the use of haptics-based steering directional cues in the steering wheel [51].

Collectively, this research is differentiated from this dissertation in that the context was purely experimental and while providing a technical foundation for blind drivers, was not intended to serve as a realistic platform to enable a blind driver to operate a vehicle in a practical sense. The core "Blind Driver Challenge" project itself culminated with a blind driver operating a vehicle on a closed vehicle test track absent other vehicles [52]. This mirrors the approach taken by the related research where the ultimate operational environment is described as either a test track or other non-naturalistic circumstance absent obstacles or other vehicles [50], [51]. Real world driving is complex task performed under often non-ideal conditions in highly dynamic circumstances often with dozens or even hundreds of other vehicles in close proximity to one another within a defined physical space [53]. Though experimental and intended for non-autonomous vehicles, this body of literature has relevance to this dissertation in that it focused on leveraging the spatial abilities of visually impaired persons in the driving context. Chapter 3 builds on what has been discussed and describes an online survey intended to investigate the

needs, preferences and concerns of visually impaired consumers as it relates to self-driving vehicle technology.

CHAPTER 3
SURVEY OF BLIND AND VISUALLY IMPAIRED CONSUMERS ABOUT SELF-DRIVING VEHICLES IN THE USA

Broad consumer adoption of self-driving vehicle technology is a prerequisite if the potential of this technology is to be fully realized. Given the potential safety concerns, likely high initial costs, and general uncertainty around the technology, consumer adoption cannot be taken for granted [54]. At present, a significant amount of consumer research is being conducted to understand consumer preferences regarding self-driving vehicle technology to enable the development of strategies to encourage consumer adoption. Studies have explored consumers' general opinion of full and partial vehicle automation, willingness to pay for self-driving vehicle technology, optimism regarding potential benefits of the technology (e.g. a reduction in potential automobile accidents) and concerns regarding potential pitfalls (e.g. vulnerability to hackers) among a host of other issues. Despite the wide-ranging research that has and is being conducted, it has been suggested that most self-driving vehicle technology being developed is not in fact accessible to persons with visual impairments [14]. I purport that this may be at least partially attributable to a scarcity of research that has focused specifically on the opinions and preferences of blind and visually impaired consumers in this regard.

To investigate this issue, I conducted an online survey involving 516 respondents who self-identified as blind or visually impaired, that explored respondents' general opinions of self-driving vehicles, opinions regarding the potential benefits of this technology, concerns regarding the technology and issues related to self-driving vehicles and visual impairment and blindness.

Related Work

Numerous studies in recent years have investigated public opinion regarding self-driving vehicle technologies, consumer preferences regarding specific self-driving systems and consumers' general willingness to pay for automated driving technologies.

In a 2013 telephone survey conducted by Continental AG in Germany, China, Japan and the U.S., 54% of the survey's 4,000 respondents indicated that they did not believe self-driving vehicles would function reliably [55]. For example, sixty-six percent of U.S. respondents indicated that they were "scared" by the concept of automated driving. A majority of respondents expressed an intention to use the technology more frequently on long freeway/highway journeys (67%) or in traffic jams (52%), but less in city traffic (34%).

Howard and Dai in a 2013 survey [56] explored the opinions of 107 respondents in Berkley, California regarding self-driving vehicles. Safety (75%) and convenience (61%) were identified by respondents as the most attractive features of self-driving vehicle technology. Additionally, 46% of respondents indicated that self-driving vehicles should operate with normal traffic, while 38% believed they should operate in designated lanes. More than 40% of respondents expressed willingness to either purchase a fully self-driving vehicle as their next vehicle or to retrofit their existing vehicle with self-driving technology if such a vehicle modification was possible. A number of respondents (35%) were also interested in having the purchase of their self-driving vehicle subsidized in some manner.

In a 2014 survey involving 1,533 respondents in the U.S, U.K. and Australia, Schoettle and Sivak investigated public opinion and concerns regarding self-driving vehicles [57]. They found that more than 50% of respondents in all three countries had positive expectations about the technology's potential benefits with respondents expressing the most confidence in the likelihood of better fuel economy occurring as a result of self-driving vehicles. Respondents in all three countries expressed significant concerns, however, regarding the technology with nearly 87% of respondents expressing some degree of concern regarding the safety consequences of equipment failure for instance. Women were found to be more concerned about the technology

generally than men and were more skeptical of its benefits. A majority of respondents in all three countries expressed some interest in having self-driving technology but were generally unwilling to pay extra for it.

Payre, Cestac and Delhomme conducted a public opinion survey in 2014 of 421 French drivers to investigate opinions on fully automated driving [58]. Men, and those scoring highly on the driving-related sensation seeking scale, were more willing to use a self-driving vehicle and were more inclined to purchase one whereas older respondents were less likely to indicate that they would purchase a self-driving vehicle but showed higher acceptance of the technology. Respondents expressed a preference for full automation on highways, in traffic congestion, for automatic parking and when impaired by drug use or alcohol.

Ipsos MORI in a 2014 public opinion survey involving 1,001 British respondents 16 to 75 years old, investigated attitudes related to cars and technological developments surrounding the automotive industry [59]. Of those surveyed, 18% felt that it was important for automobile manufacturers to focus on self-driving vehicle technologies, while 41% indicated that it was unimportant. Older people (55+) were less likely to embrace the technology than the youngest group (16 to 24), and 50% of those aged 55+ felt that the technology was unimportant compared to 30% of those in the 16 to 24 age group. Findings additionally indicated that respondents who lived in cities found self-driving vehicle technology to be more important than those living in rural environments.

In 2015 Kyriakidis, Happee and de Winter conducted a similar international public opinion survey involving 5000 respondents from 109 countries to investigate user acceptance, concerns, and willingness to buy partially, highly, and fully automated vehicles [60]. Respondents were most concerned about software hacking/misuse, legal issues, and safety. A

number of respondents (22%) indicated that they were unwilling to pay any money for a fully automated driving system while 5% indicating a willingness to pay more than $30,000 for such technology.

In a 2016 survey involving 618 respondents in the U.S, Schoettle and Sivak found that “no automation” was the preference for most respondents followed by partially self-driving vehicles [61]; approximately 16% of respondents expressed a preference for completely self-driving vehicles. Over 95% of respondents expressed some degree of concern (when all variations of concern are accounted for) regarding riding in a self-driving vehicle if there were no other transportation option available. Respondents overwhelmingly expressed a desire for manual vehicle controls to enable a human driver to take over vehicle operations at will, with 94.5% of respondents indicating that they would like a fully self-driving vehicle to have a steering wheel, gas, and brake pedals. In terms of entering route and destination information, 38% of respondents preferred the use of a touchscreen compared to 34.5% who preferred the use of a voice commands while 7.9% preferred the use of a personal portable device.

In a 2016 study involving 347 respondents in Austin, Texas, Bansai, Kockelman and Sing found that respondents on average were willing to pay $7,253 to add Level 4 automation or full self-driving capabilities to their vehicles [62]. This stands in contrast to the findings of much of the previously described research, which found that respondents where interested in the technology but were unwilling to pay extra. These findings are largely consistent with the findings of Daziano, Sarria and Leard [54], however, who found in a 2017 study involving 1,260 respondents that the average household in their study was willing to pay $4,900 extra for self-driving capabilities.

The present study is differentiated from prior work in that it was designed to specifically investigate key issues related to self-driving vehicles that I argue have been insufficiently investigated as it pertains to consumers who are blind or visually impaired; the study is the first formal survey with this focus.

Method

Online Survey

The present study was conducted as an online survey using the Qualtrics [63] survey platform. The questionnaire was adapted from a public opinion survey regarding self-driving vehicles in the U.S, U.K., and Australia conducted by Schoettle and Sivak [57]. The instrument (Appendix A) was modified to enable screen reader accessibility, to adjust the scales used and to expand the content to address topics related to visual impairment. The survey addressed:

- Respondent familiarity with self-driving vehicles
- General opinions about self-driving vehicles
- Concerns regarding self-driving vehicles
- Anticipated benefits of self-driving vehicles
- Willingness to pay for self-driving vehicle technology
- Issues related to visual impairment and blindness

Responses were gathered from January 4, 2017 through April 12, 2017.

Respondents

Participants were recruited through email notifications distributed by 16 state agencies for the blind and by the American Council of the Blind (ACB) [64]. Participation was restricted to individuals 18 years of age and older whom self-identified as blind or visually impaired. Participants were entered into a drawing for a $300 prepaid gift card as compensation. This recruitment strategy resulted in 556 replies from potential respondents with completed surveys received from 516 respondents. The final response rate of the survey was 92.8%. The margin of

error at the 95% confidence level for the results is +/- 4.0%. Demographic breakdowns for the respondents are provided in Table 3-1 through Table 3-6. Approximately 54% of respondents were female and approximately 45% were male (Table 3-2). More than half of respondents were 45 years of age or older, while those in the 18-44 age range made up 33.45% of those participating in the survey (Table 3-2). Nearly sixty percent of respondents held at least a bachelor's degree (58.92%), while fewer than 1% had less than a high school education (Table 3-3). Approximately 35% of respondents were full-time students, part-time students (Table 3-4). More than half of respondents (55.34%) indicated that they had been blind or visually impaired all of their lives (Table 3-5).

Table 3-1. Breakdown of survey respondents by gender.

Gender	Percent (*n* = 516)
Female	54.41
Male	45.40

Table 3-2. Breakdown of survey respondents by age group.

Age group	Percent (*n* = 516)
18-24	7.69
25-34	18.65
35-44	17.11
45-54	18.26
55-64	24.23
65-69	8.00
70+	5.96

Table 3-3. Breakdown of survey respondents by level of education.

Education	Percent (*n* = 516)
Some High School	0.96
High School	8.25
Some College	20.54
2 Year Degree / Associate's Degree	11.32
Bachelor's Degree	31.86
Graduate Degree	27.06

Table 3-4. Breakdown of survey respondents by level of employment.

Education	Percent (n = 516)
Employed Full-time	35.12
Employed Part-time	13.82
Not Currently Employed	19.77
Retired	21.31
Full-time Student	7.68
Part-time Student	2.30

Table 3-5. Breakdown of survey respondents by length of visual impairment.

Length of time blind or visually impaired	Percent (n = 516)
All Of My Life	55.34
Most Of My Life	21.36
Some Of My Life	18.06
I Recently Became Blind	5.24

Table 3-6. Breakdown of survey respondents by primary transportation type.

Transportation type used most often	Percent (n = 516)
Passenger car (any type or size)	38.00
Minivan, van or multipurpose vehicle)	4.41
Pickup truck	2.69

Results

General Opinion of Self-Driving Vehicles

A majority of survey respondents had heard of self-driving vehicles prior to the survey (95.96%) with most respondents having a positive impression of the technology (50.18% extremely positive, 30.44% moderately positive and 7.75% slightly positive). Fewer than 10% had a negative impression of the technology with 2.03% of respondents indicating that they held an "extremely negative" impression of self-driving vehicle technology.

Expected Benefits of Self-Driving Vehicles

Respondents were asked eight questions related to the anticipated benefits that might occur through the use of self-driving vehicle technology. With each question they were asked to select "extremely likely", "moderately likely", "slightly likely", "neither likely nor unlikely",

“slightly unlikely”, “moderately unlikely” or “extremely unlikely”. Figure 3-1 illustrates respondent perception of potential benefits accounting for all variations of “likely” (“extremely”, “moderately” and “slightly”), “neither likely nor unlikely” and all variations of “unlikely” (“extremely”, “moderately” and “slightly”). The majority of respondents felt that each of the expected benefits were likely to occur with self-driving vehicles with respondents expressing the most confidence in the likelihood of fewer automobile crashes (79.96% when all variations of “likely” combined), reduced severity of automobile crashes (79.21%) and better fuel economy (75.76%). Lower insurance rates were viewed as least likely (27.52% when all variations of “unlikely” combined).

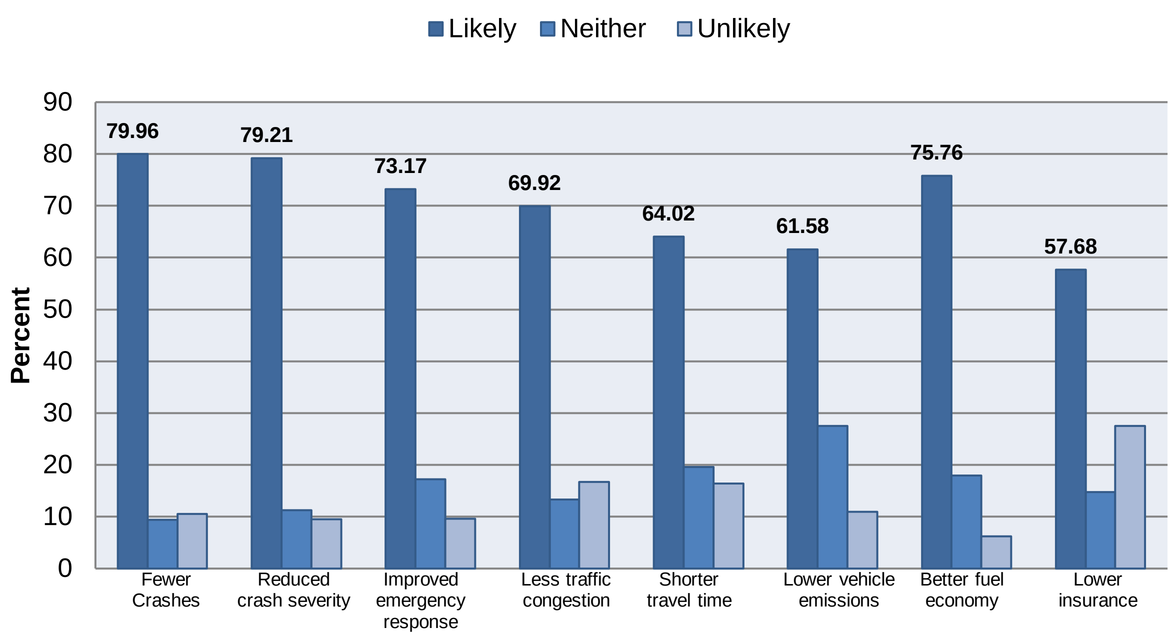


Figure 3-1. Summary of responses to Q6-Q13: “*Regarding self-driving vehicles, how likely do you think the following benefits will occur…?*” All variations of “likely” and “unlikely” have been tallied.

Self-Driving Vehicle Concerns

Operational concerns

Respondents were asked how concerned they would be about riding in a fully autonomous or self-driving vehicle as the primary operator. A definition describing a fully autonomous or self-driving vehicle accompanied the question. The most frequently selected response was "slightly concerned" (38.96%), followed by "moderately concerned" (22.82%), "not at all concerned" (21.52%) and "very concerned" (16.70%). Subsequently, respondents were asked how concerned they would be about riding in a partially autonomous vehicle as the primary operator. A definition describing a partially autonomous vehicle accompanied the question. The most frequently selected response was "slightly concerned" (30.91%), followed by "very concerned" (27.56%), "not at all concerned" (23.84%) and "moderately concerned" (17.69%). A majority of respondents expressed some degree of concern regarding their ability to operate a self-driving vehicle if one was made available to them (32.16% slightly concerned, 15.80% moderately concerned, 17.66% very concerned). Although some amount of concern was expressed by many participants, the most frequently selected response was "not at all concerned" (34.49%).

Issue based concerns

Respondents were asked 10 questions related to self-driving vehicle related issues; Figure 3-2 provides a summary of their responses. For each question respondents were asked to select "very concerned", "moderately concerned", "slightly concerned", or "not at all concerned". Respondents expressed the most concern (when all variations of concern are accounted for) about equipment failure or system failure (93.18%), followed by vehicles getting confused in unexpected situations (92.69%) and the interaction of self-driving vehicles with pedestrians and

bicycles (87.55%). The least concern was expressed about learning to use self-driving vehicles (44.09%).

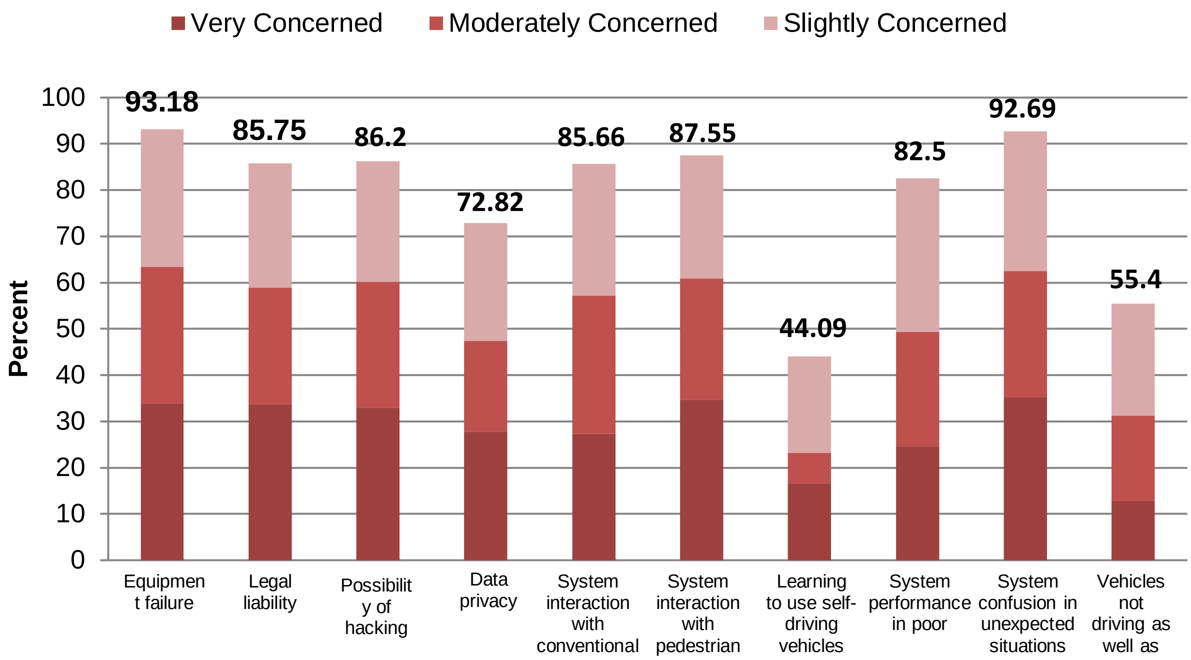


Figure 3-2. Summary of responses to Q19-Q28; 'not at all concerned' is not displayed: *"Regarding self-driving vehicles, how concerned are you about…"*.

Scenario based concerns

Respondents were presented with five potential scenarios involving self-driving vehicles; Figure 3-3 provides a summary of their responses. For each scenario they were asked to select "very concerned", moderately concerned", "slightly concerned", or "not at all concerned". Respondents expressed the most concern (when all variations of concern are accounted for) about self-driving commercial vehicles (85.07%), followed by self-driving public transportation (e.g. buses, 80.5%). Respondents were least concerned about the prospect of self-driving vehicles moving by themselves from one location to another (39.01% "not at all concerned").

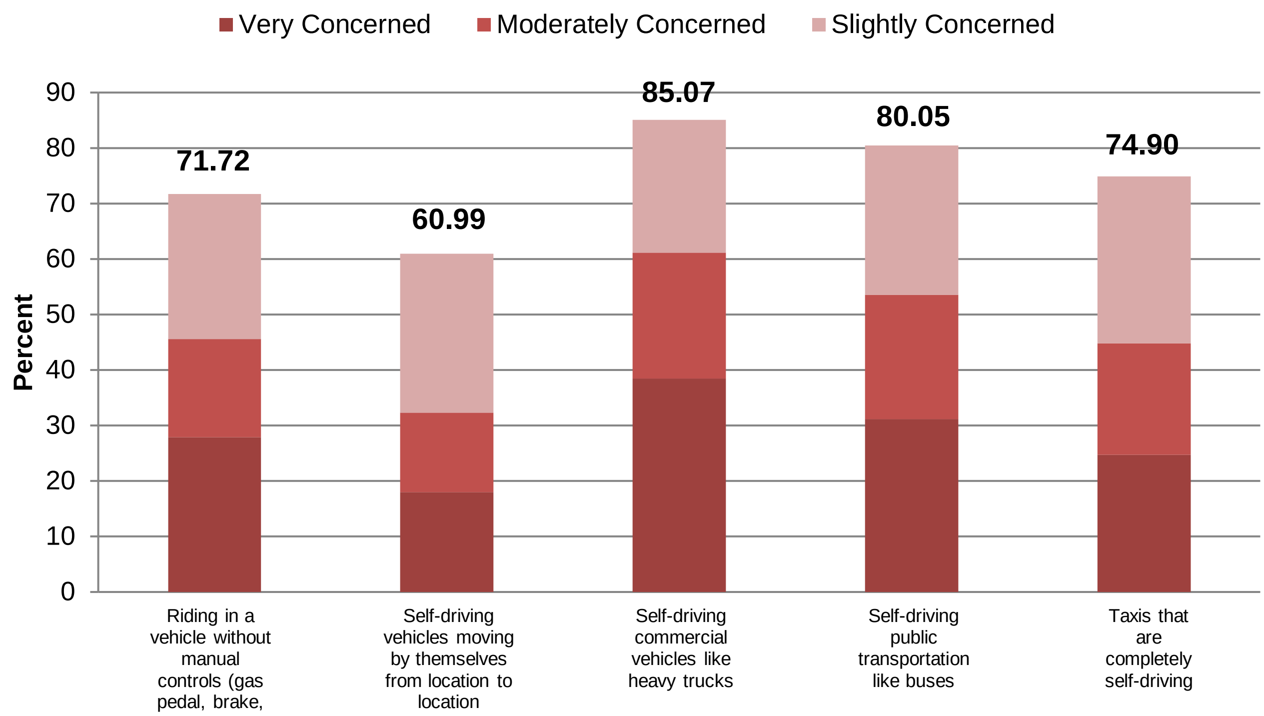


Figure 3-3. Summary of responses to Q30-Q34; 'not at all concerned' is not displayed: *"Regarding self-driving vehicles, how concerned are you about…"*.

Ownership Interest and Willingness to Pay

More than 90% of respondents expressed some interest in owning self-driving vehicle technology with 93.31% indicating that they were "extremely / very / moderately / slightly interested ". Respondents on average indicated that they were willing to pay $6,346 US extra for this technology with those at the 50th percentile indicating that they would pay $1,000 extra, and those at the 90th percentile indicating that they would pay $10,000 extra. About a third (n = 171) of respondents (33.11%) indicated that they would not be willing to pay extra for self-driving vehicle technology.

Self-Driving Vehicle Travel Time

Respondents were asked how they would occupy their time were they to travel in a self-driving vehicle and were presented with a list of nine options from which to choose from. Table

3-7 provides a summary of responses. The most frequently chosen response was “monitor the road even though I would not be driving” (31.99%), with “read” (20.31%) being the second most frequently chosen response.

Table 3-7. Percentage of responses to Q37: “If you were to ride in a completely self-driving vehicle what do you think you would use the extra time doing instead of monitoring the roadway?”

Response	Percent
Text or Talk With Friends Or Family	14.94
Read	20.31
Sleep	2.87
Watch movies / TV	1.92
Play Games	1.34
Work	12.07
Monitor The Road Even Though I Would Not Be Driving	31.99
Other	9.39
I Would Not Ride In A Completely Self-Driving Vehicle	5.17

Issues Related to Visual Impairment and Blindness

Each respondent was asked if they agreed that their needs, as a person with a visual disability, were being considered in the development of self-driving vehicles. More than half of respondents, 62.36%, said that they “strongly/somewhat/ agreed” while 20.47% indicated that they “strongly/somewhat/ disagreed”.

When asked about their concern regarding laws being put in place to prevent people who are blind from operating self-driving vehicles, 94.37% stated that they were “very/moderately/slightly concerned”; 60.58% of whom indicated that they were “very concerned”.

Statistically Significant Demographic Effects

Multiple One-way Analyses of Variance (ANOVA) were used to compare responses to survey questions for each individual demographic variable. Table 3-8 presents a summary matrix

from the series of ANOVAs, indicating statistically significant effects of demographic grouping on individual questions, either at $p \leq .05$, $p \leq .01$ or $p \leq .001$.

Table 3-8. Statistically significant effects of demographic groupings on responses to individual questions as presented through results from a series of one-way ANOVAs.

Question number	Ever heard of	General opinion	Length of visual disability	Employment status	Education	Transportation type	Age	Gender
Q3		***						
Q4		**				*		
Q5		***					*	*
Q6		***						*
Q7		***						**
Q8		***			**			**
Q9		***						***
Q10		***						*
Q11		***			**			
Q12		***			*			*
Q13		***			**			**
Q14		***	**	*	*			
Q15		***						
Q16		***	*	**			*	
Q17	**	***	*	*	*			
Q18		***						
Q19		***						
Q20		***	*					
Q21		***	*	*				
Q22		***	*	**				
Q23	*	***	*	**	**			
Q24		***		*				***

* = *p ≤ .05*

**= *p ≤ .01*

*** = *p ≤ .001*

Table 3-8. Continued

Question number	Ever heard of	General opinion	Length of visual disability	Employment status	Education	Transportation type	Age	Gender
Q25	*	***	*	*	*			**
Q26	*	***		*			*	***
Q27	*	***						***
Q28		***						***
Q29		***					**	***
Q38	*	*		**	*			
Q39		***					*	

* = $p \leq .05$** = $p \leq .01$

*** = $p \leq .001$

Prior awareness of self-driving vehicles (Q1)

Respondents who had not previously heard of self-driving vehicles expressed greater concerns about the technology than those who had. These respondents were more concerned about data privacy, destination tracking, self-driving vehicles not driving as well as human beings, self-driving vehicles moving by themselves from location to location, self-driving public transportation like buses, and self-driving heavy trucks and semis. Respondents who had not previously heard of self-driving vehicles expressed greater agreement with the contention that their needs were being considered in the development of the technology than those who had heard of it prior to the survey.

Initial opinion of self-driving vehicles (Q2)

Respondents' initial opinion of self-driving vehicles had a significant effect on every response. Respondents who began the survey with an initial favorable opinion of the technology were more likely to expect the occurrence of its benefits (i.e., a reduction in vehicle crashes) and less likely to express concerns. Respondents who held initial unfavorable views of the

technology were more likely to express concerns, viewing the technology as unsafe and unreliable for instance, and less likely to expect the occurrence of its benefits. This general principle holds for every question in the survey.

Gender (Q32)

Female respondents were found to be generally more concerned than male respondents about the self-driving vehicle issues and topics investigated during the survey. With respect to respondent concerns about their ability to operate a self-driving vehicle if one was made available to them (Q5), a significant effect of gender was observed at the $p < .05$ level for the two conditions [$F(1, 517) = 6.18$, $p =.0132$]. Post hoc comparisons using the Tukey HSD test indicated that the mean score for the female condition ($M = 2.26$, SD = 1.08) and the male condition ($M = 2.02$, SD = 1.06) were significantly different. In this study, females were shown to be more concerned about their ability to operate a self-driving vehicle if one was made available to them. Females continued to express this relatively greater concern in response to questions about riding in a self-driving vehicle with no driver controls available (e.g. gas pedal, brake pedal or steering wheel), self-driving vehicles moving by themselves from one location to another while unoccupied, self-driving commercial vehicles like heavy trucks, self-driving public transportation like buses and self-driving taxis.

Males were more likely to express a belief that the majority of the benefits of self-driving vehicles were likely to occur. With respect to respondent belief in the likelihood that the use of self-driving vehicles would result in less traffic congestion for instance (Q9), a significant effect of gender was observed at the $p < .001$ level for the two conditions [$F(1, 516) = 14.09$, $p =.0002$]. Post hoc comparisons using the Tukey HSD test indicated that the mean score for the female condition ($M = 4.94$, SD = 1.78) and the male condition ($M = 5.52$, SD = 1.70) were significantly different. Males in this study expressed a greater belief in the likelihood that self-driving vehicles

would result in less traffic congestion. Males continued to express this relatively greater belief in response to questions about the likelihood of fewer automobile crashes, the reduced severity of crashes, an improved emergency response to crashes, shorter travel time, better fuel economy and lower insurance rates.

With respect to respondent interest in buying or leasing a self-driving vehicle (Q29), a significant effect of gender was observed at the $p < .001$ level for the two conditions [$F(1, 518) = 11.52$, $p = .0007$]. Post hoc comparisons using the Tukey HSD test indicated that the mean score for the female condition ($M = 3.94$, SD = 1.37) and the male condition ($M = 4.32$, SD = 1.11) were significantly different. Mirroring their increased concerns and relative skepticism regarding their benefits, females were less interested in buying or leasing a self-driving vehicle than males.

Age (Q33)

Older respondents (55+) were the most likely to express concerns about their ability to operate a self-driving vehicle, while those in the 35 to 44 age group were the least likely (Q5). A significant effect of age was observed at the $p < .05$ level for the five conditions [$F(4, 513) = 3.03$, $p = .0172$]. Post hoc comparisons using the Tukey HSD test indicated that the mean score for the 35-44 condition ($M = 1.95$, SD = 1.06) was significantly different than the 55+ condition ($M = 2.35$, SD = 1.14). Younger respondents were more concerned about the potential for self-driving vehicles to be compromised by hackers than older respondents (Q16). A significant effect of age was observed at the $p < .05$ level for the five conditions [$F(4, 513) = 2.55$, $p = .0384$]. Post hoc comparisons using the Tukey HSD test indicated that the mean score for the 25-34 condition ($M = 2.84$, SD = 1.11) was significantly different than the 45-54 condition ($M = 2.62$, SD = 1.08). The youngest respondents were also more concerned about commercial self-driving vehicles like heavy trucks and semis (Q26). A significant effect of age was observed at

the $p < .05$ level for the five conditions [$F(4, 514) = 2.46$, $p = .0445$]. Post hoc comparisons using the Tukey HSD test indicated that the mean score for the 18-24 condition ($M = 3.25$, SD = 0.96) was significantly different than the 25-34 condition ($M = 2.62$, SD = 1.20). Younger respondents were more interested in owning or leasing a self-driving vehicle and older respondents (55+) were the least interested (Q29). A significant effect of age was observed at the $p < .01$ level for the five conditions [$F(4, 514) = 4.68$, $p = .0010$]. Post hoc comparisons using the Tukey HSD test indicated that the mean score for the 25-34 condition ($M = 4.39$, SD = 1.08) and the mean score for 35-44 condition ($M = 4.37$, SD = 1.20) were both significantly different from the 55+ condition ($M = 3.86$, SD = 1.38). Older respondents also were the least concerned about the prospect of laws being enacted that would prevent people who are blind from operating self-driving vehicles whereas those in the 25 to 34 age group were the most concerned (Q39). A significant effect of age was observed at the $p < .05$ level for the five conditions [$F(4, 509) = 2.75$, $p = .0275$]. Post hoc comparisons using the Tukey HSD test indicated that the mean score for the 25-34 condition ($M = 3.53$, SD = 0.78) was significantly different than the 55+ condition ($M = 3.19$, SD = 1.00).

Education (Q34)

For four of the proposed benefits (i.e., likelihood of fewer crashes, reduced severity of crashes, reduced traffic congestion, and shorter travel time) of self-driving vehicles discussed within the survey, higher education levels were not associated with greater expectations regarding these benefits. For three of the four remaining proposed benefits – improved emergency response to crashes, lower vehicle emissions, and better fuel economy – expectations increased with education level up to 'Some College,' but decreased as education increased further. For the potential benefit 'lower insurance rates', expectations rose through the 'Associates Degree' education level before decreasing. Respondents who stated their education

level as ‘Some High School’ were most likely to express concerns regarding system failure and data privacy and expressed the most concern about self-driving vehicles driving as well as human drivers. Higher education levels were associated with decreased concern regarding vehicles not driving as well as human drivers (Q23). A significant effect of education was observed at the $p < .01$ level for the six conditions [$F(5, 512) = 3.53$, $p = .0038$]. Post hoc comparisons using the Tukey HSD test indicated that the mean score for the ‘Some High School’ condition ($M = 3.40$, SD = 0.89) was significantly different than the ‘Some College’ ($M = 1.98$, SD = 1.17), ‘Associate’s Degree’ ($M = 1.86$, SD = 0.91) and ‘Graduate’s Degree’ conditions ($M = 1.84$, SD = 1.00). Lower education levels were associated with an increased belief in a respondent’s agreement that this/her needs were being considered in the development of self-driving car technology (Q38). Respondents who indicated that they possessed a graduate degree expressed the least agreement that their needs were being considered. A significant effect of education was observed at the $p < .05$ level for the six conditions [$F(5, 512) = 2.95$, $p = .0122$]. Post hoc comparisons using the Tukey HSD test indicated that the mean score for the ‘Some College’ condition ($M = 5.10$, SD = 1.66) was significantly different than the ‘Graduate Degree’ condition ($M = 4.43$, SD = 1.75).

Employment status (Q35)

Respondents who were part-time students were more concerned about the safety consequences of equipment failures, self-driving vehicles getting confused by unexpected situations, riding in a self-driving vehicle with no manual controls available and unoccupied self-driving vehicles moving by themselves from one location to another. Regarding the potential for self-driving vehicles to be compromised by hackers (Q16), a significant effect of employment status was observed at the $p < .01$ level for the six conditions [$F(5, 512) = 3.29$, $p = .0061$]. Post hoc comparisons using the Tukey HSD test indicated that the mean score for the ‘employed full-

time’ (M = 2.68, SD = 1.04) and ‘retired’ (M = 2.69, SD = 1.02) conditions were significantly different than the ‘employed part-time’ condition (M = 3.66, SD = 0.49).

With respect to respondent concerns about self-driving vehicles driving as well as human drivers (Q23), a significant effect of employment status was observed at the $p < .01$ level for the six conditions [$F(5, 512) = 3.61$, $p = .0032$]. Post hoc comparisons using the Tukey HSD test indicated that the mean score for the ‘employed full-time’ condition (M = 1.81, SD = 1.00) and ‘not currently employed’ condition (M = 2.24, SD = 1.08) were significantly different. Those not currently employed were thus shown to be more concerned about self-driving vehicles driving as well as humans.

Mode of transportation (Q36)

A respondent’s mode of transportation was not found to be associated with a particular perspective relative to concerns regarding self-driving vehicles or the potential benefits that could occur as a result of self-driving vehicles. Regarding respondents’ concern about riding in a partially autonomous vehicle as the primary operator (Q4), a significant effect of mode of transportation was observed at the $p < .05$ level for the six conditions [$F(5, 512) = 2.34$, $p = .0407$]. Post hoc comparisons using the Tukey HSD test, however, indicated that the mean scores for the ‘passenger car’ (M = 2.39, SD = 1.11), ‘minivan/van’ (M = 2.47, SD = 1.16), ‘pickup truck’ (M = 2.38, SD = 1.12), ‘SUV’ (M = 2.13, SD = 1.15), ‘motorcycle’ (M = 1.60, SD = 0.54), and ‘public transportation’ conditions (M = 2.62, SD = 1.12) were not significantly different from one another.

Length of time of visual disability (Q37)

Being blind or visually impaired for all of a respondent’s life was associated with higher levels of concern regarding equipment failure, data privacy, learning to use self-driving vehicles and self-driving vehicles not driving as well as humans. Respondents who indicated that they

had been blind or visually impaired for a shorter period of time, some of their life, were generally less concerned about system performance in poor weather and about self-driving vehicles getting confused in unexpected situations. Respondents who selected, “I recently became blind” were associated with greater concern regarding unoccupied self-driving vehicles moving by themselves from one location to another but with lower concern about learning to use self-driving vehicles. With respect to respondent concerns about self-driving vehicles not driving as well as human drivers (Q23), a significant effect of length of visual disability was observed at the $p < .05$ level for the six conditions [$F(3, 509) = 2.89$, $p = .0349$]. Post hoc comparisons using the Tukey HSD test indicated that the mean score for the ‘some of my life’ condition ($M = 1.76$, SD = 0.91) and ‘I recently became blind’ condition ($M = 2.37$, SD = 1.11) were significantly different. Those who indicated that their visual disability was recent were thus shown to be more concerned about self-driving vehicles not driving as well as human drivers.

Discussion

General Opinions Regarding Self-Driving Vehicles

The vast majority of respondents had heard of self-driving vehicles prior to participating in the study, the majority held a generally positive view of the technology and a majority of respondents had an optimistic view regarding the potential benefits. My findings, in this regard, are similar to those of Schoettle and Sivak [57], though respondents in the present study were most confident regarding the likelihood of fewer automobile crashes and least confident regarding lower vehicle emissions. In the Schoettle and Sivak study, respondents were most confident regarding better fuel economy and least confident regarding shorter travel time. In the present study, men were more confident regarding the likelihood of potential benefits whereas women were relatively more skeptical.

Significant concerns were raised regarding all eight of the issues addressed within the study with respondents most concerned about equipment and system failure, self-driving vehicles getting confused by unexpected situations and interactions between self-driving vehicles, bicycles, and pedestrians. While these findings are consistent with the literature in that public opinion surveys have generally suggested that consumers have significant concerns regarding self-driving vehicle technology [54], [57], [61], my findings suggest that the concerns of blind and visually impaired consumers may be somewhat different than consumers generally. While concerns regarding legal liability for owners and drivers has been a primary concern of respondents in studies by Howard and Dai [56] and Schoettle and Sivak[57], it placed 5^{th} on the list of concerns in the present study. The same is true for concerns regarding self-driving vehicles not driving as well as human drivers, which placed 7^{th} on the list of concerns in the present study but was 3^{rd} in the Schoettle and Sivak study [57].

These differences continued through the five scenarios of potential concern that were presented to respondents. While much of the literature has suggested that consumers are especially concerned about the potential absence of manual controls in self-driving vehicles [57], [61], [65], this was viewed as one of the least concerning scenarios for respondents of the present study. Respondents were most concerned regarding self-driving commercial vehicles (e.g. heavy trucks) and self-driving public transportation vehicles like buses. Overall, regarding the eight issues and five scenarios of potential concern, women expressed more concern than men and perhaps not surprisingly given their relative concerns, expressed the least interest in owning or leasing a self-driving vehicle.

The Ability to Operate Self-Driving Vehicles

While learning to use a self-driving vehicle was one of the least concerning issues for respondents of the eight presented, the ability to operate the technology was an area of concern

for older respondents (55+). Respondents in both groups were more likely to express concerns regarding their ability to operate a self-driving vehicle while those in the 35-44 age group were least likely. The issue of the control of self-driving vehicles has typically been investigated only from the perspective of the inclusion or exclusion of manual controls [65] or the preferred type of route input device [61]. Additional research is needed to identify what the specific areas of concern are for persons who are blind or visually impaired regarding self-driving vehicle operation.

Interest in Ownership and Willingness to Pay

More than 90% of respondents expressed an interest in owning self-driving vehicle technology; a high interest in ownership that is consistent with the literature [57], [60], [61]. A majority of respondents also indicated a willingness to pay extra for self-driving vehicle technology. Much of the literature in this regard, which has presumably focused on sighted consumers, has indicated that consumers generally are unwilling to pay extra for self-driving vehicle technology [57], [60], [61]. My findings indicate that blind and visually impaired consumers, on average, may be willing to pay more than $6,000 extra for self-driving vehicle technology, a sum higher than the $4900 found by Daziano, Sarria and Leard [54], presumably with sighted consumers and approaching the recent findings of Bansai, Kockelman and Sing [62] of $7253.

Issues Related to Visual Impairment and Blindness

A majority of respondents in this study indicated that they believed their needs were being considered in the development of self-driving vehicle technology; however, it has been suggested that most self-driving vehicle technology being developed is not in fact accessible to persons with visual impairments [14]. There appears to be a mismatch between respondents'

belief regarding the consideration of their needs and the actual accessibility of the self-driving vehicle technology being brought to market.

While additional research is needed to conclusively verify both sides of this question, the mismatch may be the result of influence of marketing efforts and the media. Google's Waymo, one of the leaders in the development of self-driving vehicle technology, has prominently featured a blind user operating one of it's self-driving cars in self-produced promotional videos for years [66]. The operation of its self-driving car by a blind person has also been covered with much fanfare by the media, being written about with titles like, "Blind man sets out alone in Google's Driverless Car" [9]. Given these types of marketing efforts and coverage in the media, it is perhaps not surprising that many persons who are blind or visually impaired believe that their needs are being considered in the development of self-driving vehicle technology. The uncertainty in this regard underscores the need for additional research both as it pertains to consumer opinions on the topic as well as the actual accessibility of the technology.

Over the past five years, a number of laws and regulations have been proposed that, if enacted, would potentially prevent blind persons from operating self-driving vehicles. Laws that would require a licensed driver as the primary vehicle operator, or require that the primary operator have the ability to take over control in the event of an emergency [67] would effectively prevent persons who are blind or visually impaired from operating self-driving vehicles using current technology. Over 90% of respondents indicated that they were concerned regarding the prospect of laws being put in place to prevent people who are blind from operating self-driving vehicles.

Limitations

In adapting the survey instrument of Schoettle and Sivak a number of design choices were made related to content, accessibility and structure while attempting to preserve the general

themes of the original survey, which aligned well with my research questions. In the process, I made a conscious decision to omit a question related to respondents' degree of vision loss that could have been used as a demographic variable during data analysis. The point of this exclusion was to view the survey and its data collectively as representing the perspective of blind and visually impaired consumers. An argument can be made that an opportunity was missed to dig deeper into the data to identify differences between blind and low vision consumers.

It is also important to note that for one demographic question (Q37) an uncaught error in the survey instrument may have potentially impacted the results. During revisions of the instrument the text of one of the response options to this question should have been shortened to state, "Recently" and was instead shortened to state, "I recently became blind". Given the context and the data, I believe that many respondents correctly assumed the intent of the question was, "I recently became blind or visually impaired" or simply "Recently" given the context of the question. But it is important to note the error in expressing the limitations of this study the results.

CHAPTER 4
FOCUS GROUPS OF BLIND AND LOW VISION CONSUMERS REGARDING SELF-DRIVING VEHICLES

The present study was designed as a follow up activity to the online survey (Chapter 3) with the intent of further investigating the opinions and concerns of blind and low vision consumers regarding self-driving vehicle technology. Using focus group methodology, 38 people who are blind and low vision participated in eight focus groups. Participants were asked to provide their general opinions regarding self-driving vehicles, comment on their hopes for the technology, reflect on their concerns, and express their preferences regarding interaction mechanisms among other topics in a semi-structured group discussion lasting approximately one hour per focus group.

Related Work

Relative to surveys, there have been few published investigations of self-driving vehicles using focus group or interview methodology. In 2013, professional services company KPMG conducted a focus group study with a total of 32 participants across California, Chicago, and New Jersey that is one of the few formal focus group studies to be found in the related literature [65]. Their results showed that women (median = 8.5 on a scale from 1 to 10) were more willing to use self-driving vehicles than men (median 7.5). Safety was a dominant topic of discussion during the focus groups with many participants expressing skepticism that the technology would work properly. Participants were near unanimous in expressing a need to be able to take control of the vehicle at will for a variety of reasons. Some participants expressed a lack of trust in the automated systems and expressed comfort in having manual controls available. Participants also expressed joy in driving and appreciated having manual controls as an option.

Method

The use of focus group methodology was chosen over other methods because it provided an opportunity to elicit subjective perspectives regarding the research topics while allowing for a significant amount of flexibility to pursue themes that emerged during the course of discussion.

Participant Recruitment

Interested individuals were invited to participate if they fulfilled the following criteria: age 18 or above and currently considered themselves to be a visually impaired person based on an accompanying definition that defined that as blindness or with limited vision not correctable by glasses or contact lenses. Advertisements indicated that interested individuals should also have transportation to one of two focus group locations in North Central Florida. Participants were recruited by email, newsletter, and social media announcements distributed by organizations serving individuals with visual impairments in North Central Florida and by vocational rehabilitation organizations. Those interested in participating were asked to call or email for additional information and scheduling. The Institutional Review Board of the University of Florida approved this study and each participant provided written informed consent the day of his or her focus group session. Participants were compensated with a $20 prepaid gift card for their participation.

Description of Participants

Eight focus groups were conducted in two separate locations in North Central Florida. In total, 38 participants were involved in the study in groups of 4, 5, and 6 people. Participant demographics are provided in Table 4-1 through Table 4-3. Breakdown of focus group participants by ethnicity. . Study participants had a mean age

of 51.5 (range = 18 to 90 years old) and a household annual income that ranged from under $15,000 to over $99,000. Twenty-two participants self-identified as blind, and 16 self-identified as low vision. Krueger and Casey have argued that focus group participants should share similar characteristics (e.g. gender group, age-range, social class background) in order to encourage open dialogue within the group, but with enough variation to allow for contrasting opinions [68]. An attempt was made to group participants near their preferred location in accordance with this principle with a primary factor of similarity being a participant's characterization of their vision loss and a secondary factor being their age. No other factors were considered for the purpose of constructing the focus groups (e.g. race, gender, education). During the screening and scheduling process participants were briefly presented with functional definitions of blindness and low vision [69]. They were then asked to choose the definition that *best* characterized their degree of vision loss. As a result of this approach, when feasible, participants were placed in a group with other individuals who similarly characterized their vision loss as either blind or low vision. Where placement in such a group was not possible, typically due to logistical or scheduling constraints, an attempt was made to place the participant in a group with at least one individual of similar age irrespective of whether or not the majority of the group's participants had expressed a different degree of vision loss. The approach resulted in one group that was predominantly composed of blind persons, one group predominantly composed of low vision persons, one group evenly split by degree of vision loss and three groups that were relatively homogeneous in terms of age and predominantly composed of blind persons, each consisting of older participants (55+). The remaining groups were each slightly weighted towards blind

participants in terms of composition though each group contained at least two low vision participants.

Table 4-1. Breakdown of focus group participants by degree of vision loss.

Degree of vision loss	Female (*n* = 20)	Male (*n* = 18)
Blind	45.0	72.2
Low Vision	55.0	27.7

Table 4-2. Breakdown of focus group participants by age range.

Degree of vision loss	Female (*n* = 20)	Male (*n* = 18)
18-24	10.0	22.2
25-34	0.0	16.6
35-44	5.0	11.1
45-54	15.0	11.1
55-64	30.0	27.7
65-74	30.0	5.5
75+	10.0	5.5

Table 4-3. Breakdown of focus group participants by ethnicity.

Degree of vision loss	Female (*n* = 20)	Male (*n* = 18)
White / Caucasian	90.0	61.1
Black / African American	10.0	16.6
Hispanic	0.0	16.6
Mixed Race	0.0	5.5

Procedure

Each focus group lasted approximately one hour with a procedure that was identical, excluding the semi-structured interview, for each session. After each participant was seated in the meeting space, the informed consent document, which had been emailed to each participant in an accessible format the day before each focus group, was read aloud by the study moderator. Participants were then provided with assistance, as needed, signing the informed consent document. After being provided light refreshments, a brief ice breaking exercise was led by the focus group moderator to introduce participants to one another and encourage interaction between participants. A semi-structured interview followed. Between three and five days following the focus group

session, a telephone interview was conducted with each participant to provide an opportunity to ask follow up questions after a period of reflection and to gather additional demographic information. This chapter reports on the results of each focus group's semi-structured interview as well as relevant demographic data.

Focus Group Guide

A semi-structured script was created (Appendix B) to elicit information from participants about their understanding and awareness of current developments regarding self-driving vehicles, hopes and aspirations for future self-driving vehicle technologies, concerns related to the accessibility of self-driving vehicles, and opinions regarding the legal environment for the use of this technology by persons with visual impairments. The focus group guide was pilot tested with three participants in a group setting prior to beginning data collection to ensure that it was comprehensible and comprehensive.

Data Capture and Transcription

Each focus group session was video recorded and transcribed verbatim by a professional transcriptionist prior to analysis. The completed transcript was then verified by a member of the research team against the original recordings.

Analysis

In preparation for analysis all transcripts were entered into MAXQDA [70], a computer program for quantitative data analysis. After initially familiarizing ourselves with the data, two investigators independently coded all quotations from participants. For each researcher, this hybrid process began with a small set of apriori codes agreed upon by the research team in advance, then continued with codes inductively identified within the data. Each coding was then categorized and refined by each researcher independently. Both independent analyses were then merged into a single definitive version by a third

researcher with any disagreements in coding and categorization settled by this third researcher and agreed upon by the research team collectively.

Results

Self-Driving Vehicle Concerns

Are the needs of individuals with visual impairments being adequately considered in the development of autonomous vehicle technologies?

While opinions varied, most participants expressed the view that the needs of individuals with visual impairments were not being adequately considered in the development of autonomous vehicle technologies. Negative experiences with past technologies were frequently cited as examples of why they believed these needs were likely being ignored:

> No, I don't / I don't think they do. And they didn't when they invented the quiet car. And that's, you know, that was an invention that's plagued me. I mean, I love hybrid vehicles and what they do for the environment, but I hate hybrid vehicles and how dangerous they are. They're like sharks in the water now. You don't know when it's coming up behind you. It may strike. (P38)

> I know that in the past with all the new technology that's come out so far, blind people have been kind of an afterthought. (P37)

Many participants expressed a belief that the technology presently exists to solve most autonomous vehicle accessibility challenges, but that manufacturers need to be made aware of the importance of the issue:

> Like, on the side like Tesla and Uber and whatnot, I'm sure there's someone somewhere thinking about that, but I don't think it's in, like, the forefront. (P34)

> If you KNOW of all these obstacles, they can be overcome. And the technology, it pretty much exists now. It's just a matter of marrying that technology, you know? (P17)

Parking, orientation, and vehicle location

A variety of issues were raised related to the parking of an autonomous vehicle, orientation to a destination upon parking and the location and identification of a visually impaired operator's vehicle at the conclusion of a trip.

Many participants expressed concerns regarding their ability to provide parking guidance to an autonomous vehicle without the ability to see the surrounding area. Some of the concerns expressed related to safety:

> How do you try to set a car to park where you want it to park if you can't see where to show it to park or tell it to park or whatever? You might be parking in the / across a railroad track. (P12)

Some expressed concerns related to convenience and practicality, with travel to shopping malls being a frequently provided example of the need to tell a self-driving vehicle specifically where to park:

> When you pull into a shopping mall, you know, you got like this one out here is, you got Penney's on one end, Sears in the back and Belk's on the other end. Well, you know, you need to be able to tell it… (P11)

The ability to orient oneself to the desired destination (e.g. a building's front door) upon arrival to a location was a widely discussed topic. Many participants felt that this was an unanswered question that would need to be addressed by the technology:

> Now, if I drive up in a car and get out of the car, how do I know where the door is? In other words, there's a…the car has to do a lot besides just drive. (P24)

One participant raised questions about how the technology would enable her to orient herself to her desired destination in the event that she were dropped off in a parking lot:

> And there's also, you know, if it takes you to a location and it like drops you off in the middle of like a parking lot, you know, which building or which direction that your actual destination is? You know, something that would also, like, help you figure that out and know where that is. (P23)

In response, another participant (P21) suggested dedicated autonomous vehicle parking to aide in general orientation.

Many participants raised questions about the technology necessary to enable an autonomous vehicle operator with visual impairments to locate his or her vehicle in a large crowded space like a shopping center parking lot. A number of solutions were expressed across focus groups to include programming the vehicle to return at a specified time and location (P30, P32), to key chains designed to vibrate based on proximity to the vehicle (P34).

Location verification

The desire for a vehicle feature that would enable an operator with visual impairments to verify his or her arrival at a desired location was a topic of great interest. A majority of participants across focus groups commented that such a feature was important to some degree and that they would be concerned about inadvertently getting out of the vehicle in the wrong place. A commonly expressed view was that the technology should provide some type of backup system to prevent such an occurrence:

> I think my operating system should take care of it. You know? It’s like she’d…she’d take care of everything. So, I think the operating system should say, “Don’t get out of the car. You’re in the wrong…you’re in a field.” (P32)

In many cases the expressed desire for this feature closely related to negative experiences with automotive navigation systems where the participant had observed these systems lead others in the wrong direction, make errors or otherwise fail to operate properly. One participant’s comment was representative of many regarding this topic:

> …you know, I’ve experienced on MV, you know, our public transportation that, you know, the GPS saying, “You have arrived at your destination” and, you know, and the driver says, “No, we haven’t.” So, you know, it’s not all it seems. Like GPS is fallible, you know, at times. (P20)

Situational awareness

The desire for a vehicle feature that would, at any given time, provide information on an operator vehicle's relationship to other vehicles, landmarks, pedestrians, obstacles and the final destination was frequently discussed. Many participants across focus groups expressed a view that the self-driving vehicle's technology should be able to provide such information in real time to mirror the type of information that a sighted operator would have available through the use of cameras, mirrors, and sight:

> I think it would make the person sitting in the car feel a little bit more at ease. You know, that you know, since you can't see where you're going or where you're at, that it would tell you like, "Well, you know, we are like half a mile away from your destination." (P2)

> …you don't necessarily know, like, where you are in relationship to where you're actually going. Something that might help you, like place, like where you are. (P23)

Interaction with non-autonomous vehicles

Participants generally expressed skepticism that autonomous vehicles would be able to successfully operate alongside non-autonomous vehicles due to the unpredictability of human drivers:

> I think that the fact that they have to interact with people driving is a downfall too, because, you know, people are really bad drivers. I ride with my daughter all the time and the people constantly running red lights, cutting us off and doing things, you know. And I would…you know, you would wonder how the car would react to things like that. (P33)

> My downside is…To me, my – this is my opinion – I just don't see an autonomous car being able to react to human error that quickly. (P25)

Many participants commented that as autonomous vehicles became more common and displaced non-autonomous vehicles on the road they believed the interaction problem would lessen as captured in this exchange between three participants in group six:

> Well, I think the autonomous vehicles are like the flu shot. The more people that get the flu shot, (P25 laughs) the less chance of an epidemic. The more autonomous vehicles that are on the road… (P27)

> The more of them that are on the road, the safer the roads will be. (P26)

Help and roadside assistance

How to and who to ask for help in the event of a vehicle breakdown or unforeseen event was a topic that was brought up repeatedly in the study. While the overwhelming majority of participants stated that they had never owned or operated a vehicle, the suggested approaches took the form of a type of monitoring and assistance service similar to General Motors' OnStar [71] which was specifically named several times:

> Yeah, that would be good, if they had some kind of like, like a home center (P2: Yeah. Yeah), you know, that paid attention. Like a security system for cars that keeps track of where your car is going. So, if you're lost or something, you're able to get help. (P4)

> Well, I…I think about something along the lines of – and I've never used it before, but, you know, something along the lines of OnStar. In other words, you know, if you get into some trouble, if there's vehicle trouble, you know, with the actual vehicle itself, being able to call, you know, somebody to come and help you. 'Cause, obviously, if I was riding it by myself and the car had a problem and was maybe automatically pulled over, I wouldn't know where I was. (P20)

Legal liability

A small number of participants raised questions regarding legal liability in the event of an accident. Some participants expressed concerns about the seemingly unsettled liability questions in the event of an autonomous vehicle accident while several blind participants expressed concerns that they would be automatically assumed to be liable as captured in this exchange between two participants in group two:

> You can't even be your own witness? (laughs) (P6)

> (laughs) Yeah, you're just getting blamed for it for sure. (P5)

Potential Benefits of Self-Driving Vehicles

The majority of participant comments in the study that focused on the potential benefits of self-driving vehicles centered on the potential for increased independence,

personal mobility and the potential for time savings versus participants' existing means of transportation.

Independence and mobility

Many participants specifically referenced "independence" when referring to the potential benefits of self-driving vehicles with many participants expressing a hope that self-driving vehicles would enable them to no longer rely on friends, relatives or public transportation for their transportation needs:

> I would definitely say the benefit would be to not have rely on people to take you (P6 nods) around. That you could just get up and go whenever you want to, whenever you want to. (P7)

> Independence and the ability to go from point A to point B without having to ask somebody to drop what they're doing to do that for you. (P16)

Within the context of the discussion regarding independence, several participants specifically discussed a desire for basic transportation capabilities that would enable them to return to work as expressed by one blind participant:

> You know, I think one of the things that's important to understand is, you know, everybody is looking at these high-end abilities, you know, things like luxury, comfort, you know, safety about, you know, an ability to go anywhere. I don't think that we have to start there. You know, if I could purchase an AV that…I was in home healthcare sales rep, but, you know, two years ago. You know, I…Every week, I called on the same doctor's offices, the same hospitals, the same nursing homes. You know, I ran the same route every day, on time. You know. And if I could have a vehicle that I could program to do nothing but that route and how to get here and maybe the grocery store, I would be totally 100% happy. (P16: Definitely, yeah.) You know? And I think that's one of the things that these engineers are missing is: they're trying to make the all-inclusive, you know, panacea, you know. And that's not really what people with disabilities are concerned with. (P14: Right.) Yea it would be nice to have. But we're just looking for the basic mobility and independence that most people totally take for granted.

Participants in the study commented on the impact that the inability to operate a personal vehicle had on their daily lives. Participants indicated that it impacted where they lived,

their diet, their shopping habits, their medical care, their employment and their ability to visit friends and relatives. Nearly all participants responded positively to the potential independence and mobility benefits of self-driving vehicles:

> Well, the idea of being able to get in a car at the time you wanted to and go wherever you want it to and get in it and come back home when you wanted to, it would mean an awful lot, I think. (P12)

One blind participant indicated that she did not see any benefits however (P29).

Time savings

Participants also expressed overwhelmingly positive opinions about the potential time savings of the use of a self-driving vehicle over their current forms of transportation, which, in most cases was public transportation, friends or family. Many shared personal stories about their daily challenges or the challenges of friends with visual impairments and how these challenges could potentially be overcome with the use of a self-driving vehicle:

> I know a guy who goes to work and he spends three hours to get there and like two hours coming home. And that's for 25 years he's been doing that. (P25: Oh my God!) So, can you imagine how valuable that time is that he is losing? (P26)

> And…And what you…What people don't realize what you could in 30 to 45 minutes, it takes on a bus two hours to four hours. [P28: Or more.] Like getting here. (P25)

Licensing and Training

The discussion of legal and regulatory issues related to self-driving vehicles centered on laws that could potentially restrict access to persons with visual impairments. Broadly within the study these discussions generally focused on the potential requirement that self-driving vehicle operators possess a valid driver's license or on potential training requirements.

Many participants expressed concerns about the prospects of laws being put in place that would effectively prevent persons with visual impairments from operating self-driving vehicles. The most concerning prospect for many was the requirement that a valid driver’s license be required to operate a self-driving. Several participants expressed the view that this amounted to a form of discrimination.

> So, I think they would have to make some laws, like he was saying, to…for people not to do that. 'Cause we have rights too. (P3)

> But regardless, I’d really…I personally hate…That’s what ADA is all about. (P25: Yeah.) (P24)

The topic elicited a variety of comments and some degree of disagreement with several participants suggesting that a driver’s or operator’s license of some kind should be required to, at a minimum, promote safe operation and prevent children or individuals with limited cognitive abilities from operating self-driving vehicles alone:

> I think, the first thing that comes (P19: Safety.) to my mind would be, you know: Would…I mean, it seems logical that if we’re gonna operate something like that we’d have to get a driver’s license. And I…I’m just not sure how that’s gonna work. (laughs) (P20)

> I would say, you don’t put a sixteen-year-old behind the wheel. (P38)

In many of these discussions within the study, a compromise of sorts that seemed acceptable to the group that emerged was the concept of an “operator’s license” that could be earned through a training program and testing:

> When you drive a normal car you gotta go and get your driver's license and take a class, so there should probably be a class to take for this, too. I think. I mean, that would make sense. Maybe not that extensive or whatever, but, you know, just like all the safety issues and stuff like that. It would make sense to have that. (P5)

> And I think to be on the safe side and keep you from having some issues, I think it’s better that you have to take a test. (P31)

The Human-Machine Interface of Self-Driving Vehicles

The discussion of the human-machine interface (HMI) of self-driving vehicles focused on the manner in which participants anticipated that they would interact with a self-driving vehicle and their preferences in this regard.

A majority of participants anticipated that self-driving vehicles would implement some type of speech interaction capability. For example:

> I hope it's so that you can just get in the car and say, “I want to go to “such and such church” and it'll take you there. And I hope I can get in and say, “I want to go home”, when it's over. (P11: Well) I hope they can simplify it somewhat. (P12)

Concerns were expressed about the accuracy of speech input however with personal experiences with voice recognition errors in Apple’s Siri [72] being cited as examples by several participants.

Participants expressed a variety of opinions, however, regarding their preferred primary means of interacting with a self-driving vehicle. While some expressed a preference for speech input, several expressed a desire to interact with the vehicle primarily through the use of their smartphone as captured in this exchange in one of the focus groups:

> Because like most visually impaired or blind individuals, like we have smart phones. So, is there a way to put it in through our phone that it will sync with the car? Well, I’m not saying “Is there a way?” but “Could there be a way?” I guess, that’s what I’m asking. I guess, that would probably be the number one thing. (P21)

> I think that would probably be a good idea ‘cause a phone is something I can, like, hold up closer to me so I can see it easier. And also, it will read it back to me, like, that’s already accessible in that way versus like having to look at something else. And I’d also say to make like buttons or different things maybe more distinguishable so you know which one is which. (P23)

The use of a touchscreen to interact with an autonomous vehicle was described by many participants as a backup means of interaction. One participant with low vision who

favored the use of a smart phone as a primary means of interaction preferred the use of a touchscreen as a backup form of interaction in the event that her smartphone failed albeit with an iPhone like “voiceover” feature that would indicate what icon was being touched. Several blind participants disagreed with this comment however citing past problems with voiceover and the inaccessibility of standard touch screen displays.

Purchase Considerations

Vehicle purchase considerations as it related to self-driving vehicles largely revolved around cost, vehicle maintenance, and the presence of backup systems.

Most participants who commented on the topic expressed a view that while the costs are at present unknown, self-driving vehicles would likely be costly, if not prohibitively so. For example:

> … let’s face it, most of these vehicles to begin with, they’re gonna be economically prohibitive for most of us to be able to purchase and maintain. (P36)

Several participants also commented about the uncertainty of repair costs or even where or how to get the vehicle repaired or maintained. For example:

> And since it’s run mainly by technology, you know, where do you take it for its 50,000 overhaul or whatever? (P19)

A small number of participants expressed concerns about the reliability of primary self-driving vehicle systems. These participants questioned what would happen if primary systems failed during vehicle operation and considered the presence of a backup system to be a key purchase consideration. For instance:

> It must have. What if the main system malfunctions, you know, and it can’t literally drive you? Well, if you’re on the interstate and it malfunctions, would they have like a backup system? (P29)

Risk and Trust

Participants expressed a broad range of views as it related to whether or not they would trust in the safety and reliability of self-driving vehicle technology.

Some participants rejected the idea outright as too risky as did one blind participant:

> …I just would not feel full trust at turning myself totally loose with any type of a / Even if it's a computer. And I've worked with computers too long that I know they can make / get a glitch in them. And I think there is still a possibility of risk. (P1)

Several participants also expressed concerns and raised the possibility of malfunctions due to computer viruses and hacking. One participant stated for example:

> Computers aren't infallible. You know, they get viruses, they get / other people get in and take control. You know? So, you have to think about all that stuff, too. And that would make me very nervous. (P10)

Many participants who commented on the topic indicated that they viewed riding in a self-driving vehicle as being no riskier than riding with a human driver:

> The risk involved. For me, it's no, even more than getting in the car of my wife. (P11)

Some participants however indicated that they would actually feel safer in a self-driving vehicle:

> But we almost daily risk our lives by getting into a vehicle (P25: Oh yeah, I agree!) with a stranger who may be the worst driver. (P29: That's true, yes.) (P28: Yeah.) They may be drunk, they may be on drugs, they may have stayed up all night fighting with their girlfriend. Whereas the autonomous vehicle does not get distracted, does not get tired. I think it's just way, way, way safer. (P28: I agree.) (P27)

A blind participant who had recently lost his sight described to the group being driven by his wife who had never driven before and was in the process of learning to drive:

> She's got to learn it. So now I'm riding in a computer that's learning, you know, a self-taught computer. So instead of having, you know, the option of

> maybe a program glitch happening, I'm riding a computer that doesn't have a clue what it's doing yet. You know? So I'd feel safer in an AV. (P17)

For some participants the potential independence and mobility benefits simply outweighed any risks. One participant who was progressively losing her sight and no longer had the ability to drive stated:

> Pitfalls? None. I don't care if they crash me into a wall, I'll wear a helmet. I just want to get out of my house. I don't care. I'll be a test driver. I just want out. I just want my freedom. They outweigh any / any problems. I'll sign a liability waiver. (P32)

Discussion

General Opinions Regarding Self-Driving Vehicles

The vast majority of participants expressed an awareness of self-driving vehicle technology; with all but one participant within the study indicating a belief in their general understanding of the technology when asked at the outset of their respective focus group. Participants expressed views that, while somewhat skeptical, were generally more positive than the related literature [57], [61] as it pertained to the benefits of self-driving vehicle technology. The overwhelming majority of participants were resolute regarding their belief that self-driving vehicles could potentially be life-changing technology for them personally. While the majority expressed a view that there are considerable unknowns regarding the technology that need to be addressed, they were generally optimistic about the potential personal benefits. Participants also expressed optimism for society at large believing that self-driving vehicles could potentially make driving generally safer, while reducing the impact on the environment.

Concerns regarding the potential legal liability of owners/drivers/operators of self-driving vehicles have been raised as a substantial concern in the related literature [56], [57]. Participants expressed similar concerns in the present study but generally

related these concerns to their visual impairment and not the absence of an active driver, as is typically the case in the related literature. Several participants questioned whether there would be a presumption of their liability if a self-driving vehicle were to be operated by a person with visual impairments and how an individual would defend his or herself from spurious legal claims without the ability to provide visual testimony regarding an accident. These concerns, while similar, are somewhat different from the legal liability issues raised in the related literature that often explore whether legal liability should be assigned to the vehicle manufacturer or operator.

Human-Machine Interface

This research suggests that the Human-Machine Interface (HMI) of a self-driving vehicle for a person who his blind or low vision will likely need to do more than simply allow an operator to input a route or destination. The HMI for an operator who is blind or low vision will likely need to serve this purpose while also satisfying the need for situational awareness, location verification, and needs.

Study participants' desires for a self-driving vehicle HMI closely aligned with their degree of vision loss and their age. Blind participants generally expressed preferences for both speech input capabilities and the use of a smartphone application. Many participants anticipated that self-driving vehicles would utilize speech input as a default means of interaction but were wary of the system inaccurately interpreting their utterances or of generally poor performance based on past experiences with Apple's Siri [72], Microsoft's Cortana [73], and Amazon's Alexa [74]. Many participants indicated that they found their personal smartphone to be very accessible and would prefer to control a self-driving vehicle using a smartphone application if possible though they acknowledged that a backup system would be necessary in the event that they did not

have a phone, or their battery died. Blind participants were extremely resistant to a standard touchscreen, viewing them as being entirely inaccessible with several indicating some acceptance of a touchscreen with Apple “voiceover” [35] capabilities.

Participants with low vision also expressed preferences for both speech input capabilities and the use of a smartphone application but also expressed an interest in touchscreen interaction. Like blind participants, many participants with low vision expressed a belief that self-driving vehicles would utilize speech input as a default means of interaction but expressed somewhat less concern about the potential for voice recognition problems. Participants with low vision also found their personal smartphones to be very accessible and expressed a desire to control a self-driving vehicle using a smartphone application if possible. Participants with low vision expressed interest in the use of a touchscreen, largely as a backup to the use of a smartphone application, but suggested the incorporation of contrasting colors, enlarged buttons, and Apple “voiceover” [35] capabilities. The current findings stand in contrast to those of Schoettle and Shivak [61] who, in a survey presumably of sighted respondents, found that a many respondents preferred touchscreen interaction. It is important to note that relatively younger (under 30) blind and low vision participants in the present study were the most emphatic about the desire to use their personal smartphone or a smartphone application as a control device for a self-driving vehicle with older participants accepting of the concept but open to other approaches.

Studies by Schoettle and Shivak [61] and KPMG [65] have suggested that a majority of potential operators of self-driving vehicles have a preference for manual controls to allow the vehicle to be controlled by a human operator in an emergency situation or for enjoyment. A very small number of the participants of the present study

expressed a similar desire. All but one of these participants were people with low vision who felt that they should have some ability to control the vehicle in an emergency situation if they observed a potential hazard.

The need for the self-driving vehicle's technology to provide some means to satisfy the need for situational awareness while in transit and to aide the operator in verifying their arrival at the correct location was expressed by the majority of participants in the study. Most participants expressed some concerns about traveling without having some awareness of the direction that they were traveling in and their immediate surroundings (e.g. current street, surrounding vehicles, buildings, pedestrians). Participants also expressed hesitance about getting out of the vehicle upon arrival, especially in the case of a self-driving taxi that would perhaps immediately leave, without assurances that they had arrived in the correct location. These concerns were closely related to skepticism regarding the reliability of GPS technologies and negative assumptions regarding the technologies that would be used to input desired destinations (e.g. unreliable speech systems). Older participants (55+) were especially concerned about the ability of the HMI to relay information regarding parking options and building locations. Many of these older participants expressed a belief that the challenge of getting from the vehicle to their desired building or final destination and back would be nearly as complicated a technical challenge as the development of the self-driving vehicle itself. While the majority of participants felt that these challenges could be solved with existing technology they were unsure how.

Self-Driving Vehicle Cost

Much of the self-driving vehicle literature of the past decade has suggested that in cases where people would consider owning self-driving vehicle technology these same

individuals in most instances would not consider paying extra for it [57], [60]. Recent studies [54], [62] have suggested a break from this trend, finding that consumers may be increasingly willing to pay for self-driving vehicle technology depending upon the cost. In the present study, only a few participants took the position that they were unwilling to pay anything extra for autonomous vehicle technology with very few being steadfast in this view. While not every participant verbalized a position on the issue, only one participant indicated during the discussion that they would not be willing to pay for a self-driving vehicle.

In this study, the question for many participants was not whether they were willing to pay or pay a premium for this technology, but rather whether they would be able to afford what many assumed would be very costly technology. This question was exacerbated by the fact that the overwhelming majority of participants had never owned or purchased a vehicle before, and, therefore, had little direct frame of reference for vehicle costs in general. Several participants in the study expressed an interest in the Tesla brand and the "Autopilot" feature specifically [75]; indicating that they had conducted research on related features and pricing. These participants, coupled with those who had exposure to vehicle pricing from past experience, friends, and relatives, ultimately helped to frame the discussion around vehicle costs in several of the groups. The majority of groups arrived at an estimate at or near $100,000. This appeared to be the believed cost of a near-autonomous Tesla that was often discussed in the same context. This cost for most participants was viewed as unaffordable though quite a few participants indicated that they were willing to pay that or more if that was what it would cost for a self-driving vehicle. Many of the participants espousing this latter view were

older participants (55+) who questioned whether the technology would become commercially available soon enough for them to benefit.

Legal and Regulatory Issues, Licensing and Training

Discussions related to the legal environment for self-driving vehicles, the licensing requirements for their operation and the need for training were cordial but generally contentious throughout the study. In some cases, participants indicated that their concerns were based on second hand information or rumors. The majority of the study's participants indicated that they had been following national and local discussions around these issues with many participants indicating that they believed, based on these discussions, that it was possible that persons with visual impairments would effectively be blocked from owning or operating self-driving vehicles. Of particular concern were two types of laws: 1) laws requiring that an individual operating a self-driving vehicle have the ability to take over control in the event of an emergency, and 2) laws that would require a licensed driver to operate a self-driving vehicle.

Participants were split regarding laws that would require an individual operating a self-driving vehicle to have the ability to take over as necessary. While some participants found this premise to be unreasonable given that such a vehicle would be designed to be fully automated, others argued that present or near-future technology would exist that would enable a blind or low vision driver to safely bring a vehicle to a stop in the event of an emergency. These participants, while in a minority, did not believe that such a law would prevent the operation of a self-driving vehicle by persons with visual impairments.

While some participants were overtly against the idea of requiring a conventional driver's license, some participants felt that a license of some sort should be a requirement given the serious nature of vehicle operation. These participants repeatedly raised

concerns about the prospect of children or people with cognitive disabilities operating self-driving vehicles. Those against licensing raised a number of arguments against it, but the majority viewed it as an attack on their civil liberties and as overt discrimination against persons with disabilities. In all but two of the focus groups, the discussion gradually trended towards the concept of an “operator’s license” that would require a certain amount of training on the operation of self-driving vehicles generally but would not exclude persons with physical disabilities from ownership or operation.

Consideration of User Needs

Many participants shared impassioned personal stories while discussing whether or not they felt the needs of people who are blind or low vision were being adequately considered in the development of self-driving vehicles. While opinions varied, most participants expressed the view that their needs were being largely ignored. In all cases, evidence for this was not any experience with an inaccessible self-driving vehicle, as none of the participants had firsthand experience with the technology but was instead negative experiences in other areas of their lives related to other technologies. Many participants expressed a view that technology was often designed and developed without adequate input from people with disabilities generally and was often forced upon them without adequate training or explanation. A number of participants commented that major companies routinely moved to new technologies without properly considering the needs of people with disabilities and potential concerns regarding inaccessibility. The movement towards touchscreen soda machines was cited several times by participants as a problematic technology that was being broadly introduced without proper consideration of accessibility concerns. Several participants described challenges that they had faced in having their accessibility concerns addressed on a local and state level and questioned

their ability to have their concerns addressed by, arguably, much more difficult to reach international businesses. The majority of participants specifically cited awareness as a key issue. Many expressed a belief that the technology and technical capability currently exists to make self-driving vehicles universally accessible but questioned whether manufacturers and decision makers were generally aware of the importance of doing so. At a minimum, these findings suggest that more needs to be done to reach out to organizations that serve people who are blind and low vision and to people directly to better inform them about what is being done to develop accessible self-driving technology. At the same time, more may need to be done to make self-driving vehicle technology more accessible while including more stakeholders with a range of visual impairments in the design and development process.

Limitations

While the use of focus group methodology has its merits, there are also weaknesses with this approach. Perhaps one of the major weaknesses may be found in the composition of the focus groups themselves, which were constructed according to Krueger and Casey's [68] guidelines. The goal of implementing the guidelines was to structure each group according to degree of vision loss and participant age range, due largely to recruitment, scheduling, and logistical constraints, several of the focus groups ended somewhat mixed in terms of these factors. Generally, low vision persons were underrepresented in most groups as most groups were slightly weighted towards blind persons. My use of a functional definition of vision loss as opposed to the use of a medical definition of visual acuity may have also practically limited my ability to precisely group participants by their degree of vision loss. Given the active participation

of nearly all participants in the focus groups it seems that the aforementioned limitations had little impact on the discussions themselves.

CHAPTER 5
DEVELOPING PERSONAS WITH DISABILITIES TO AIDE IN THE DESIGN OF AN ACCESSIBLE SELF-DRIVING VEHICLE HUMAN-MACHINE INTERFACE

With the conclusion of the investigational and exploratory activities documented in Chapters 3 and 4, the research moved into a user-centered design phase intended to culminate with the development of an accessible self-driving vehicle human-machine interface. This chapter discusses the inception of that design phase and specifically the development of personas with disabilities for use in subsequently discussed participatory design sessions.

Related Work

Personas, popularized by Cooper [76], are fictional people with names, ages, genders, and any number of other characteristics that aide designers in grounding their design decisions around user needs. Typically the written depiction of these characteristics are accompanied by a picture and a textual narrative that is written to make the persona seem like a real person while also providing a story that relates the specific needs and personal goals of the persona in the context of the product being designed [76]. The use of personas has been integrated into the design process of many Fortune 500 companies [77], and according to Cooper and Reimann [78], persona use during the design process can ultimately improve the usability of a final product. Although research focused on the creation of personas with disabilities specifically for the design of automotive systems is not readily found in the literature, several studies in recent years have explored the use of personas in the design of advanced driver assistance systems and the creation and use of personas with disabilities.

Lindgren et al. [79] have proposed the use of personas as an interface design tool in the development of advanced driver assistance systems (ADAS). The authors

conducted a human factors workshop with eight participants, three systems developers, two interaction engineers, one technical psychologist, and two interaction designers. Participants were presented with four personas and 15 ADAS, were asked to identify specific systems that they believed would be relevant for specific personas, rank these systems, and comment on the basis for their choices from the perspective of the persona. The results indicated that the four personas each had different needs as was reflected in the type of ADAS chosen for them by the study's participants. The authors argue that their findings suggest that the use of this approach was effective in surfacing design issues and considerations that would not become apparent using more traditional approaches.

Schulz and Fuglerud [80] have proposed a process for the creation of personas with disabilities, which is based on the collection and analysis of real data. Their process suggests the use of focus groups, interviews, surveys, or observation as a means of collecting information regarding disabled individuals, their use of assistive technology and their environment. This information is then used as the basis for personas and, the authors suggest, may lead to more realistic traits, needs, attitudes, and habits. Schulz and Fuglerud argue that their approach is more effective that other approaches in capturing the needs of users with disabilities during the design process.

Morris and Mueller [81] have discussed the development and use of personas as a tool to help stakeholders understand the needs and preferences of consumers with disabilities and to promote inclusion during the design process of mobile technology. The authors presented data from a biennial survey distributed in the United States on the actions, activities, and attitudes of 590 respondents who are blind, low vision, deaf and hard of hearing as it pertains to mobile technology. Data was collected via Web,

telephone, mail, and in-person interviews. The resulting data was distilled into four broad user types representing each of the four discussed disabilities.

Pascaul, Ribera and Granollers [82] studied the use of personas with disabilities as a means of personalizing the communication of website accessibility errors on content management systems. The authors describe an interview and testing process involving users with visual, auditory, motor and cognitive disabilities to gather personal and spontaneous comments to be used for persona creation. The needs and motivations of users, drawn from interviews and testing, are then condensed into personas that may ultimately be used to promote empathy between the content writer and the final user.

Pretorius and Sangham [83] conducted user research that culminated in the development of personas informing the design of an online government services portal in South Africa. A total of 72 rural users and 90 staff members participated in focus groups and interviews, to include interviews with disabled citizens to understand their accessibility needs. Two surveys of 1,275 and 344 respondents were conducted with users of the existing government website.   Twelve personas were developed as a result of the research process to include a persona designed to represent the needs of the disabled interviewees and respondents involved in the research process.

Persona Development Process

A multi-method user-centered design approach previously utilized by LeRouge, Ma, Sneha, and Tolle [84] for persona development in the consumer health technology domain was extended for the present study and is illustrated in

Figure 5-1.

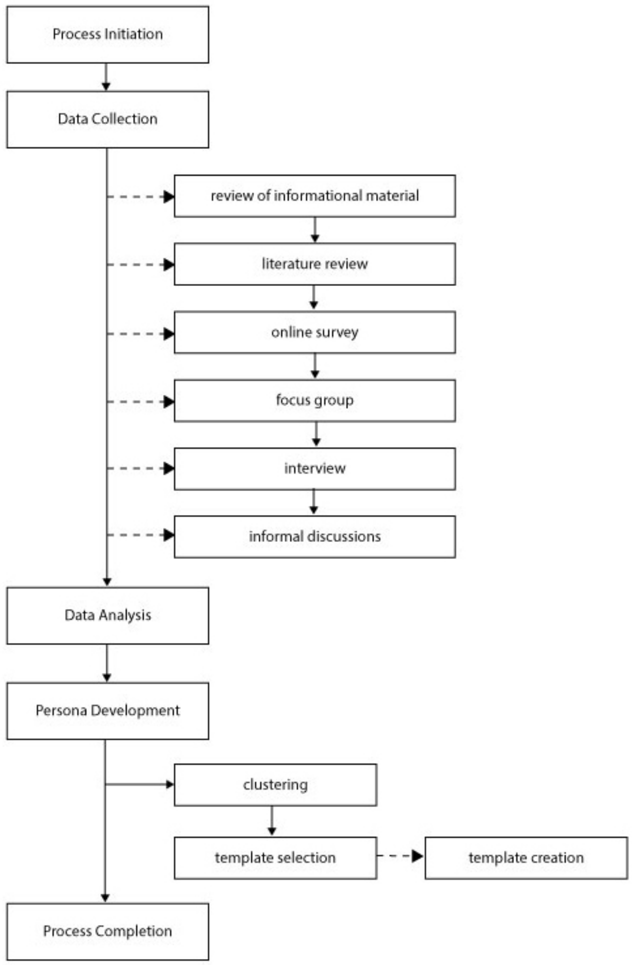


Figure 5-1. Persona development process adapted from LeRouge, Ma, Sneha and Tolle with data collection activity modifications[84].

Process Initiation

The process borrows heavily from community-based participatory research (CBPR), which is a collaborative research approach in social science that relies heavily on community partners [85]. According to Lazar, Feng, and Hochheiser, one of the greatest challenges of conducting research with users with disabilities is gaining access to the participants themselves [19]. Recognizing this, the process was initiated by working outward; attempting to establish relationships with the closest candidate community partner (local chapter of the National Federation of the Blind) while identifying larger

candidate partners at the state and national level. Once the local partnership was established, this relationship was leveraged to established relationships with other organizations at a state level, regional level, etc. This process was followed until contacts had been established nationally for the project.

Data Collection

Data collection closely followed the prescribed process and utilized a broad set of data sources to provide a deep understanding of the target population, blind and low vision persons, and their potential needs relative to self-driving vehicle technology. Recognizing that identifying key community partners and establishing relationships takes time, data collection began at research conception and began with activities that required the least direct access to blind persons and stakeholders (e.g. review of brochures on blindness, access to online material, literature review). Data collection concluded with activities that required the most access (e.g. online survey, focus groups, informal discussions with providers and community leaders). While the described activities were not conducted solely to support persona development, they served as standalone formative research in their own right. Thee artifacts and data from each of these activities are the foundation upon which the personas are based.

An early review of informational material was conducted while key community partners were identified, and relationships were cultivated. Print and online informational material on blindness and low vision were reviewed in conjunction with the scientific literature on visual impairment to provide a foundational understanding of vision loss. This material also enhanced familiarization with the many organizations that advocate for persons with visual disabilities. Written notes were made regarding this material. After relationships with community partners were established, an online survey was conducted

(Chapter 3), which was followed by eight focus groups (Chapter 4). Relevant data from both investigational activities was referenced during persona creation. Several informal telephone discussions were held throughout 2017 with heads of state government agencies serving blind persons, the heads of two national organizations of the blind, the president of a local rehabilitation organization for persons with visual disabilities and several blind and low vision community leaders. These conversations contributed greatly to an understanding of the needs of blind and low vision persons and contributed significantly to the persona creation process. Many individuals follow up with resources, email lists for instance, and were often able to correct inaccuracies in my understanding of user needs and issues related to visual impairment. Written notes were made of many of these conversations.

Development of Personas

Personas were developed iteratively, through a process of categorization and refinement, relying heavily on the initial coding of responses conducted during focus group data analysis (Chapter 4). Using MAXQDA, four clusters were used to organize the data from the focus groups and interviews: characteristics, disability, technology and transportation. The Characteristics cluster represents personal and family characteristics that may impact the system under design including demographic and background information. The Disability cluster represents physical or mental disabilities that impact the system under design but notably not those that are unrelated. The Technology cluster represents technical factors (e.g. attitude towards technology and use of digital platforms) that may impact the system under design. While the Transportation cluster represents factors related to transportation to include motivations for the use of specific transportation types, frustrations regarding transportation, and overall degree of mobility.

Each coded response was placed within one of the four clusters and was traceable back to the participant. Using this approach, themes emerged within each cluster. One theme that emerged in the Transportation cluster for instance was the desire for alternatives to public transportation. Three codes were associated with this theme: (1) independence, (2) mobility and (3) time savings. Clusters, themes and codes were color coded to facilitate visual recognition of patterns that appeared within and across the coding system.

A persona template was developed that extended the general and technology characteristics collected by the persona template of Nielsen [77] (e.g. computer skills, educational level, description of daily life, etc.) with characteristics that focused on disability and domain specific (transportation) characteristics. Table 5-1 provides an overview of the template's content.

An iterative process of clustering and tracing, associating coded responses with each participant to review participant characteristics (e.g. degree of vision loss, age, gender, ethnicity), was followed until several distinct groups emerged. Personas were developed, representing each group, following the template described in Table 5-1. Demographic information from the public opinion survey of blind and visually impaired consumers was used to add demographic information to each created character and information gleaned during the data collection process was used to add depth.

Table 5-1. The persona template used in the present persona creation process, adapted from Nielsen [77] with modifications to include context related disability characteristics and attitudes towards automotive technologies.

Category	Template data
Demographics	Age Ethnicity Gender Marital Status Family/Living Situation Native Language Education Income Employment Status Occupation
Background	Personal Interests Habits / Personality
Focus Area	Motivations Frustrations
Context Related Disability	Type Severity (if applicable) Length Origin
Technology	Existing Computer/Internet Skills And Experience Use of Digital Platforms Attitude Towards Technology Ownership And Use Of Mobile Technology Use of Assistive Technology
Transportation	Primary Means Of Transportation Attitude Towards Primary Means Of Transportation Frequency of Use
Influencers	Influential People or Entities That Surround The Persona That May Influence Choices
Daily Life	Description Of Work Or Daily Life

Results

Analysis revealed patterns that led to the development of three personas. While the race/ethnicity of the personas was randomly assigned in order to be representative of the study’s participants, the personas otherwise reflect differences identified during analysis.

Personas: Cassie is a 24-year-old graduate student with low vision who relies on public transportation to commute between home and campus (Figure 5-2). Cassie typically rides the bus and is happy that it is available to her as a transportation option. She feels that public transportation is inflexible however and doesn't meet the needs of her busy lifestyle and spontaneous personality. She would welcome another option but views public transportation as her only cost-effective choice at the moment.

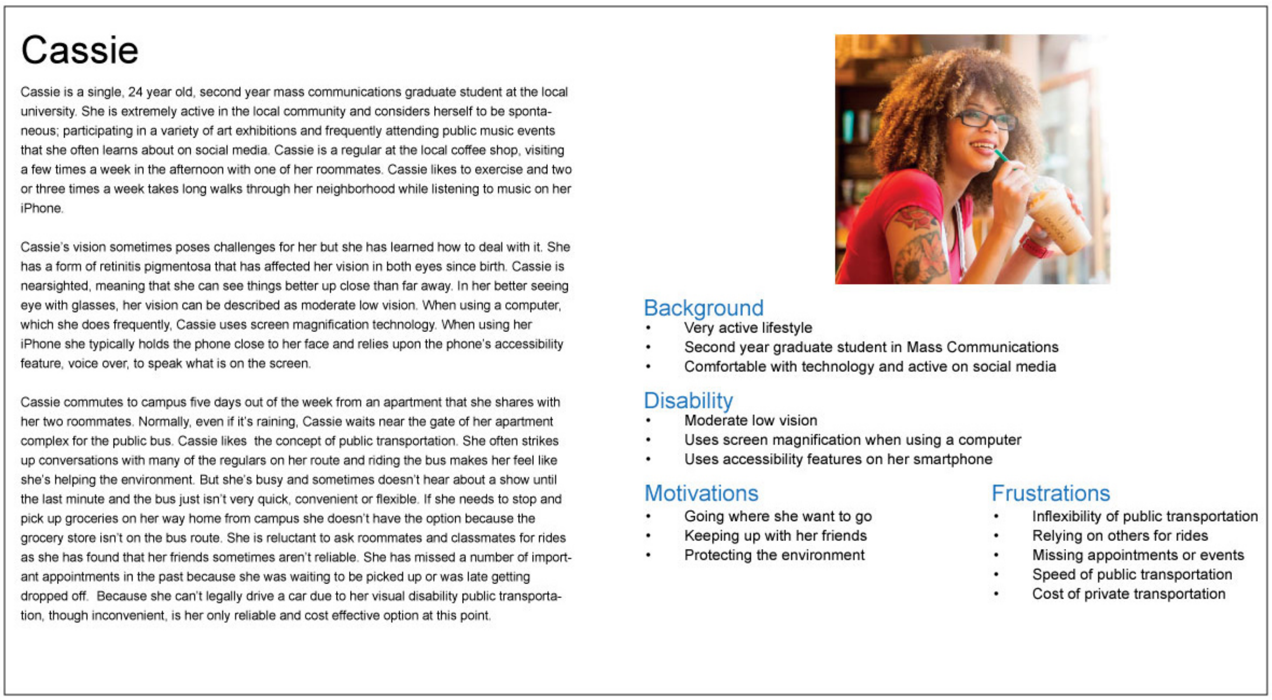


Figure 5-2. Persona for Cassie, a 24-year-old graduate student with low vision.

Walter is a 48-year-old columnist and editor for an online financial magazine who has been blind since birth (Figure 5-3). Walter commutes using a public bus from the home he shares with his wife and three daughters in the suburbs of a midsize city to a downtown office building where he works. He typically spends roughly three hours a day in transit. While Walter is grateful for the availability of public transportation, without which he would have tremendous difficulty getting to work and providing for his family,

the lengthy commute and time away from his family is something he thinks about quite frequently. He has considered other means of personal transportation, to include car services, but the cost has been prohibitive. He would be interested in a means of personal transportation if it were comparable to the cost of an automobile.

Walter

Walter is a married, 48 year old father of three. He has worked for seven years as a columnist and editor for an online financial magazine specializing in financial news about the technology industry. Previously, he spent roughly a decade working in the financial services industry. Before that he was in college where he completed a bachelor's degree in business. Walter's two major interests outside of work are sports and technology; he's an avid follower of the Baltimore Orioles and he's passionate about advances in science and technology. On most mornings, shortly before heading out for work, he reviews sports scores and the latest trends in technology on his smartphone while drinking a cup of coffee.

Walter has been blind since birth due to a genetic condition and is unable to drive a car. He can recognize when a light is on in a room or when it is light or dark out but he has no usable vision. His wife would happily drop him off at work but given the need to get the kids to school, where the family lives and where his office is downtown, it just wouldn't make sense. So for the past seven years Walter has been riding the bus an hour and a half into the city in the morning and an hour and a half back in the evening. He appreciates that he has access to public transportation but has missed out on a number of opportunities due to his reliance upon it. Walter was offered his dream job as a reporter for a well-respected news website a few years ago but was forced to turn it down when he found out he would have to provide his own transportation to interviews. While this professional loss stung, it is nothing in comparison to the daily disappointment he feels at losing hours of his life stuck on bus due to his inability to drive a car. These are hours he loses away from his wife and away from his three daughters.

In most other aspects of his life Walter feels that technology has helped him to overcome his visual disability. Using screen reading technology he is able to access resources online usually without difficulty, using his smartphone he is normally able to take walks and navigate without a problem, transportation and mobility he believes is one of his last great hurdles.

Background
- Married father of three daughters
- Having difficulty finding a balance between home life and job as a financial columnist
- Very tech savvy; active on social media

Disability
- Blind since birth due to a genetic condition
- Uses a screen reader when using a computer
- Uses accessibility features on his smartphone

Motivations
- Getting between work and home
- Providing for his family
- Spending time with his family

Frustrations
- Lengthy commutes
- Missing family time and events
- Inflexibility of public transportation
- Cost of private transportation

Figure 5-3. Persona for Walter, a 48-year-old financial columnist who is blind.

Hannah is a 72-year-old grandmother who lives with her daughter, a single mother, and her granddaughter (Figure 5-4). Hannah has a form of retinal disease that has gotten progressively worse over the years and now she is legally blind. Since her retirement nearly twenty years ago, Hannah has been an active volunteer in the local community but since her husband passed away about eight years ago she has had difficulty getting around. She relies on her daughter primarily for transportation, but her daughter is seldom home as she works two jobs. Hannah is often reluctant to ask for rides from

friends or other family members. Their home is not on the bus route and the local shuttle service for persons with disabilities requires advanced scheduling, which is sometimes inconvenient. As a result, Hannah has difficulty getting around and to her medical appointments. She would welcome a means of personal transportation if it was something that she could learn to use relatively easily.

Hannah

Hannah is a 72-year-old retired grandmother. She begins most mornings sitting in on the front porch of home she shares in a quiet community with her daughter, a single mother and her granddaughter. She likes the fresh air and the sounds in the morning as everyone heads off to work and school. She's been retired for nearly twenty years now and has spent much of that time doing volunteer work at her church and at the local community center.

Hannah is not very computer savvy but does have a smartphone that she uses frequently. She uses it to listen to the news and loves listening to audiobooks at night when she is getting ready for bed. She occasionally uses a computer with a screen reader but finds the smartphone to be more usable because she can talk to it.

Hannah used to travel quite a bit but that has slowed down a lot since her husband passed away about eight years ago. Hannah has Leber congenital amaurosis, an inherited retinal disease that causes severe vision loss at birth. Over the years her sight has gotten progressively worse and now she is legally blind, able to see only motions or extremely bright lights.

Since her husband has passed away, he was sighted, just getting around has become really difficult. Hannah's daughter works two jobs and often doesn't have time to drive Hannah around and her granddaughter isn't old enough to drive yet. Where they live is not on a bus route so that isn't an option either. There is a public shuttle but to use it you have to schedule your trip a day in advance, which isn't always possible. Hannah does have a lot of friends but she fields uncomfortable asking them to make a special trip to pick her to take her grocery shopping or to the store. Most of the time she would rather wait until her daughter has time to take her. She has missed doctor's appointments in the past because she did not have transportation and missed openings when others canceled because she couldn't get there fast enough.

Background
- Lives with her daughter, a single mother, and granddaughter
- Relies on her daughter for transportation
- Is not very tech savvy but is a novice computer user and has a smartphone

Disability
- Has a progressive retinal disease and is now legally blind
- Uses a screen reader when using a computer
- Uses accessibility features on her smartphone

Motivations
- Getting out of the house and to social functions / community gatherings
- Making medical appointments
- Spending time with friends and family

Frustrations
- Relying on others
- Missing social events
- Missing medical appointments
- The inflexibility of public transportation
- The lack of access to public transportation

Figure 5-4. Persona for Hannah, a 72-year-old retiree who is blind.

Discussion

In this chapter I have described and demonstrated an iterative multi-step process of data analysis used to develop personas with disabilities. Chapter 6 demonstrates the use of the derived personas in a participatory design process similar to that recommended by Grudin and Pruitt [86].

CHAPTER 6
PARTICIPATORY DESIGN SESSIONS TO EXPLORE THE DESIGN OF AN ACCESSIBLE SELF-DRIVING VEHICLE HUMAN-MACHINE INTERFACE

User-centered design (UCD) is a design philosophy that is focused on the needs of a product or system's end users and brings a focus on these needs into the design process [87], [88]. It has been suggested that the popularization of this philosophy has resulted in products that are more usable and better satisfy end user needs [88]. With the goal of developing an accessible self-driving vehicle human-machine interface, a UCD process conducted through a series of participatory design sessions with visually impaired persons was used. In a manner similar to that proposed by Grudin and Pruitt [86], the personas described in Chapter 5 were employed within the participatory design process to better engage participants in the design activity and scenarios were used to provide realistic narratives within which the technology under design could be used by each persona.

Related Work

Participatory design: A number of studies have explored the use of co-design, often referred to as participatory design, in the development of technology for users with disabilities. Williams, Buehler, Hurst, and Kane [89] explored the use of participatory design in the development of a wearable navigation device for people with visual impairments. In a study involving eight adults with visual impairments, they explored features and form factors for wearable navigation technology. The authors found that participant engagement was much higher when participant activities during the design sessions were structured and when tangible materials were used. Feng, Azenkot, and Cakmak [90] explored the use of participatory design in the development of a design solution for indoor navigation for multi-purpose robots designed to guide blind people to

indoor destinations in a socially acceptable manner. In a study involving three designers and five non-designers who were sighted, blind and low vision, participants were tasked with developing specifications for how a robot should walk with a blind person. In a study involving four participants, Sahib, Stockman, Tombros and Metatla [91] utilized a participatory design approach in the development of a search interface for users with visual impairments. The authors actively involved a blind user with knowledge of assistive technologies on the design team and used a scenario as the basis for discussion between designers and users. The authors contend that a participatory or co-design approach based on a textual narrative scenario, tailored to the abilities of those involved in the design activity, better engages them in the design process.

Method

Participant Recruitment

Participants were recruited with the assistance of a vision rehabilitation and resource center in North Central Florida. Advertisements regarding the study were distributed via email to center clients inviting individuals interested in participating to call or email study staff for additional information and scheduling. Participation was restricted to individuals aged 18 and older with a degree of vision loss that ranged between moderate visual impairment [92] in the better seeing eye with best conventional correction to blindness. Participation was further limited by age given the need for a specific number of participants from specific age ranges; a maximum of five blind participants above the age of 55 were needed for instances. The Institutional Review Board of the University of Florida approved this study and each participant provided written informed consent the day of each design session. Participants were not compensated for their participation.

Description of Participants

Sixteen one-hour design sessions were conducted over a five-month period at a center for visually impaired persons in North Central Florida (Figure 6-1). In total, 13 participants were involved in the study in two groups of four people and one group of five. Group size and composition had been specified prior to participant recruiting, and groups were differentiated by desired age range and degree of vision loss. Group one was intended to include participants who self-identified as having low vision in the 18-35 age range. Group two was intended to include participants who self-identified as blind in the 18-54 age range. Group three was intended to include participants who self-identified as blind age 55 or older. During recruitment, participants were placed in the associated group that most closely aligned with their age and degree of vision loss. No other factors were considered for the purpose of constructing the groups (e.g. race, gender, education). Group one, composed of two male and two female participants, had a mean age of 31 years old (range = 23 to 36 years old), a household annual income that ranged from under \$15,000 to \$45,000 and was composed entirely of persons with low vision. One member of Group one held a four-year degree, one had some college experience and the remaining group members held a high school diploma/GED. Group two, composed of three male and two female participants, had a mean age of 35.2 (range = 32 to 41 years old), a household annual income that ranged from under \$15,000 to \$55,000 and was composed entirely of blind persons. Three members of Group two had some college experience, and the remaining group members held a high school diploma/GED. Group three, composed of one male and three female participants, had a mean age of 75.25 (range = 64 to 81 years old), a household annual income that ranged from \$25,000 to over \$76,500 and was composed entirely of blind persons over age 55. One member of Group

three held a graduate degree, two held four-year degrees and the remaining group member held a high school diploma/GED.

Participatory Design Sessions			
	Group Number and Description		
Session Number	Group 1 Low Vision Age 18-35	Group 2 Blind Age 18-54	Group 3 Blind Age 55+
Session 1	May 24, 2017 4 Participants Scenario Creation	May 24, 2018 5 Participants Scenario Creation	May 24, 2018 4 Participants Scenario Creation
Session 2	June 14, 2017 3 Participants Creation of Interaction Narrative	June 14, 2017 4 Participants Creation of Interaction Narrative	June 14, 2017 4 Participants Creation of Interaction Narrative
Session 3	June 28, 2017 3 Participants Completion of Interaction Narrative	June 28, 2018 3 Participants Completion of Interaction Narrative	June 28, 2018 4 Participants Completion of Interaction Narrative
Session 4	July 26, 2017 (Rescheduled from July 14) 3 Participants Wizard-of-Oz Interaction	July 26, 2017 (Rescheduled from July 14) 2 Participants Wizard-of-Oz Interaction	July 26, 2017 (Rescheduled from July 14) 2 Participants Wizard-of-Oz Interaction
Session 5	August 9, 2017 2 Participants Wizard-of-Oz Interaction	August 9, 2017 2 Participants Wizard-of-Oz Interaction	Session Canceled (2 participants canceled the day of the session (August 9 and one arrived 50 minutes late)
Session 6	Session Canceled (Rescheduled from 9/20 to 9/27; ultimately canceled due to participant schedule change)	September 27, 2017 (Rescheduled from September 20) 2 Participants High Fidelity Prototype	September 27, 2017 (Rescheduled from September 20) 3 Participants High Fidelity Prototype

Figure 6-1. Participatory design sessions; group description and study dates.

Procedure

Each design session lasted approximately one hour and followed a consent/refreshment/ice breaker process that was identical. After each participant was seated in the meeting space, the informed consent document, which had been emailed to

participants with email addresses in an accessible format prior to the design session, was read aloud by the study facilitator. Participants were then provided with assistance, as needed, signing the informed consent document. After being provided light refreshments, a brief ice breaking exercise was led by the design session facilitator to encourage interaction between participants. Though the use of an ice breaking exercise enabled participants to become familiar with each other after the initial session, it was continued in subsequent sessions to encourage dialogue. The procedure that followed this consent/refreshment/ice breaker process was largely different for each session. As a rule, attendance by at least two members of each group was required to conduct a design session. If fewer than two members were present, the session was canceled. In total, two of the originally planned 18 sessions where canceled while five sessions were rescheduled and occurred on alternate dates. Sessions were conducted on average approximately 3.5 weeks apart. Sessions were video recorded for later analysis.

Session one

Following the consent/refreshment/ice breaker process an audio recording was played where a professional voice actor, speaking in first person, introduced participants to the group's assigned persona. For the remainder of the session, participants and the facilitator, using a scenario template developed by the facilitator as a guide (APPENDIX C), collaboratively described a scenario that explained how the group's assigned persona would use the human-machine interface in the self-driving vehicle. The facilitator transcribed this scenario in its final version.

Session two

Following the consent/refreshment/ice breaker process the audio recording of the group's assigned persona was played and the scenario created in the prior session was

read aloud to serve as the starting point for the discussion. An audio recording was then played where the assigned persona, speaking in first person and recorded by the same actor used previously, described their current location. The persona explained their need to travel to a series of destinations and expressed their desire to do so in a self-driving vehicle. For the remainder of the session participants and the facilitator worked collaboratively to define the human-machine interface and the system interaction process necessary to enable the group's persona to reach their desired destinations using the persona's present location as a starting point.

Sessions three through six

In sessions three through six, following the consent/refreshment/ice breaker process the introductory audio recording of the persona from session one was played to re-introduce participants to the group's assigned persona given the time gap between sessions. The audio recording from session two was then played where the group's assigned persona, speaking in first person, described their current location and explained their need to travel to a series of destinations. To serve as a starting point for discussion, the progress of the group's persona in his or her travel to their desired final destination was provided (e.g. "Cassie is currently at the mall and still needs to stop at the grocery store before heading home"). The scenario created in session one was then read aloud to act as a bridge between the present problem and the design solution. The facilitator introduced mockups and prototypes, developed between sessions based on participant recommendations from prior sessions, to the group. All mockups and prototypes were evaluated by the group collectively within the context of discussion (i.e. would this be useful to the persona in the current context?).

Between three and five days following the final design session a telephone interview was conducted with each participant to provide an opportunity to ask follow up questions after a period of reflection and to gather additional demographic information.

Results

Group One: Low Vision Participants Age 18 to 35

Session one

All four members of Group one attended session one. The design activities of the session began by introducing participants to their assigned persona, Cassie, via a biographical voice recording that was played for the group (see voice script, Appendix D). Participants were then asked to collectively craft a scenario that would describe how Cassie would use and benefit from a self-driving vehicle. A scenario template was provided as a guide (Appendix C) and was read aloud to the group to initiate the scenario creation process. The introduction of the scenario had been pre-written by the study moderator and was read aloud during the introduction of the template:

> Cassie usually takes the bus to get where she needs to go around town. She doesn't mind; it's good for the environment and it doesn't cost a lot. But Cassie's very busy and riding the bus is slow and not very flexible, it's not a good match for her active lifestyle. She would prefer to drive a car but has moderate low vision and cannot drive a car. Cassie has just been given access to a new self-driving car as a beta tester that she hopes may solve her transportation needs.

Participants were asked to use this introduction and within the context of the scenario template, identify Cassie's primary need, her specific needs regarding the human-machine interface and the positive impact on her life of her use of a self-driving vehicle. Participants identified a single high-level need regarding Cassies's overall use of a self-driving vehicle:

> Cassie needs to be able to go where she wants, privately, without needing another person's assistance.

Participants identified nine primary needs from the system's--machine interface:

1. Vehicle status warnings
2. An indicator of the number of miles to the final destination
3. Information regarding outside temperature and weather
4. Alerts regarding the presence of emergency vehicles
5. Information regarding the presence of other vehicles
6. Location information to the entrance of the final destination
7. Vehicle parking information
8. The location of the vehicle door
9. Speech, touch, and smartphone interaction capabilities

This collaborative scenario creation process ended with a complete scenario that was transcribed by the moderator:

> Cassie usually takes the bus to get where she needs to go around town. She doesn't mind; it's good for the environment and it doesn't cost a lot. But Cassie's very busy and riding the bus is slow and not very flexible, it's not a good match for her active lifestyle. She would prefer to drive a car but has moderate low vision and cannot drive a car. Cassie has just been given access to a new self-driving car as a beta tester that she hopes may solve her transportation needs. The self-driving car allows Cassie to quickly, safely and reliably to go where she wants to go, when she wants to go. The vehicle's human-machine interface allows Cassie to enter her route and destination information using either her phone, touch or speech input. The system also tells her when she has arrived, gives her information to let her know if she has arrived in the right place and gives her information en route to let her know that she is going in the right direction. Cassie is now able to get around quickly and easily without having to rely on anyone else for her transportation needs.

Session two

Three members of Group one attended session two. The design activity began by playing an audio recording where the assigned persona, Cassie, described her current location, explained her need to travel to a series of destinations and expressed her desire to do so in a self-driving vehicle:

> Hi this is Cassie…I'm currently at my apartment in Gainesville, Florida and I need to make a few stops on the way to my friend's house to get ready for the show tonight. I need to stop at Macy's at the Oaks Mall to buy an outfit to wear. Then I need to stop at the nearest grocery store on the way to the

> University of Florida campus. After that I need to go to Weimer Hall at UF to pick up some things I left earlier. Then I need to head to my friend's place at the Lux 13 apartment complex.

Participants were asked to construct a detailed narrative based on the provided information that would describe the process that Cassie would use to successfully go from her starting location to her final destination in a self-driving vehicle. Participants were asked to refer to the human-machine interface that Cassie would interact with in the self-driving vehicle as "ATLAS". The narrative creation process began in session two and was not completed until session three.

Session three

Three members of Group one attended session three. The design activities of the session continued what was discussed in session two and focused on the construction of a detailed narrative that would describe the process that Cassie would use to successfully go from her starting location and waypoints to her final destination in a self-driving vehicle. Through a process of brainstorming, discussion and debate, which the facilitator moderated and directed, participants summarized an 18-step process (lettered items: notes, suggestions, and observations are italicized):

1. Cassie requests the car using her smartphone
    a. Either by voice, using GUI or speaking to a person by phone (dispatcher)
2. A vehicle arrives and starts beeping, sending an arrival message to Cassie's smartphone
3. Walking directions to the vehicle are sent to her phone
4. When she gets to the vehicle the vehicle recognizes her and unlocks
5. The vehicle asks if she wants to use her smartphone or the in-vehicle system
6. Cassie enters a destination using her smartphone or the in-vehicle system
    a. A button is available that lets her switch to the in-vehicle system when she chooses

b. Using her smartphone, she can either speak instructions or use the GUI

c. The in-vehicle system has a large "talking" touchscreen, the ability to invert colors, large print, zoom and language options (e.g. Spanish, French)

d. Using the voice user interface: whatever the system is saying should be displayed on the screen and touch and speech should work seamlessly.

e. A large physical button (1-3 inches in diameter) that turns voice interaction on or off is located in a place where it can't be accidently bumped

f. Cassie should have the option of entering all of her stops at the beginning ("I need to go to the Oaks Mall, the grocery store, Weimer Hall and the Lux 13 apartments")

7. In transit, the vehicle provides and estimated time of arrival (should announce once every five minutes); narration can be turned off.

    a. Cassie should be able to ask the system where she is at any time and the system should provide the closest intersection, street name, direction she is going and surrounding landmarks

    b. Everything that is spoken should be displayed on the screen

    c. If the vehicle needs to swerve or make an emergency movement, then it should notify the user

    d. The vehicle should ask if it needs to perform a major reroute because of an accident or construction, if the re-route is trivial it should proceed but either way it should still tell her what it's doing

8. Upon arrival at the mall the vehicle drops Cassie off at the curb

    a. If possible, it provides walking directions from the vehicle to the door

    b. The vehicle should then park itself or hover (drive around) if it can't find an open parking space

9. Cassie follows the same process to summon the vehicle to come pick her up.

10. She enters the vehicle and says, "Take me to the closest grocery store to the university of Florida campus" or "Take me to the closest store to Weimer Hall"

    a. She still has the option to enter destination information in the car or using her smartphone

11. She arrives at the grocery store

a. The vehicle drops her off if possible

b. If not possible the vehicle will find the closest legal parking space and then give her walking directions to the door

c. Directions will be sent to her smartphone

12. Ready to leave the grocery store

    a. The smartphone app gives her walking directions back to the car

    b. The vehicle beeps until she reaches the car

13. Upon entering the car, it asks, “Do you still need to go to Weimer Hall?”

14. Upon arrival at Weimer Hall

    a. The vehicle drops her off if possible next to curb

    b. The system provides walking directions to Weimer hall

15. Ready to leave Weimer Hall

    a. Cassie follows the same process to summon the vehicle to come pick her up.

16. Cassie enters the destination, using voice, touch or smartphone

17. In transit

    a. If the system indicates that she is passing a convenience store or other store she can say, “Hey ATLAS stop here…”

18. Upon arrival at LUX 13 Apartments

    a. The car should wait either a period of time, (e.g. five minutes) or when she notifies it to leave - whichever comes first

Session four

Three members of Group one attended session four. Between sessions three and four seven distinct user interface designs were conceived in response to the interaction process of sessions two and three and participant comments. Each of these designs was informally evaluated against Nielsen’s user interface heuristics [93] by the author. A

three-interface paper prototype was developed of what was determined to be the superior design (Figure 6-2).

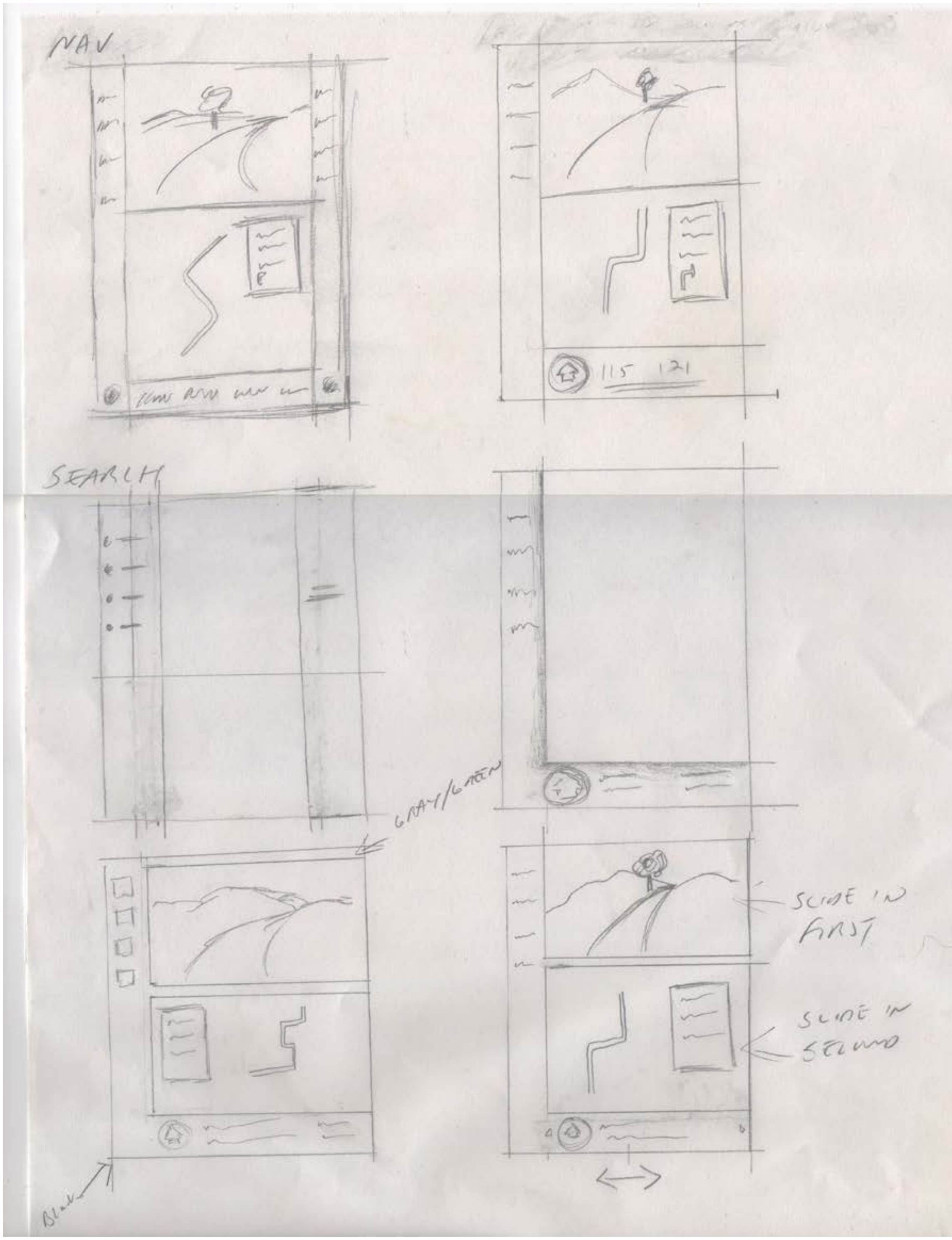


Figure 6-2. Preliminary sketches of the ATLAS system with a vertical screen orientation.

A full color mockup of the home screen of the user interface (Figure 6-3) was also created and displayed on a Microsoft Surface tablet. The mockup was intended to increase users' engagement with the paper prototype by demonstrating in a more realistic manner how the final system might appear.

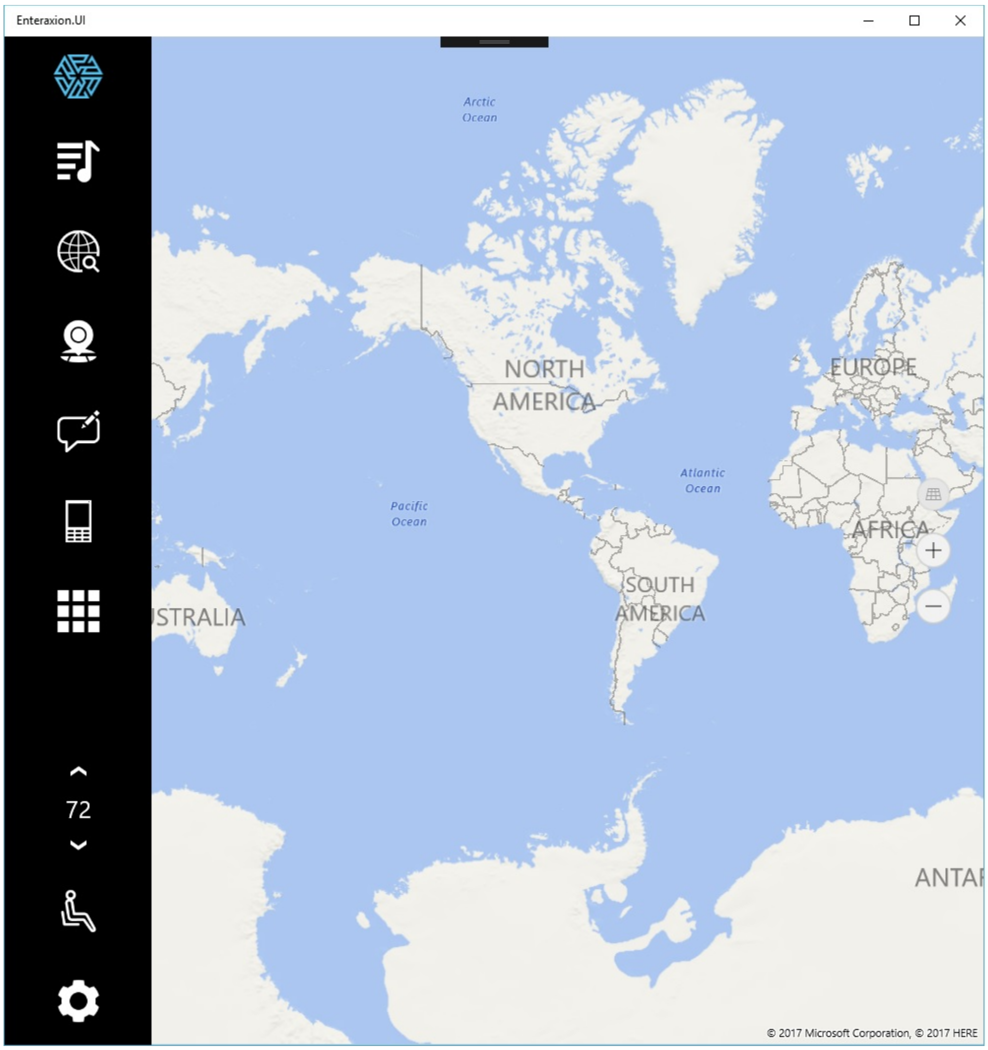


Figure 6-3. Full color mockup of the ATLAS system with a vertical screen orientation.

During session four, the facilitator interacted with each participant individually in a "Wizard of Oz" [19] scenario using the paper prototype to simulate interaction with the system. Participants were given the following instructions to begin the scenario:

> Imagine that you are in a self-driving vehicle equipped with the ATLAS system that we have been developing over the past few weeks. Use the system to direct the vehicle to the JC Penny at the Oaks mall in Gainesville, Florida.

The facilitator acted as the system's voice user interface by giving instructions and responding to participant voice commands based on a predefined script (Appendix E). System dialogue was improvised when interaction went off script. The facilitator also moved the paper prototype as necessary to simulate the user's movement through different screens and to provide a simulated visual response to voice commands and touch input. To simulate a "talking" touch screen similar to Apple's Voice Over [94], the facilitator would provide a verbal description when a button on the paper prototype was touched. Following each interaction, comments from the group regarding the interaction were solicited. Following all three interactions the group, led by the moderator, discussed the interaction and potential improvements.

Voice user interface. While participants generally responded favorably to the concept of simply speaking to the system, they were critical of specific aspects of the interaction. During the scenario, participants were given cues regarding their present location (e.g. "We are at the intersection of 20th street and Main street. We will be passing McDonalds on the right in .5 miles"). While participants responded favorably to the presence of the cues, they felt that they lacked relevant information (traffic conditions, location of pedestrians, etc.) Participants also felt that the information provided upon arrival at a location was insufficiently detailed.

Participants overall praised the ability to speak naturally while making requests of the system but initially raised questions about how such capability could be implemented; questioning the scenario's believability. Several expressed a belief that the interaction as demonstrated was far-fetched or unlikely. Participants also expressed

confusion about what specific commands or utterances the system would recognize in practice. This confusion was most apparent at the beginning of a scenario when participants expressed consternation at how to initiate the interaction process.

Graphical user interface. Participants were least critical of the paper prototype / visual interface perhaps due to its limited use. During the scenario, none of the participants attempted to accomplish the scenarios tasks by directly interacting with the paper prototype. While the white background of the paper prototype was viewed as acceptable, participants indicated a preference for a dark background and a large white font as displayed on the mockup. The vertical buttons of the paper prototype were viewed as being too small and the use of icons absent any text explanation was referred to as confusing. The concept of raised notches on the physical edge of the display to guide users towards the interface's vertical buttons was suggested up during the course of discussion.

Session five

Two members of the group attended session five. Between sessions four and five, four user interface designs were conceived based on participant feedback from session four. Each of the four interfaces was evaluated informally against Nielsen's user interface heuristics [93]. A four-interface (e.g. four page) paper prototype was developed based on the selected design. The new design used a horizontal screen orientation but maintained the vertical navigation with the intent of implementing the "physical notch" feature discussed during the prior session. A full color mockup of the selected design (Figure 6-4) was created and displayed on a Microsoft Surface tablet to further participant engagement. An alternate design, which had not been selected for prototyping, was refined into a full color mockup for review by design session participants. This alternate

design also used a horizontal orientation but employed significantly larger buttons and large text (Figure 6-5).

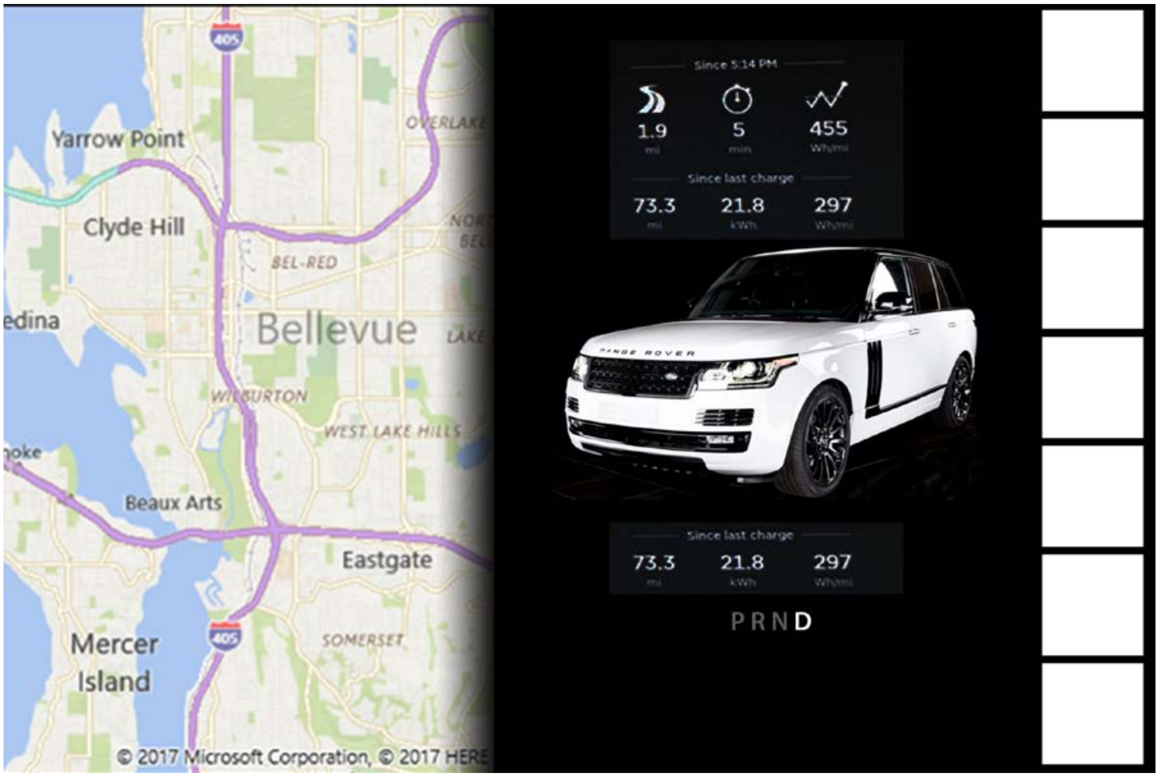


Figure 6-4. Full color mockup of the ATLAS system with a horizontal screen orientation.

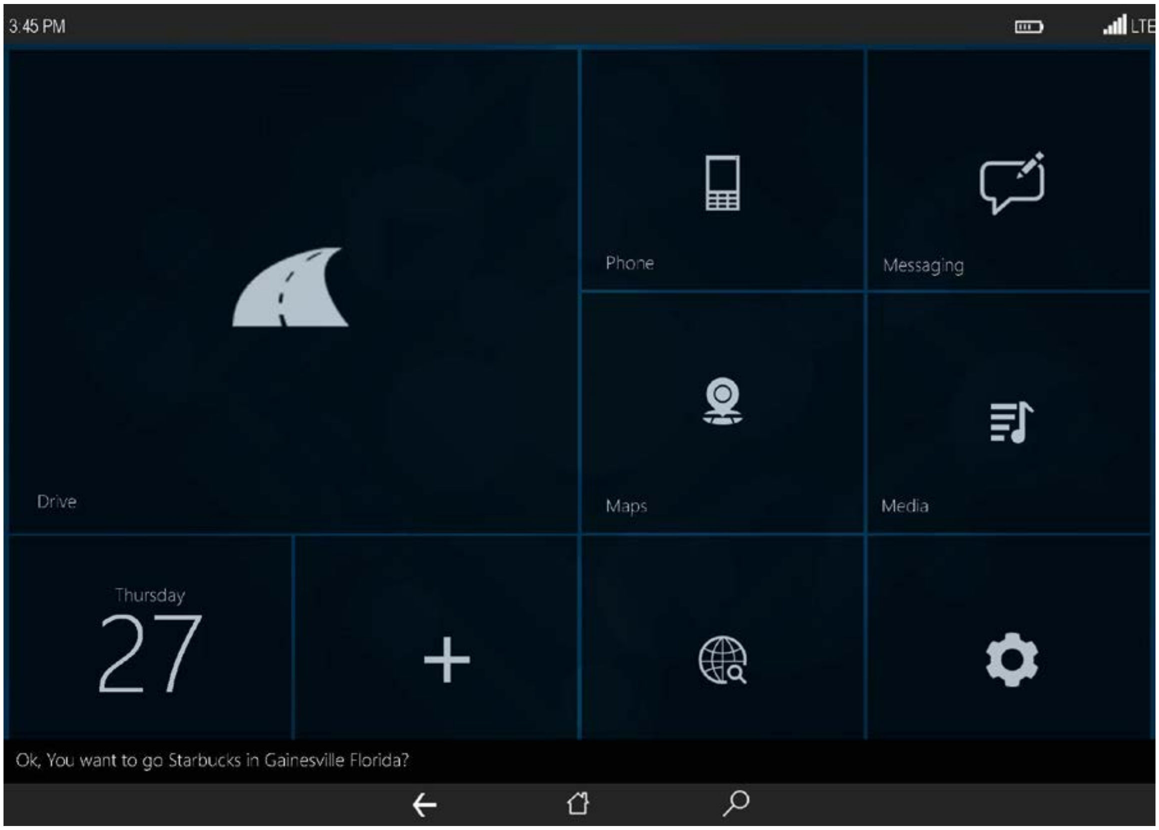


Figure 6-5. Alternate full color mockup of the ATLAS system with a horizontal screen orientation.

Similar to session four, each participant interacted individually in a "Wizard of Oz" [19] scenario using the paper prototype to simulate interaction with the system. Participants were given the same scenario and task instructions as those given in session four. While the facilitator continued to act as the system's voice user interface, the script used (Appendix F) had been revised to address participant concerns from the prior session.

Voice user interface. The response to the voice interaction capabilities of the simulated system was decided more favorable than the response during session four. Given that the interaction began with basic instructions regarding how to communicate with the system, participants expressed a greater understanding of how to begin an interaction. Participants also felt that the simulated voice prompts were more explicit.

Modifications were also made between sessions to the in-transit cues and location arrival information. The in-transit audio cues were modified to include traffic conditions, travel direction, pedestrian locations and a general description of the vehicle's immediate surroundings. Arrival information was modified to include explicit questions from the vehicle related to parking. While participants responded favorably to the new in-transit cues, the arrival information was viewed as overly complicated and time consuming.

Graphical user interface. Although participants responded favorably to the paper prototype, the associated full color mockup and the alternate mockup, a clear preference was expressed for the alternate mockup. An emerging consensus was that speech was the preferred method of interaction and that the graphical user interface should be a largely secondary means of interaction. Participants expressed significant hesitance in using a touch screen, even a "talking" touch screen, in the context of controlling the vehicle. Despite these concerns participants responded favorably to the alternate mockup, indicating that the large icons and font were easier to see.

Session six

Between sessions five and six, the schedules of two of the participants changed and one participant became unavailable due to medical treatment. The original September 20th session was rescheduled to September 27th. Only one member of Group one was able to attend on September 27th however so the session was canceled. No agreed upon date could be found that accommodated participants' revised schedules before the scheduled final software development effort so session six was not rescheduled.

Group Two: Blind Participants Age 18 to 54

Session one

All five members of Group two attended session one. The design activities of the session began by introducing participants to their assigned persona, Walter, via a biographical voice recording that was played for the group (see voice script, Appendix G). Participants were then asked to collectively craft a scenario that would describe how Walter would use and benefit from a self-driving vehicle. A scenario template was provided as a guide (Appendix C) and was read aloud to the group to initiate the scenario creation process. The introduction of the scenario had been pre-written by the study facilitator and was read aloud during the introduction of the template:

> Walter takes the bus five days out of the week to get to work. He's happy that the bus is available, but his long commute is time consuming and takes time away from his family. He would prefer the ability to drive a car but is blind and cannot operate a conventional motor vehicle. Walter just purchased a self-driving vehicle that he hopes may solve his transportation needs.

Participants were asked to use this introduction and within the context of the scenario template, identify Walter's primary need, his specific needs regarding the human-machine interface and the positive impact on his life of his use of a self-driving vehicle. Participants identified a single high-level need regarding Walter's overall use of a self-driving vehicle:

> Walter needs to go from one place to another quickly and reliably

Participants identified seven primary needs from the system's human-machine interface:

1. Vehicle parking information and capability
1. Location information to the entrance of the final destination
2. Speech, touch, and smartphone interaction capabilities
3. Information regarding proximity to the final destination
4. Voice navigation directions
5. Information regarding the posted speed limit
6. The presence and location of other vehicles and pedestrians

7. Information regarding the vehicle's ambient environment

This collaborative scenario creation process ended with a complete scenario that was transcribed by the moderator:

> Walter takes the bus five days out of the week to get to work. He's happy that the bus is available, but his long commute is time consuming and takes time away from his family. He would prefer the ability to drive a car but is blind and cannot operate a conventional motor vehicle. Walter just purchased a self-driving vehicle that he hopes may solve his transportation needs. He needs to travel between home and work in an optimal time. The vehicle's human-machine interface allows Walter to enter his route and destination information using a smartphone, accessible touch screen, manual controls and voice commands. The system also provides situational information while in transit, tells him when he has arrived and provides directions or orientation information to his final destination. Walter is now able to travel between work and home quickly without relying on public transportation.

Session two

Four members of Group two attended session two. The design activity began by playing an audio recording where the assigned persona, Walter, described his current location, explained his need to travel to a series of destinations and expressed his desire to do so in a self-driving vehicle:

> Hi this is Walter…I'm currently at home in Silver Springs, Maryland and I need to make a few stops before heading into work. I need to go to the nearest Panera to grab breakfast and after that I need to stop at the Sports Town in Ellsworth Place Mall to buy my daughter Meghan a birthday present. I have an interview at city hall about the tax breaks a pharmaceutical company is receiving, and after that I need to head to the office at the Transamerica Building downtown.

Participants were asked to construct a detailed narrative based on the provided information that would describe the process that Walter would use to successfully go from his starting location to his final destination in a self-driving vehicle. Participants were asked to refer to the human-machine interface that Walter would interact with in the

self-driving vehicle as "ATLAS". The narrative creation process began in session two and was not completed until session three.

Session three

Three members of Group two attended session three. The design activities of the session continued what was discussed in session two and focused on the construction of a detailed narrative that would describe the process that Walter would use to successfully go from his starting location and waypoints to his final destination in a self-driving vehicle. Through a process of brainstorming, discussion, and debate, participants summarized a 15-step process (lettered items: notes, suggestions and observations):

1. Walter walks out of his house and presses a location button (car starts to beep).
    a) A beeping sound leads to the driver's side door
    b) Group consensus: Walter shouldn't have a problem finding the car door without the beep
    c) The vehicle doesn't have any manual controls but has an emergency shutoff button
2. When he fastens his seatbelt and closes the door the car starts talking to him
    a) He can choose to require a password to start the vehicle or the system can recognize his face
3. Walter pushes a button to turn off voice commands or to activate the commands
    a) Some type of toggle button
4. Walter enters the destination to Panera
    a) He can ask for the closest Panera and is presented with options
    b) He can specify the address using voice commands or talking touchscreen
    c) He can say go to 'Breakfast' if stored in system
5. Walter arrives at Panera
    a) Vehicle gives Walter parking options (must park for safety)
    b) Likely not an option to safely drop him off up front

c) It can park in available handicap space or closest available space otherwise

d) Vehicle can also hover, circling parking lot until a space becomes available

6. The system tells Walter directions to the door and sends directions to his smartphone

7. Ready to leave Panera

a) He receives smartphone directions back to the car

b) Maybe a large key fob (if you don't have a phone) with a screen that somehow provides directions to the vehicle

8. Needs to enter the destination to Sports Town in Ellsworth Place Mall

a) Note: a general consensus emerges that he would use the voice interface exclusively

9. In transit

a) The system provides an estimated time of arrival

b) The system describes places he's passing, "Tell me if I'm passing any grocery stores on the way".

c) The system describes landmarks and things of interest

d) The system should provide immediate and real time notifications that an obstacle has appeared and provide information while making evasive maneuvers.

e) The system should provide information while yielding to emergency vehicles

f) The vehicle should be able to speed in an emergency if Walter authorizes it

g) Should the system notify law enforcement that you are speeding/going to the hospital or having an emergency? This would prevent people from frivolously using system and will alert local law enforcement

h) Should notify operator if it needs to reroute or detour and give reasons why

10. Arrival at Elsworth Place Mall

a) Walter has the choice of having the vehicle park or drop him off at the front door

b) The vehicle should provide directions to front door and send directions to a secondary device (smartphone or key fob)

11. Ready to leave

a) If possible and safe the vehicle should come pick him up (maybe by pressing button on key fob). It should get as close as possible and provide directions to the vehicle

b) The vehicle should beep until Walter enters

12. Needs to enter directions to City Hall

a) Walter should be able to say, “take me to the closest parking garage or parking facility to city hall”.

b) Upon arrival Walter should be able to get out and let the car park or order the car to park

c) When it’s time to leave, the car should come to pick Walter up at the entry/exit

d) If the vehicle can’t find a parking spot, it should hover until it finds an available parking spot or is summoned

13. Ready to leave City Hall

a) Walter goes back to the entrance of the garage and summons the car

14. Enter the destination to the TransAmerica building

a) Likely using the voice user interface.

15. Arrival at Transamerica building

a) Should be able to say, “Find the closest available free parking location to Transamerica building”

Session four

Two members of Group two attended session four. Given the limited indication of the use of a graphical user interface by participants in Group two, a paper prototype developed for Group one (Figure 6-2) was used within the session. During session four each participant individually participated in a “Wizard of Oz” [19]scenario to simulate interaction with the system. Participants were given the following instructions to begin the scenario:

> Imagine that you are in a self-driving vehicle equipped with the ATLAS system that we have been developing over the past few weeks. Use the

system to direct the vehicle to the Ellsworth Place Mall in Baltimore, Maryland.

The facilitator acted as the system's voice user interface by giving instructions and responding to participant voice commands based on a predefined script (Appendix H). System dialogue was improvised when interaction went off script. The facilitator also moved the paper prototype as necessary to simulate the system's visual response to voice commands and touch input. To simulate a "talking" touch screen like Apple Voice Over [94] the author would provide a verbal description when a button on the paper prototype was touched. Following each interaction, comments from the group regarding the interaction were solicited. Following both interactions, the group, led by the moderator, discussed the interaction and potential improvements.

Voice user interface. Participants expressed confusion initially regarding what commands the system was capable of responding to and expressed a desire for more clear directions in this regard. Both participants expressed a desire to control all vehicle systems and access all vehicle information using the voice user interface. In addition to specifying a route and destination information, the ability to request the time, temperature, fuel status and locate places of interest by voice were requested features.

The group was split regarding the effectiveness of the in-transit location cues. One participant felt that the cues were insufficiently detailed while the other argued that they were irrelevant if the passenger had no prior knowledge of the surrounding area. Both participants were critical of the destination arrival process. The minimal inclusion of any detailed information regarding the exterior environment was viewed as a significant shortcoming that would undermine a user's ability to recognize their arrival at the correct location. Participants were also unsure of what to say to park the vehicle or to receive walking direction to the building's entrance.

Graphical user interface. Participants had no comments regarding the paper prototype / visual interface and no participant chose to directly interact with it during the scenario.

Session five

Three members of the group attended session five. Similar to session four, the author interacted with each participant individually in a "Wizard of Oz" scenario to simulate interaction with the system. The scenario utilized a revised paper prototype from Group one. Participants were also given the same scenario and task instructions as those given in session four. The facilitator continued to act as the system's voice user interface, and the script used (Appendix I) was changed between sessions four and five in response to participant feedback in the prior session.

Voice user interface. Participants responded more favorably to the simulated voice interaction of session five than in session four. The interaction began with basic instructions regarding how to communicate with the system, what actions the system was capable of taking, and instructions regarding how to initiate a trip. Participants who had attended session four indicated that the revised voice interaction was a significant improvement. In addition to the initial instructions, session five's VUI script included more descriptive and declarative information generally and increased direct prompts to guide the user.

Modifications were also made between sessions to the in-transit cues and location arrival information. The in-transit audio cues were modified to include traffic conditions, travel direction, pedestrian locations, and a general description of the vehicle's immediate surroundings. Participants responded favorably to the in-transit cues but were concerned that they might prove annoying given their described one-minute frequency. It was

suggested that the cues should either be based on distance traveled or that the ability to control how much information was vocalized should be made apparent to the user. Arrival information was modified to provide detailed information about the arrival location (e.g. presence of people, vehicles, trees, etc.) and to prompt the user for specific parking guidance. Participants welcomed the improvements but requested the addition of more explicit information that clarified specifically how to return to or summon the vehicle.

Session six

Two members of the group attended session six. Between sessions five and six a high-fidelity prototype was developed and deployed to a Microsoft Surface tablet that combined system features suggested throughout the design sessions across all three groups. Participants interacted individually with the prototype within the following scenario while seated at a desk:

> Imagine that you are in a self-driving vehicle equipped with the ATLAS system that we have been developing over the past few weeks. Use the system to find and go to the nearest Kmart.

Participants were then interviewed individually regarding their experience.

Voice user interface. The high-fidelity prototype utilized facial recognition to determine if the user had prior experience with the system or needed to complete the mandatory tutorial (Appendix Q). Participants responded favorably to this process but felt that the tutorial was too long. Participants were split on whether the tutorial should be required for new users. Participants responded favorably to the flexibility of the system’s voice commands, generally expressing a view that the commands were flexible but explicit enough to provide appropriate direction.

Group Three: Blind Participants 55 and Older

Session one

All four members of Group three attended session one. The design activities of the session began by introducing participants to their assigned persona, Hannah, via a biographical voice recording that was played for the group (see voice script, Appendix J). Participants were then asked to collectively craft a scenario that would describe how Hannah would use and benefit from a self-driving vehicle. A scenario template was provided as a guide (Appendix C) and was read aloud to the group to initiate the scenario creation process. The introduction of the scenario had been pre-written by the study moderator and was read aloud during the introduction of the template:

> Hannah relies on her daughter and friends to go the store, church and see friends. She prefers riding with her daughter, but her daughter is often at work and doesn't have time to take her places. She would prefer a personal vehicle but is blind and cannot drive. Hannah has just received access to a self-driving vehicle as a beta tester that may solve her transportation needs.

Participants were asked to use this introduction and within the context of the scenario template, identify Hannah's primary need, her specific needs regarding the human-machine interface, and the positive impact on her life of her use of a self-driving vehicle. Participants identified four high-level needs regarding Hannah's overall use of a self-driving vehicle:

> Hannah needs to the ability to go from one place to another reliably without the need to rely on other people.

Participants then identified eight specific needs from the system's human-machine interface:

1. Speech interaction capabilities
2. Vehicle parking information and capability
3. Location information to the entrance of the final destination
4. Information regarding proximity to the final destination
5. The presence and location of other vehicles and pedestrians

6. Information regarding the vehicle’s ambient environment
7. Information regarding the vehicle’s anticipated actions (e.g. preparing to stop)
8. Access to a human operator or other help/emergency assistance

This collaborative scenario creation process ended with a complete scenario that was transcribed by the moderator:

> Hannah relies on her daughter and friends to go the store, social events, and doctor’s appointments. She prefers riding with her daughter, but her daughter is often at work and doesn’t have time to take her places. She would prefer a personal vehicle but is blind and cannot drive. Hannah has just received access to a self-driving taxi as a beta tester that may solve her transportation needs. The self-driving car allows Hannah to go where she needs to go without relying on others. The vehicle’s human-machine interface allows Hannah to enter her route and destination information using voice commands or an accessible touch screen. The system also provides situational information while in transit, tells her when he has arrived, and provides directions or orientation information to her final destination. Hannah is now able to travel independently and safely.

Session two

All four members of Group three attended session two. The design activity began by playing an audio recording where the assigned persona, Hannah, described her current location, explained her need to travel to a series of destinations, and expressed her desire to do so in a self-driving vehicle:

> Hi, this is Hannah...I’m at home in Chesapeake, Virginia, and I have a few places that I need to go. First, I have a doctor’s appointment at Chesapeake General Hospital. After that I need to go to Macy’s at MacArthur Center Mall in Norfolk to buy my granddaughter a present for her birthday. On the way I need to stop at the nearest decent restaurant to have lunch. Afterwards, I’m meeting some friends at the Great Bridge Community Center.

Participants were asked to construct a detailed narrative based on the provided information that would describe the process that Hannah would use to successfully go from her starting location to her final destination in a self-driving vehicle. Participants were asked to refer to the human-machine interface that Hannah would interact with in

the self-driving vehicle as "ATLAS". The narrative creation process began in session two and was not completed until session three.

Session three

All four members of Group three attended session three. The design activities of the session continued what was discussed in session two and focused on the construction of a detailed narrative that would describe the process that Hannah would use to successfully go from her starting location and waypoints to her final destination in a self-driving vehicle. Through a process of brainstorming, discussion and debate, moderated and directed by the facilitator, participants summarized a 15-step process (lettered items: notes, suggestions and observations are italicized):

1. Hannah uses an app to request a pickup or she calls the self-driving car company and speak to a person
   a) Hannah receives a message on her smartphone that the car has arrived
   b) The vehicle has an identifiable beep
   c) The message contains walking directions, and a smartphone app guides you to the car. The message contains information on the type of car and a PIN number to enter to access the car.
2. The vehicle recognizes Hannah (perhaps using facial recognition)
3. Hannah would enter the destination to the Hospital by voice though an accessible "talking" touch screen is available (they feel that each time it should tell you where to go)
   a) Hannah says, "take me to Chesapeake General Hospital"
4. The system defaults to full narration during transit, though a toggle button is available to turn the information on and off
5. In transit to Chesapeake General Hospital
   a) The system provides an estimated time of arrival and landmarks to give clues that the vehicle is going in the right direction
   b) Hannah can ask the system where she is at any given time

c) Hannah should be notified if the vehicle needs to detour and should be notified in real time if the car needs to make an evasive maneuver

d) If there is an emergency the vehicle should be able to call 911 and Hannah should always have the ability to tell the vehicle to go to the nearest hospital

e) Hannah should receive constant notification regarding where she is

6. Leaving Chesapeake General Hospital

7. Hannah needs to search for nearest restaurant

8. Hannah arrives at the restaurant

    a) If the vehicle can't drop her off at front, the vehicle needs to park itself

    b) If the vehicle parks she needs directions to the front of the restaurant

    c) Directions should be sent to Hannah's smartphone or to a smart key fob

9. Ready to leave restaurant

    a) Have directions to the vehicle sent to Hannah's smart key fob or smartphone

10. Enter destination to MacArthur Mall

    a) Hannah can either say the address or tell the system to take her to MacArthur Mall

11. Arrive at MacArthur Mall

    a) The vehicle should be able to drop her off at the closest entrance to Macy's

    b) If the vehicle can't drop her off at front, the vehicle needs to park itself

    c) If the vehicle parks she needs directions to the front of the restaurant

    d) Directions should be sent to Hannah's smartphone or to a smart key fob

12. Leaving Macy's

    a) Hannah should use the smart key fob or smartphone to have vehicle return

13. Enter destination to Great Bridge Community Center

    a) Hannah can either say the address or say take me the Great Bridge Community Center

14. Arrives at the Great Bridge Community Center

15. The vehicle should wait five minutes and then leave unless dismissed with the smart phone or smart key fob

Session four

All four members of Group three attended session four. Given the limited indication of the use of a graphical user interface by participants in group three, a paper prototype developed for Group one was used within the session. During session four the facilitator interacted with each participant individually in a “Wizard of Oz” scenario to simulate interaction with the system. Participants were given the following instructions to begin the scenario:

> Imagine that you are in a self-driving vehicle equipped with the ATLAS system that we have been developing over the past few weeks. Use the system to direct the vehicle to the Chesapeake General Hospital in Chesapeake, Virginia.

The facilitator acted as the system’s voice user interface by giving instructions and responding to participant voice commands based on a predefined script (Appendix K). System dialogue was improvised when interaction went off script. The facilitator also moved the paper prototype as necessary to simulate the system’s visual response to voice commands and touch input. To simulate a “talking” touch screen like Apple’s Voice Over [94] the facilitator would provide a verbal description when a button on the paper prototype was touched. Following each interaction, comments from the group regarding the interaction were solicited. Following both interactions, the group, led by the facilitator, discussed the interaction and potential improvements.

Voice user interface. Participants were unsure how to get started with the simulated voice interaction and expressed difficulty imagining that they were talking to a machine. Once this initial hurdle was overcome, participants indicated that they would

prefer being able to simply speak to the self-driving vehicle versus interacting in any other manner.

Participants requested persistent in-transit cues (e.g. travel direction, traffic, etc.), and the majority felt that these cues should be continuous to help the user understanding what the system was doing at all times. One participant, however, suggested that, for her, this would be annoying and requested the ability to turn of the in-transit cues altogether. She was only interested in knowing when the vehicle was starting a trip and when she had arrived.

Participants were generally satisfied with the parking instructions provided during the interaction under the condition that the vehicle was capable of parking itself and returning to pick them up.

Graphical user interface. Participants uniformly expressed a resistance to the use of a touch screen or any type of touch interaction. Citing previous negative experiences with touch screens, participants were concerned about making errors that would impact their safety while in the vehicle.

Session five

Two members of Group three canceled the day of the design session, August 9th, 2017 and one member arrived fifty minutes late to the study facility. As a result, the session was canceled. Two sessions with Group three were scheduled to take place on September 20th; a makeup session five and session six. Sessions for all groups were canceled on September 20th however per the request of Florida Center for the Blind staff. Session five was ultimately not rescheduled.

Session six

Three members of the group attended session six. Between sessions four and six a high-fidelity prototype was developed and deployed to a Microsoft Surface tablet that combined system features suggested throughout the design sessions across all three groups. Participants interacted individually with the prototype within the following scenario while seated at a desk:

> Imagine that you are in a self-driving vehicle equipped with the ATLAS system that we have been developing over the past few weeks. Use the system to find and go to the nearest Kmart.

Participants were then interviewed individually regarding their experience.

Voice user interface. The high-fidelity prototype utilized facial recognition to determine if the user had prior experience with the system or needed to complete the mandatory tutorial. Participants expressed concerns regarding the length of the facial recognition process and requested audio notifications of what the system was doing during the 8-17 second facial recognition process. Participants responded favorably to the presence of a tutorial at the beginning of the scenario but generally felt that it was somewhat confusing and did not clearly provide instructions on how to use the system. While participants were satisfied with the ability to speak naturally when interacting with the system, they were generally confused about when they were supposed to speak and what the system was doing given that the system was activated from standby mode using a keyword, “Atlas…”. Participants requested some type of notification (e.g. a tone or beep) to indicate when the system was requesting their direct input and more clear indicators regarding what the system was doing.

Discussion

Viewed collectively, aggregating feedback from all three groups, the design sessions indicated the need for eight core capabilities in any final high-fidelity prototype:

1. User Account Creation: A feature supporting the ability to distinguish one user from another and store system preferences.
2. Location Search: A feature supporting the ability to search for places of interest (e.g. “Starbucks” versus 100 E. 5th Street; the Starbuck’s location).
3. Destination Specification: A feature supporting the ability to enter a specific destination (e.g. 100 E. 5th Street, Gainesville, Florida).
4. Situational Awareness: Features supporting the ability of a user to identify their present location relative to their final destination and the vehicle’s relationship to other vehicles, pedestrians, and landmarks.
5. Location Verification: Features supporting the ability of a user to verify their arrival at the appropriate final destination using non-visual means, recognize the presence of any hazards like oncoming traffic, and have general awareness of the exterior environment (e.g. weather conditions).
6. Destination Direction: Features supporting the ability of a user walk from their arrival point to the entrance of their ultimate destination as applicable.
7. Parking and Return: Features supporting the ability to park or direct the vehicle to park that also support the ability to return to the vehicle as necessary.
8. Voice User Interface: The ability to control vehicle functions using speech input.

Limitations

There are two primary limitations of the design sessions; both related to scheduling. The first limitation relates to the inconsistent time gap between the sessions themselves. While every effort was made to space each session consistently two weeks apart, due to logistical and scheduling constraints some sessions were two weeks apart while others were as many as eight works apart. On average, design sessions were conducted 3.53 weeks apart. I argue that the impact of this time gap was relatively minimal given that steps were taken in the study’s procedure to reengage participants with each other at the beginning of each session and with the process by reviewing prior

progress. The second limitation relates to the two canceled sessions of Group one and Group three. While it would have been preferable to have six sessions for each of the study's three groups, unforeseen changes to participant schedules and logistical issues created scheduling and rescheduling constraints. Given that both cancelations occurred towards the end of the design process, I argue that this limitation had a relatively minor impact as well.

Key Takeaways

Participants uniformly requested that the system provide complex functionality that was accessed via an easy to use, straightforward, voice user interface. As participants gravitated increasingly toward speech as a primary means of interaction over the course of the design sessions, they increasingly expressed disdain for any type of touch interaction. Ultimately, resistance was expressed broadly regarding the use of any manner of touch screen as a primary interaction mechanism despite attempts to conceptualize a touchscreen that would be accessible. General participant opinion regarding the use of a smartphone or mobile device also shifted during the design sessions. While the use of a smartphone had been raised in prior phases of the research effort and early in the design sessions, participants gradually deemphasized smartphone interaction throughout the design process as a primary interaction mechanism. Even participants who were proponents of incorporating smartphones as an interaction mechanism felt that such interaction should be limited largely to parking scenarios and circumstances where the user needed directions to or from the vehicle.

Participants also indicated that tasks that were viewed as being potentially problematic early in the process were not in fact likely issues. Chief amongst these was the task of finding a vehicle's door. Nearly all participants dismissed this as a trivial

activity for a person who had experienced vision loss for even a brief period of time. Participants were similarly dismissive of the process of finding and buckling a seat belt. Participants were significantly concerned about exiting the vehicle. Feature requests in this regard were two-fold. Participants requested features that would help them verify their arrival in the correct location as well as features to enable them to exit the vehicle on the “safe” side. Significant concerns were raised about the prospect of opening the vehicle door into oncoming traffic or stepping into traffic or another hazard.

Chapter six has discussed the collaborative design of an accessible self-driving vehicle human-machine interface. The application of participant concerns and observations in the development of the final ATLAS prototype are discussed in Chapter 7.

CHAPTER 7
THE ATLAS SELF-DRIVING VEHICLE HUMAN-MACHINE INTERFACE: ARCHITECTURE AND IMPLEMENTATION

The development of the *Accessible Technology Leveraged for Autonomous vehicles System*, or ATLAS occurred subsequent to the conclusion of the participatory design sessions discussed in the previous chapter. During this development period relevant, features from the iteratively produced prototypes were combined to create a version of ATLAS to be used in quasi-naturalistic formal testing.

The ATLAS System

System Overview

The development of ATLAS was motivated by a desire to address the self-driving vehicle accessibility challenges suggested by the visually impaired survey respondents (Chapter 3), focus group participants (Chapter 4) and design session participants (Chapter 6) involved in this dissertation research. Recognizing that the system could also prove beneficial to sighted users as well, who might benefit from the ability to remain situationally aware using non-visual means, a secondary goal was the development of a usable and interactive graphical user interface that could satisfy the experiential needs of sighted users. Table 7-1 lists individual user needs uncovered through the earlier focus groups and participatory design session and describes the associated system feature(s) intended to address them.

Table 7-1. User need and associated system feature(s).

User Need	System Feature
Speech Interaction Capabilities	Mixed initiative voice user interface using cloud-based language model
System Personalization	Facial recognition-based user account creation; Continuous affect analysis to detect operator distress
Situational Awareness	Vocalized location specific information; Unity vehicle model of vehicle behavior
Location Verification	Spatial audio for hazard projection; vocalized description of exterior environment using image analysis
Destination Specification	Destination entry using either voice user interface or graphical user interface
Location Search	Location search using Microsoft LUIS and Google Places API for entity recognition
Directional Guidance to Final Destination	Not addressed
Parking and Return	Not addressed

System Implementation

Though ATLAS is a single system, it has been designed around service-oriented design principles and utilizes a service-oriented, multi-tiered architecture. The core of ATLAS is a Microsoft Universal Windows Platform (UWP) application [95], written in C#. Diverging from the approach of Asp.Net, Windows Presentation Foundation and WinForms, which required specific deployment environments, the UWP provides a core application-programming interface across devices. With this approach, a single application package can be installed on a range of devices and can be made available to consumers through the Microsoft Store. Though it is necessary to tailor the application for different form factors and types of input, a single application may be deployed to a Microsoft Surface tablet, desktop computer, mobile device, Microsoft HoloLens, or other hardware provided that the Windows 10 operating system is present. The use of a UWP application was chosen over other approaches given my familiarity with Microsoft .Net development, the decision to use C# for application logic, the desire to deploy the application to a Microsoft Surface tablet and the inherent compatibility of UWP

applications with Microsoft’s Language Understanding Intelligence Service [96] and Microsoft’s Face API [97].

Voice User Interface

Throughout the investigational and design activities, participants indicated a significant desire for a robust voice user interface (VUI). Voice interaction in ATLAS was enabled through the development of a speech recognition and speech synthesis library written to augment the Universal Window’s Platform existing speech capabilities, the development of a project-specific dialogue manager and the incorporation of language understanding as a service using a cloud-based language model.

Dialogue strategy

Based on what was learned during the participatory design sessions, the version of ATLAS used in the study was designed to utilize a mixed-initiative dialog strategy [98]. In a directed dialog strategy, the system initiates and directs all interaction. Using this approach, a system might ask a user a highly specific question (e.g. “What time do you want to schedule the appointment?”) and will anticipate a highly specific response (e.g. “1:30 pm”). In a mixed-initiative dialog strategy, at times the user has the initiative, and other times, the system will assume the initiative as needed to request missing information. Within ATLAS, first time users must complete a tutorial (Appendix L) during which, the system maintains the initiative. At the conclusion of the tutorial, initiative is relinquished to the user who may initiate a system action using the “hot word” to activate the voice interface (“Atlas”). Depending upon the user’s utterance the system will then assume the initiative as necessary. A user interested in learning the present time while the system is in standby for instance might say the hot word, “Atlas”,

to activate the voice interface followed by his or her request for the time. Given that the system uses mixed-initiative, the user could also simply say, “Atlas, what time is it?”.

A sample dialogue is presented that demonstrates a mixed initiative interaction between the system S and a user U that is possible within ATLAS:

U: “ATLAS, I’ve been in an accident!” (The user has the initiative)

S: “You have been in an accident?” (The system assumes initiative)

U: “Yes!”

S: “Ok, you have been in an accident. Please stay calm and remain in your vehicle if it is safe to do so. I am contacting emergency services now. For your safety all exterior cameras and microphones have been activated. Is anyone injured?”

U: “Yes!”

S: “I have notified emergency services regarding potential injuries, they are on their way.” (Initiative is returned to the user)

Given that the system uses a mixed initiative approach, participants of the prior design sessions suggested the presence of an audible cue to indicate when the system was expecting a user response. A similar cue is present when input is anticipated using the Job Access With Speech (JAWS) [99] and NonVisual Desktop Access (NVDA) [100] screen reading software; two popular accessibility tools widely used by persons with visual impairments. A brief beep was incorporated whenever the system assumed the initiative and expected a response as demonstrated in this sample dialogue:

U: “ATLAS, drive” (The user has the initiative)

S: “Ok, where do you want to go?” (The system assumes initiative)

S: beep

U: “I want to go to Starbucks in Gainesville, Florida.”

S: “Ok, you want to go to Starbucks in Gainesville, Florida?”

S: beep

U: “Yes”

S: “Ok, finding Starbucks in Gainesville, Florida. Please wait, this might take a moment.”

Pervasive dialogue elements: The design of the ATLAS dialogue strategy also included the development of an error recovery strategy and a strategy for universal commands. ATLAS utilizes an approach to voice user interface error handling that combines escalating detail and rapid reprompting depending upon the situation. In all cases, when the speech recognizer fails to return a recognition result within the specific confidence threshold (moderate confidence or higher) or the user fails to respond within a three second window, the system reprompts the user while repeating the question (e.g. “I’m sorry, what did you say?”). In certain situations, such as within the tutorial when users are gaining familiarity with the system, the user is given additional detail and specific directions on how to respond to the prompt (e.g. “I’m sorry I didn’t understand you. Try saying yes or no.”). Within the tutorial, when users are unable to respond to the practice prompt appropriately after three attempts (“Say, ATLAS what time is it?”), the system switches to a new prompt entirely (“It seems like you’re having trouble. Let’s try something else. Say, ATLAS what day of the week is it?”). At any point in a dialogue the system is able to respond to the universal commands of “Help”, “Exit”, “Quit”, “Emergency”, “Stop” and “Accident”.

Speed of speech: My observations of blind and visually impaired persons have suggested that in many cases, users with significant visual impairments use speech technology that makes utterances at an accelerated speed. During the design sessions,

however, many participants indicated that the system should not be configured to speak at an accelerated speed as a default. Participants argued that an accelerated speed would prove challenging for those newly visually impaired such as for elderly persons with gradual vision loss. As a result, ATLAS retained the default speech speed of the UWP platform.

Speech recognition and speech synthesis

The UWP provides speech recognition capabilities through the Windows.Media.SpeechRecognition API [101] that is made up of a speech runtime, recognition APIs, predefined grammars for dictation and a default system user interface. Using the predefined grammars, speech recognition is enabled using a remote web service that returns results to the device. The default grammars are capable of detecting up to 10 seconds of speech input. Given that default speech recognition uses a web service, connection to a network is required and speech input functionality requires an opt-in by the user to enable any speech recognition enabled applications to access the user's microphone.

Speech synthesis is enabled in UWP applications through the Windows.Media.SpeechSynthesis API [102]. Using this API, a speech synthesis engine can be configured to convert a text string to an audio stream (e.g. text-to-speech or TTS) and voice characteristics, pronunciation, volume, pitch, rate and speed may be modified programmatically. Within UWP applications, only a single voice can be designated per speech synthesis engine, only predefined Microsoft voices installed on the system can be used to generate speech and each voice generates synthesized speech in a region-specific language.

Despite the presence of existing speech recognition and speech synthesis capabilities within UWP, implementing speech recognition and speech synthesis for ATLAS required the creation of a specialized library. Complexity was introduced due to the use of a mixed initiative dialog strategy, which required continuous recognition and voice interface activation from standby using the hot word "Atlas". While the Windows.Media.SpeechRecognition API provides continuous recognition capabilities, the recognizer struggles with differentiating between the conclusion of an utterance and natural pauses during speech. Alternating between continuous recognition sessions and text-to-speech events was also found to be inefficient, resulting in pauses of several seconds between the conclusion and initiation of recognition/speech events. To address these issues, I developed a specialized library that utilizes the speech recognition and synthesis APIs but efficiently synchronizes recognition and synthesis events using an asynchronous programming approach. Within this library, the speech recognition task is quickly concluded following an absence of speech of more than three seconds, while the speech synthesis task is quickly initiated. The coordination of task initiation and cancellation enabled using the library effectively addresses the delays and inefficiencies of using the speech recognition and synthesis APIs in a standalone fashion.

Dialogue management

A dialogue manager within a voice user interface determines what actions the system takes in response to user input. The dialogue manager within ATLAS is written in C# and takes as input either the raw user utterance from the speech recognizer or the user's intent from the language understanding model. The dialogue manager performs one or more actions based either on keywords detected within the utterance (e.g. "Quit",

“Help”) or on the user’s interpreted intent based on processing the utterance through the cloud-based language model.

Language understanding

Language understanding technology uses machine learning and a language model to enable an application to understand a user’s intent using the user’s own words. A system capable of language understanding might use a language model to determine that a user who says, “Find me a car for January 9th” wants to reserve a rental car on the 9th day of the first month. ATLAS uses Microsoft’s LUIS [96] language understanding service to host a language model in the cloud that maps user utterances, consumed as text input, to a user’s intent (e.g. what action they want to perform). The ATLAS language model, Enteraxion Atlas v 1.1, contains 40 custom and prebuilt intents, processes utterances received as HTTP requests through the model and returns a response as a JSON object. The LUIS model also returns any relevant objects or entities that were detected during processing as well as a confidence score between 0.00 (no confidence) and 1.00 (highest confidence). A request to, “Find Starbucks in Gainesville, Florida” for instance returns the intent, “Places.FindPlace” with a confidence score of 0.86 and encyclopedia (Starbucks) and geography (Florida) entities. The resulting JSON object can then be consumed by ATLAS, which then takes action based on the content of the response.

Graphical User Interface

While participants of this dissertation’s investigational activities expressed a preference for a robust voice user interface, an accessible graphical user interface (GUI) was also designed in response to participant feedback. The ATLAS GUI was implemented using extensible application markup language (XAML), which uses a

declarative syntax that builds on XML 1.0. The GUI design utilizes a block-based structure that focuses on the use of large, bold text, simplified icons, large buttons and the use of a moderate contrast theme. While evaluating a number of interface designs in prototype form during the prior participatory design sessions, users with some vision generally preferred a dark background with light text. Based on participant feedback, comprehensive full color mockups were developed for each user interface (Appendix M). Care was taken to implement each interface in a manner that closely mirrored the associated mockups using XAML.

Navigation and Global Positioning

The incorporation of navigation and global positioning was one of the more challenging aspects of system implementation. Early in the design process, the Microsoft Surface was identified as a likely candidate for application deployment due to my familiarity with the platform and the 12.3” screen size. Unlike other Microsoft mobile products, Surface tablets Series 1 through 4 lack an internal global positioning receiver and native global positioning capabilities. Such features only became available on a limited number of Surface Pro 5 tablets in December 2017 [103]. Absent internal GPS, the Surface tablet uses location capabilities enabled through the Windows 10 operating system that are based on the presence of an Internet connection. It has been widely reported that operating system’s native ability to calculate locations in this manner is widely inaccurate [104, p. 10],[105], resulting in calculations that in some cases, are miles away from the device’s true location. Given that this level of inaccuracy would render ATLAS essentially unusable, a global positioning library was written to consume raw GPS data from a USB GPS receiver connected to the device. The library consumed data in the National Marine Electronics Association (NMEA) format [106] and processed

the $GPGGA and $GPRMC messages to return a high precision longitude, latitude and speed over ground in miles per hour.

Maps

Mapping within the system is enabled using Microsoft's Bing Maps [107] and an associated UWP Map Control. The UWP Map Control enables the display of road maps, aerial maps and three-dimensional maps within a Universal Windows Platform application. The map also has native support for traffic display, transit markers and local businesses. Using information from the Google Places API and location information from the global positioning library the system displays route (Figure 7-1), current location and destination. The map also adjusts as the detected device position is updated.

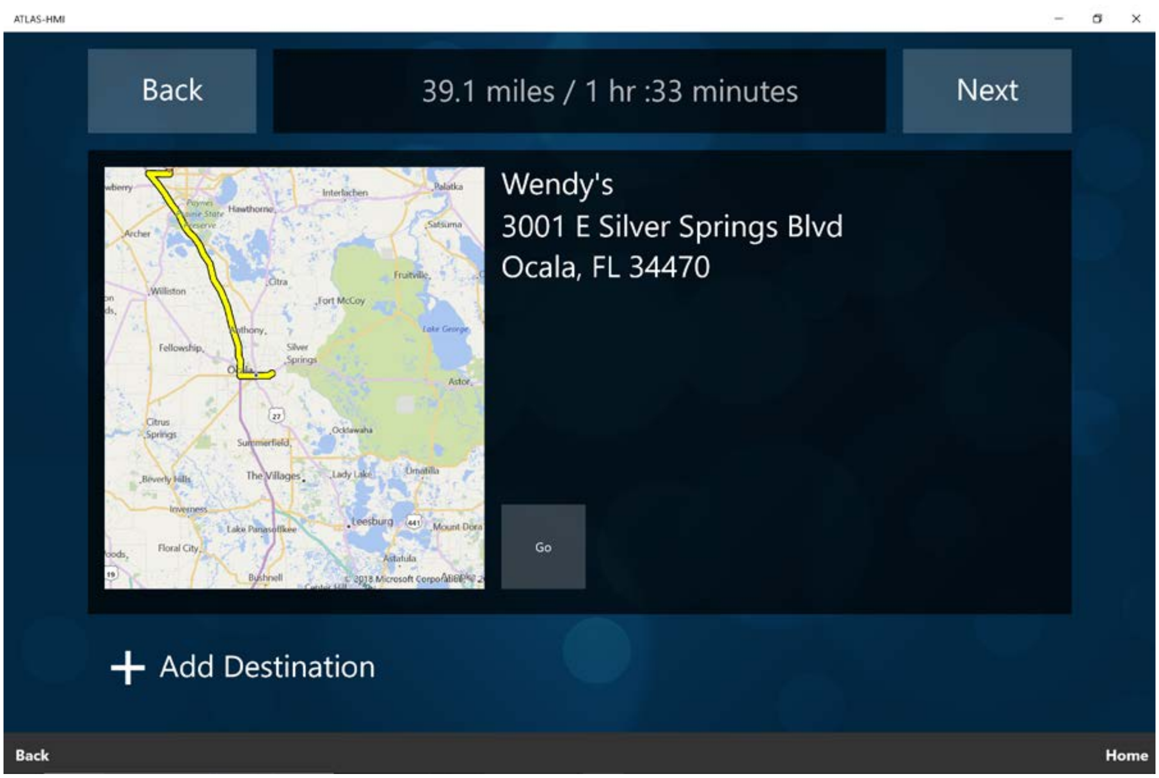


Figure 7-1. Screenshot of the ATLAS prototype route overview user interface.

A map calculations library that I developed augments the system's native mapping capabilities. This library uses global positioning data and data from the Google Places API [40] to calculate the present bearing using a spherical formula [108], distance to final destination using the Haversine distance formula [109], percent of trip remaining and time remaining in a trip. This information is used within the system to update the map, adjust the visual trip indicator (Figure 7-2) as well as to notify the user verbally regarding the trip's progress.

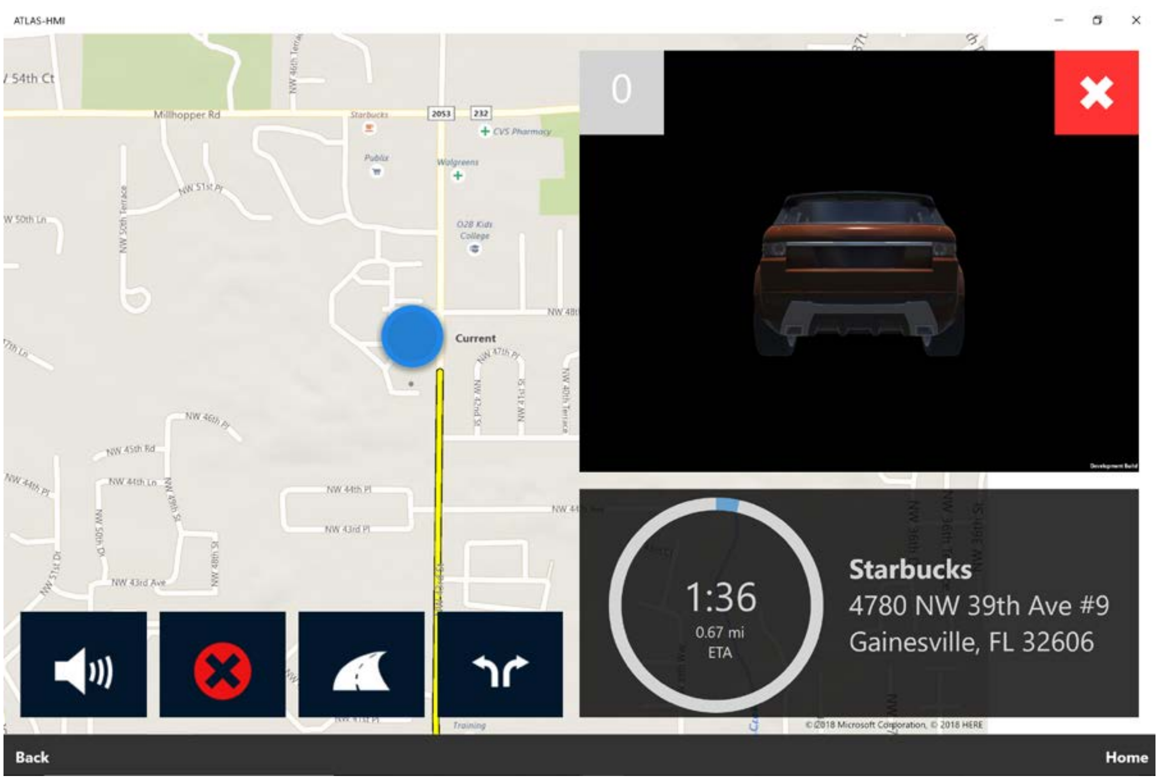


Figure 7-2. Screenshot of the ATLAS prototype main navigation user interface.

Location Identification

The Google Places API [40] has been used to enable ATLAS to identify places and addresses. The API is a web service that returns information regarding points of interest, geographic locations or addresses using an HTTP request. ATLAS utilizes the returned longitude and latitude, location type, and relevant images to provide relevant information to the user using both the voice and graphical interfaces.

Visual Representation of Vehicle Behavior

Participants of this dissertation's investigational activities expressed an interest in being informed of the vehicle's actions; this was true of both low vision and blind participants. A visual indicator of the vehicle's actions was designed to complement the speech indicator of system actions. A commercially available vehicle model was purchased and modified using the Unity [110] game engine to represent the self-driving vehicle and associated vehicle behaviors (Figure 7-3). The model was programmed using custom scripts written in C# to respond based on specific system actions (e.g. braking, driving, changing lanes, stopped). If, for instance, the vehicle began to stop at a final destination located to the right of vehicle, the animation would depict the vehicle stopping while the camera adjusts to show the vehicle's left side.

Figure 7-3. Unity vehicle model animation states; each associated with a vehicle behavior (e.g. moving, changing lanes, stopped, etc.)

Facial Recognition and Affective Analysis

A minority of participants of this research's design sessions expressed a desire for a customized user experience based on their individual preferences. Given that some research of automation-related ADAS has shown that drivers' perception of usability and comfort varies with different implementations of the same underlying technology[111] and that depending upon the implementation, system operation may be described as "harsh" or "aggressive" [112], it was deemed appropriate to include features that supported detection of operator discomfort and enabled ride customization. To enable this

level of customization it was determined that a means of recognizing individual users was necessary beyond a traditional key or a password. A traditional physical key does not provide the necessary support for individual identification while a password might prove both difficult to use for visually impaired users and has limited security when entered verbally. Facial recognition was viewed as an ideal compromise between security and convenience.

Facial recognition is enabled within ATLAS using the Surface’s built in camera and the Microsoft Azure Face API V 1.0 [97]. Upon system start, the user is talked through the system’s facial recognition process. The process includes the activation of the Surface’s camera and initiation of a live video stream. The system prompts the user to adjust his or her head to face the camera as the system attempts to capture an acceptable image from the video stream. Upon image capture, ATLAS takes the image and uploads it to Microsoft’s Cognitive Services for analysis in the cloud by the Face API. The Face API is capable of detecting up to 64 human faces in a single image and returns an identification and verification score in a range of 0.00 (no confidence) to 1.00 (highest confidence) as a JSON object. The API can also return optional data like age, gender, smile intensity, facial hair, head pose, glasses, emotion, hair and accessories. As implemented in ATLAS, this entire process takes between eight and fifteen seconds after which, the user is either directed to the system’s home screen or guided through a brief setup process.

Beyond initial setup and user account creation, the Face API is also used to detect user agitation or distress while in transit. ATLAS is configured to continuously monitor the user’s face and using the Face API in conjunction with the Microsoft Emotion API [113] analyze the user’s face for the presence of eight emotions: anger, contempt, disgust,

fear, happiness, neutral, sadness and surprise each with a score in the range of 0.00 (no intensity) to 1.00 (highest intensity of emotion). At present, the system defaults to conducting an emotion analysis every 30 seconds while the vehicle is in transit given the high data usage required and practical data limitations. If data consumption is not an issue however this frequency can be adjusted to as frequently as every three seconds. The system is configured to respond to anger, surprise, and fear if either rises above 0.50 with a priority placed on fear. Upon detection, the system will respond verbally (e.g. “I have detected that you might be experiencing discomfort…”) and inquires regarding the need to modify system acceleration, braking, or general driving behavior. The creation of this feature has been informed by research on active cruise control systems (ACC) [112] that has shown that users are often disturbed by the systems’ braking and acceleration behavior. Given that self-driving capabilities incorporate aspects of ACC the creation of such a feature was viewed as a logical solution to the identified problem.

Image Analysis

The inability to verify arrival at a final destination was identified as a significant problem by both participants of this research’s focus groups and design sessions. In an attempt to address this issue, ATLAS utilizes the Microsoft Computer Vision API [114] to analyze images of the vehicle’s exterior for vocalization. The API is capable of analyzing an uploaded image and returning a JSON object containing a description of the image and confidence (from 0.00 to 1.00) and tags describing elements identified in the image with individual confidence scores (from 0.00 to 1.00). While the code necessary to implement this feature has been implemented, given the inability to add an external camera to the deployed device due to the use of the single virtual COM port by the GPS receiver, this feature is unavailable within the system.

Spatial Audio

Participants of the research's focus groups and design sessions expressed significant concerns regarding the prospect of stepping into oncoming traffic inadvertently upon arrival at a location. Projecting traffic noise from the direction of the road hazard was implemented through spatial audio as means of notifying users of the nearby roadway in a realistic manner.

Spatial audio, which includes the perception of audio within a three-dimensional space, has been implemented within the system to work in concert with exterior analysis. Spatial audio in ATLAS is enabled using the Windows 10 AudioGraph 1.1 API [115]
, which provides a set of classes to combine audio nodes in a workflow for audio routing and mixing. This API allows audio sources to be positioned within a three-dimensional space using pre defined audio node emitters. Within ATLAS, spatial audio is used to position the sound of traffic in the direction of a nearby street upon arrival at a location. The system uses two speakers that are positioned to face the operator.

Hardware

ATLAS was deployed to a Microsoft Surface Pro 4 tablet with an Intel Core i7 processor, 12.3" full HD display, 16GB of RAM, a 512 GB solid state drive and a single USB 3.0 port. To enable global positioning, ATLAS uses a Global Sat BU-353-S4 [116] magnet mount, low power consumption GPS receiver connected to the Surface's USB 3.0 port. To support spatial audio the system uses two Logitech MX Sound Bluetooth speakers [117]. Internet connectivity is enabled using a mobile hotspot generated by an Alcatel OneTouch Idol 3 smartphone with the Windows 10 operating system.

Chapter seven has discussed how distinct system features were implemented in the ATLAS prototype with the intent of addressing user needs identified in earlier phases

of the research process. Chapter seven describes a quasi-naturalistic evaluation of the ATLAS system, conducted with the intent of determining whether ATLAS is successful at satisfying the needs of visually impaired self-driving vehicle operators.

CHAPTER 8
EVALUATION OF THE ATLAS SELF-DRIVING VEHICLE HUMAN-MACHINE INTERFACE PROTOTYPE

The present study was intended to evaluate the usability and accessibility of the ATLAS self-driving vehicle human-machine interface under quasi-naturalistic to address questions about the ability of the system to satisfy the experiential need of visually impaired users.

Study Design

To effectively design interfaces for self-driving vehicles, the study of human interactions with this technology is a logical prerequisite. Given the emerging nature of the technology, there are few approaches available to researchers that are both safe and are capable of producing ecologically valid results. Road testing of actual self-driving vehicle technology would be ideal, however there are significant legal and regulatory hurdles and the risk to life and property due to the possibility of significant system failures. While advanced driving simulators provide controlled conditions where all manner of human interaction with automotive systems have been studied, driving simulators have limitations in testing autonomous technologies. Current simulator technology is limited in its ability to accurately replicate inertial forces and realistically depict all aspects of the real world believably [118], which may undermine participants' suspension of disbelief [119]. Study results may therefore lack ecological validity and be of limited value in predicting how users might interact with an autonomous system in similar real-life settings.

The Real Road Autonomous Driving Simulator (RRADS) methodology of Baltodano, Sibi, Martelaro, Gowda and Ju [120] was designed to address these issues by creating a physical as opposed to digital simulation of a self-driving vehicle. The RRADS

methodology uses a traditional Wizard of Oz [19], [121], [122] approach involving two wizards and a single vehicle; a Driving Wizard and an Interaction Wizard. The Driving Wizard drives the vehicle on a predetermined route in a manner that is designed to simulate the driving behavior of a self-driving vehicle system. The Interaction Wizard, seated in the rear of the vehicle, is available to assist the participant in the event that they require assistance or wish to terminate the study. Participants approach the vehicle, are seated within the vehicle and exit the vehicle in a manner that completely obscures the presence of the Driving Wizard during the trial. An opaque partition is used within the vehicle to block the participant's view of the Driving Wizard or the vehicle's primary controls (e.g. steering wheel, pedals or shifting mechanism). Although testing using the RRADS methodology poses obvious risks, perhaps the most significant being the risk of accident or injury, it is hypothesized that the mental leap necessary to suspend disbelief is lowered under these conditions. Instead of asking the participant to imagine that a simulated vehicle and an entire digitally created world are real as in a simulator study, RRADS asks the participant to simply imagine the absence of a human driver who cannot be seen in an otherwise real context.

In an effort to increase the ecological validity of the study while testing the ATLAS system under quasi-naturalistic conditions, the RRADS methodology was determined to be a preferred approach relative to a simulator study. Conditions are described as "quasi-naturalistic" given that participants were not randomly assigned to a condition.

Method

Research Questions and Hypotheses

The primary goals of the study were to gauge users' perception of the ATLAS system's operation, to evaluate how well the system satisfied users' experiential needs, to determine if design inconsistencies exist with respect to the system's user interface and to determine if interaction with the prototype affected users' perception of self-driving vehicles broadly. The study aimed to answer the following research questions:

> R_1: To what extent do individuals who are visually impaired face barriers when interacting with the ATLAS system?
>
> R_2: What is the association between interacting with the ATLAS system and users' perception of self-driving vehicles?

Based on these questions the following hypotheses were developed:

> H_{01}: Participants will not, on average, find the ATLAS system to have "good" or better usability as measured using the system usability scale questionnaire.
>
> H_{A1}: Participants will, on average, find the ATLAS system to have "good" or better usability as measured using the system usability scale questionnaire.
>
> H_{02}: After interacting with the ATLAS system, participants will express a diminished belief in the likely ease of use of self-driving vehicles as measured using the self-driving car assessment scale.
>
> H_{A2}: After interacting with the ATLAS system, participants will express a greater belief in the likely ease of use of self-driving vehicles as measured using the self-driving car assessment scale.
>
> H_{03}: After interacting with the ATLAS system, participants will express a reduced degree of trust in self-driving vehicles as measured using the self-driving car assessment scale.
>
> H_{A3}: After interacting with the ATLAS system, participants will express a greater degree of trust in self-driving vehicles as measured using the self-driving car assessment scale.

Table 8-2 describes the relationship between the research questions, hypotheses and measures used.

Table 8-1. Relationship between research questions, hypotheses and measures.

Research Question	Hypotheses	Measures
R1: To what extent do individuals who are visually impaired face barriers when interacting with the ATLAS system?	H_{a1}	System Usability Scale Questionnaire; Situational Awareness and Location Verification Scale
R2: What is the association between interacting with the ATLAS system and users' perception of self-driving vehicles?	H_{a2}; H_{a3}	Self-Driving Car Assessment Scale

Participants

Participants were recruited by email, newsletter, and social media announcements distributed by organization serving persons with visual impairments in North Central Florida and vocational rehabilitation organizations. Interested individuals aged 18 or above who identified as visually impaired were invited to participate. Visual impairment for the purpose of the advertisement was defined as blindness or limited vision not correctable by glasses or contact lenses. Those interested in participating were asked to call or email for additional information and scheduling. The University of Florida's General Consul's Office, Office of Risk Management, and Institutional Review Board approved the study and each participant provided written informed consent the day of his or her study session. Participants were compensated with a $40 prepaid gift card for their participation.

In total, twenty participants were involved in the study, which was conducted over a ten-day period. Demographic breakdowns for the respondents are provided in Table 8-2 through Table 8-7. Fifty-five percent of participants were female and 45% were male (Table 8-2). Seventy percent of participants were between the ages of 45 and 64, while those 35 and under made up 15% of those participating in the study (Table 8-3). Eighty

percent of participants had at least some college (Table 8-4). Fifty percent of participants were unemployed (Table 8-5).

Table 8-2. Breakdown of survey respondents by gender.

Gender	Participants (n = 20)
Female	11 (55%)
Male	9 (45%)

Table 8-3. Breakdown of survey respondents by age group.

Age group	Participants (n = 20)
18-24	0
25-34	3 (15%)
35-44	0
45-54	7 (35%)
55-64	7 (35%)
65+	3 (15%)

Table 8-4. Breakdown of survey respondents by level of education.

Education	Participants (n = 20)
Some High School	1 (5%)
High School Diploma / GED	3 (15%)
Some College	8 (40%)
2 Year Degree / Associate's Degree	4 (20%)
Bachelor's Degree	3 (15%)
Graduate Degree	1 (5%)

Table 8-5. Breakdown of survey respondents by level of employment.

Education	Participants (n = 20)
Employed Full-time	2 (10%)
Employed Part-time	3 (15%)
Not Currently Employed	10 (50%)
Retired	4 (20%)
Full-time Student	1 (5%)
Part-time Student	0

During the screening and scheduling process participants were presented with functional definitions of blindness and low vision [69]. They were then asked to choose the definition that best characterized their degree of vision loss; five participants self-identified as blind and fifteen self-identified as low vision using this approach. The day

of the study session, and after providing written consent, participants were asked to provide their medically diagnosed central visual acuity in their better seeing eye with conventional correction. Participants who indicated a visual acuity of 20/200 or worse, legal blindness in the United States [69], were classified as blind for the purposes of the study. The two participants who were unaware of their medically diagnosed visual acuity were classified according to their self-identification as either blind or low vision. Based on this approach the study included 12 participants who self-identified as blind or who were medically diagnosed as legally blind and eight participants who were not legally blind and could therefore be considered low vision (Table 8-6). More than half of respondents (65%) indicated that they had spent some part of their life with sight (Table 8-7).

Table 8-6. Breakdown of survey respondents by legal characterization of visual impairment.

Legal characterization of visual impairment	Participants (n = 20)
Blind	12 (60%)
Low Vision	8 (40%)

Table 8-7. Breakdown of survey respondents by length of time of visual impairment.

Length of visual impairment	Participants (n = 20)
Some Of Your Life	13 (65%)
Most Of Your Life	2 (10%)
All Of Your Life	4 (20%)
I Am Newly Visually Impaired	1 (5%)

Apparatus and Testing Environment

Atlas prototype

A modified version of the ATLAS prototype was used in the study. During pilot testing, the system’s facial recognition feature performed inconsistently; on several occasions failing to recognize users with existing system accounts. The problem was traced to the inconsistent lighting conditions in the rear of the vehicle. The facial

recognition process was deactivated in the version of the system used for the study. The tutorial process was subsequently made optional; users could choose to exit the tutorial at any time by saying “Quit” or “Exit” after which the system would confirm the action and exit the tutorial as necessary. The features of the test system were otherwise consistent with the features and capabilities discussed in Chapter 7.

Test vehicle

A 2018 Volkswagen Atlas sport utility vehicle was used as a test vehicle. To provide clarity given that the Volkswagen and system under test share the same name, ATLAS will be specifically used to refer to the system under test while Volkswagen will be used to refer specifically to the test vehicle. The Microsoft Surface tablet, on which the ATLAS system was deployed, was affixed to the rear of the front passenger seat of the Volkswagen using an Kenu Airvue [123] tablet mounting device (Figure 8-1). The system’s speakers were placed unobtrusively under the front seats and the USB global positioning sensor was taped to the front passenger side window. The smartphone used to provide Internet connectivity to the system was placed on the rear seat. The tablet, speakers and smartphone received continuous power from a 750 W power inverter connected to a 12-volt outlet located in the rear of the front console.

Figure 8-1. ATLAS prototype and supporting hardware within the test vehicle.

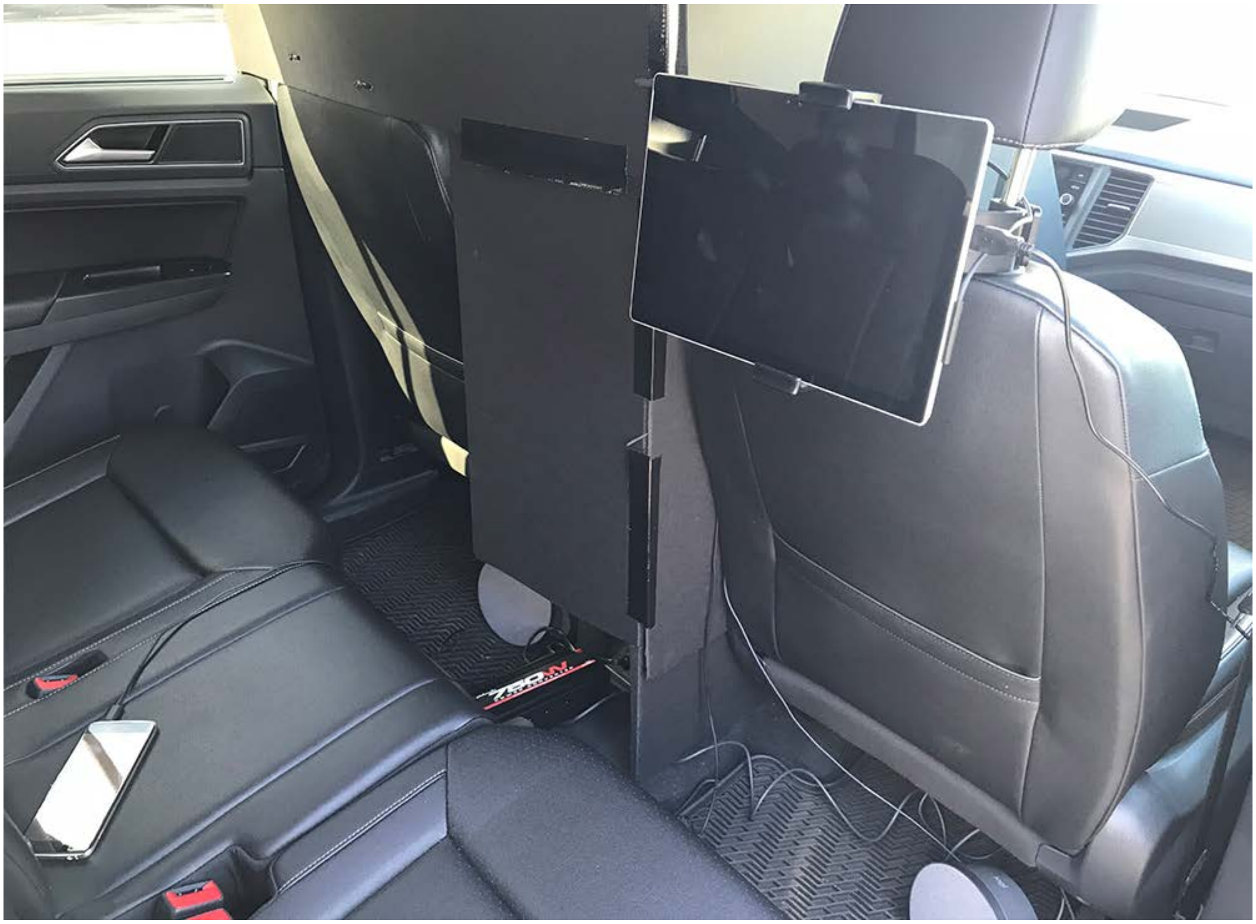


Figure 8-2. ATLAS prototype and rear of vehicle partition.

Camera placement

Figure 8-3 illustrates camera placement within the vehicle. A Vivitar DVR 917 HD [124] action camera was affixed to the rear passenger window closest to the participant using a suction mount to capture participant interaction with the ATLAS system. An Insignia NS-CT1DC8 [125] dash camera was affixed to the front windshield using a suction mount to capture a clear view of the road.

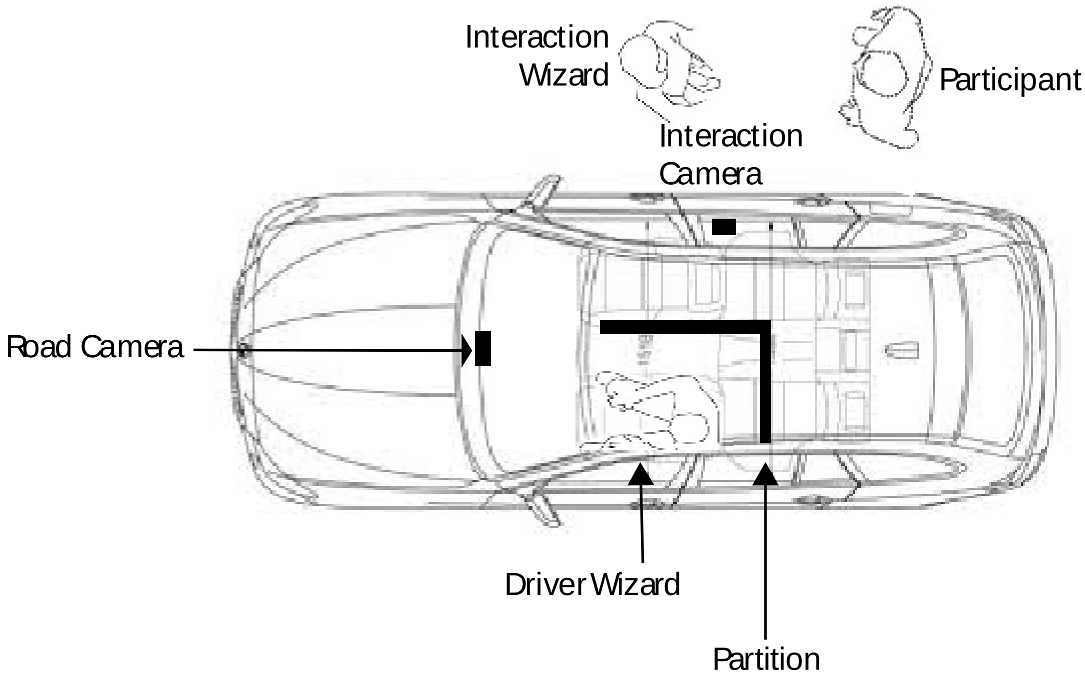


Figure 8-3. Camera and partition placement with the test vehicle.

Partition

An opaque partition, necessary to obscure the Driver Wizard and vehicle controls from participant view, was constructed of black, two-centimeter thick form board, black Velcro straps and duct tape (Figure 8-4). The partition was primarily secured to the vehicle by its weight, shape and position, as one side was wedged between the front passenger seat and the center console. Additional support was provided through the use of zip ties, black duct tape and black Velcro straps. The partition was designed to obscure a driver shorter than 186 centimeters and was trimmed to allow line of sight to the passenger mirror and passenger side blind spot sensor.

Figure 8-4. Passenger view of RRADS partition upon vehicle approach.

Pilot study

A pilot study was conducted with five participants to evaluate the feasibility of the procedure, evaluate the preliminary road course and prepare for any adverse events that might occur during the actual study. Based on the findings of the pilot, the road course was expanded from approximately two miles to 3.9 miles to better balance the distance between identified waypoints. Modifications were also made to the number of tasks (reduced from six to four) and the number of questionnaires (reduced by one) to better align the study procedure with the one-hour time span that had been allotted for each trial.

Road course: A 3.9-mile course spanning six roads was selected in Ocala, Florida (Figure 8-5). The course was selected for its relatively light traffic, mixture of commercial and residential conditions and proximity to the study's staging area. Speeds ranged from 25 miles per hour to 45 miles per hour and the course included interaction with traffic lights and stop signs. Seven practice trials suggested that the course could be completed in as little as 14 minutes in light to moderate traffic.

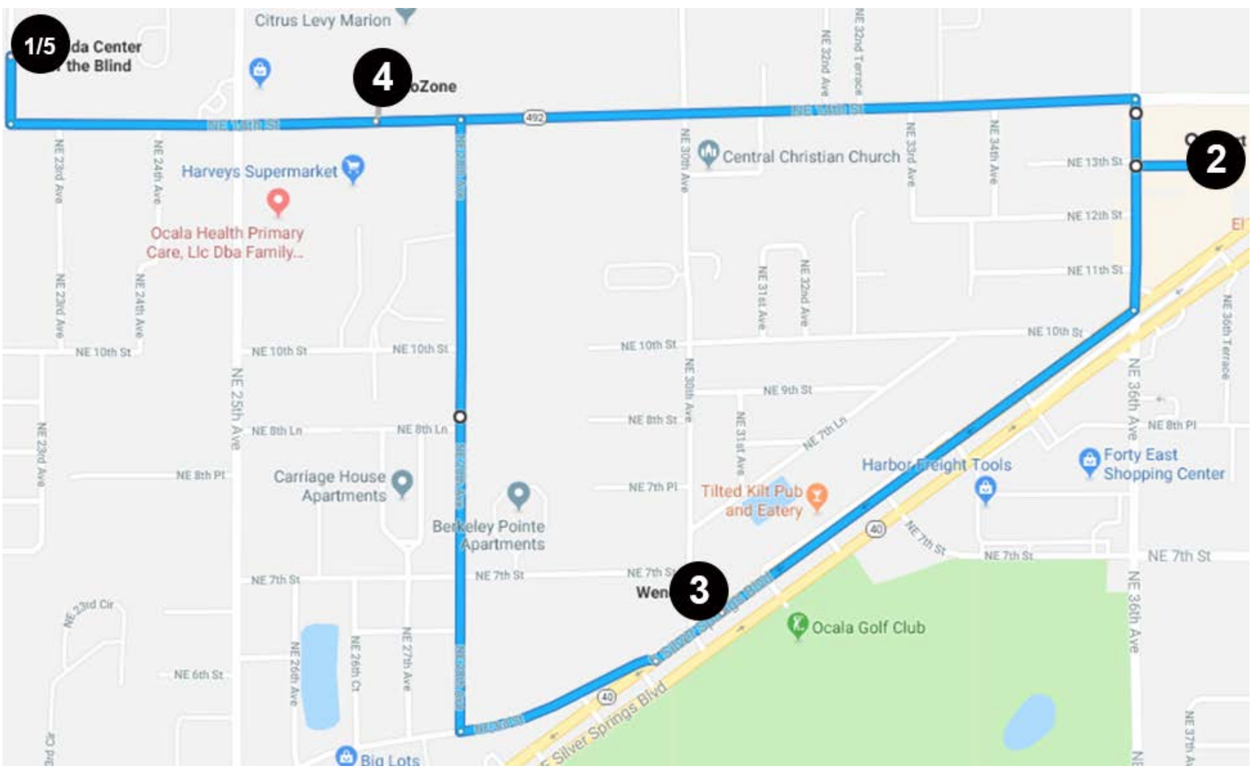


Figure 8-5. The study road course with five waypoints: 1) The Florida Center for the Blind, 2) Kmart, 3) Wendy's, 4) Autozone and 5) The Florida Center for the Blind.

Procedure

The procedure was designed to fit within an one-hour session and consisted of a single scenario and its corresponding tasks. Participants began their session seated in a

closed room with a member of the study team who would serve as the Interaction Wizard. As a preliminary activity, each participant was read the IRB approved informed consent document that had been emailed in an accessible format prior to the study session. Overt deception was not used, and participants were told that they would be interacting with a prototype in a simulated, as opposed to real, self-driving vehicle. Participants were also told that a licensed driver would be behind the wheel at all times. Permission was also explicitly requested to video record the study for later transcription.

After obtaining consent, participants completed a demographic questionnaire that was read aloud (Appendix N). Participants then verbally completed the Self Driving Car Assessment Scale (SDCA) [126] (Appendix O). The SDC is a 24-item, seven-point Likert scale (from 1 = strongly disagree to 7 = strongly agree) instrument designed to assess respondents' perception of self-driving vehicles across eight dimensions: 1) perceived reliability, 2) cost, 3) appropriateness, 4) enjoyment, 5) perceived usefulness, 6) perceived ease of use 7) user experience and 8) intention to use. Participants were then walked to the waiting test vehicle, approaching from the rear passenger side to obscure their view of the driver area. The Interaction Wizard ensured that all participants were buckled prior to attempt the tasks.

Once seated and buckled within the vehicle, participants were read the scenario introduction and informed that they would complete a tutorial and receive task instructions as the study progressed. Participants were given no further instructions regarding system operation. Participants were asked to refrain from speaking to the Interaction Wizard unless they needed to have the current task repeated, wanted to end the trial, or had a safety related question or concern. Participants were asked to hold all other questions until their return to the staging area. After receiving consent to begin,

participants attempted the study's tasks and the driving activity began. Task performance data (e.g. attempts, successful/unsuccessful) were recorded. In the event that the participant was unsuccessful at specifying the appropriate waypoint following three attempts, the Interaction Wizard interceded and manually entered the correct information to continue the study on the defined route. All participants were presented with the same scenario and tasks. Upon the vehicle's return to the staging area, the participant was returned to the interview room by the Interaction Wizard. Another member of the study team entered and asked the user to verbally complete the System Usability Scale Questionnaire (SUS) [127], which was read aloud (Appendix P). The SUS is a 10-item, five-point Likert scale (from 1 = strongly disagree to 5 = strongly agree) that provides a global view of system usability through a weighted score in the range of 0-100. Following the administration of the SUS, a video recorded semi-structured interview was conducted and a two-item, seven-point Likert questionnaire designed specifically for the study was administered (from 1 = strongly disagree to 7 = strongly agree), referred to subsequently in this chapter as the Situation-Location scale:

1. I found that the ATLAS system was helpful in making me aware of my surroundings and location during the scenario.
2. I found that the ATLAS system was effective in helping me to verify that I arrived at the correct location during the scenario.

The trial concluded with the Self-Driving Car Assessment Scale (Appendix N), which was administered for a second time, post participant interaction with the prototype.

Scenario

In the study's single scenario participants were told that they had been given access to a self-driving vehicle for one day:

> As part of a new program from a self-driving vehicle manufacturer, you have been given access to a new self-driving vehicle for one day. A self-driving vehicle is a vehicle that controls steering, acceleration, and braking

> without direct driver input. You have decided to use the vehicle to run a few errands. This self-driving vehicle is equipped with the ATLAS system that you can use to control most functions of the vehicle. ATLAS also monitors you throughout the trip to determine if you are experiencing discomfort.

Participants were then asked to use the ATLAS system to navigate to four waypoints using the study staging area as a starting point: the nearest Kmart, the nearest Wendy's, the nearest Autozone and the Florida Center for the Blind, in that order. Waypoints were provided one at a time by the Interaction Wizard. The ATLAS system was preconfigured to search specifically within Ocala, Florida to prevent participants from specifying a destination outside of the predefined area approved for the study. Geofences [128] were programmatically inserted within the route at approximately half-mile intervals (Figure 8-6) when the distance between waypoints was more than ¾ mile (e.g. between waypoints 1 and 2, 2 and 3, 3 and 4). The geofences provided a consistent geographic point where information regarding the trip would be vocalized (e.g. direction, traffic conditions, points of interest). Geofences were also programmatically inserted around the four waypoints to consistently trigger arrival notifications.

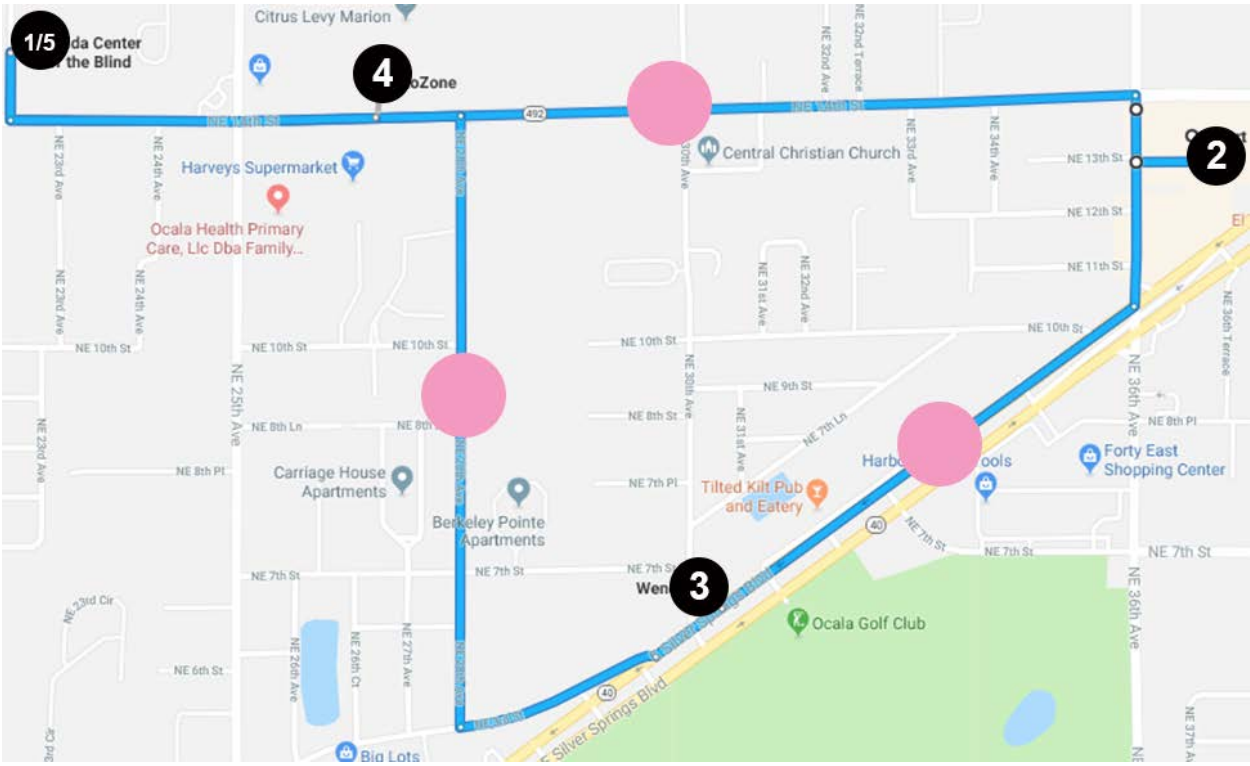


Figure 8-6. The study road course with waypoints (black circles) and geofences (pink circles) marked.

Data Capture and Transcription

Each semi-structured interview was video recorded and transcribed verbatim by a professional transcriptionist prior to analysis. The completed transcript was then verified by a member of the research team against the original recordings.

Analysis

System usability scale questionnaire: Following the process of Bangor, Kortum and Miller [129], raw SUS scores, from 0 to 40, were converted to a normalized score between 0 and 100. This normalized score was then mapped to an adjective rating scale from “worst Imaginable [usability]” to “best imaginable [usability]”.

Self-driving car assessment scale: Descriptive statistics (i.e., means, medians and standard deviations) were calculated for each of the variables. Paired t-test were used to compare responses to the SDCAS pre and post interaction with the ATLAS prototype.

Analysis of interview data: In preparation for analysis all transcripts were entered into MAXQDA [14], a computer program for qualitative data analysis. Given the short length of the interviews (< 3 minutes) and the relatively constrained nature of the questions, I conducted analysis of interview data alone. After initial familiarization with the data, all quotations from participants were coded. This hybrid process began with a small set of a priori codes developed in advance based on the interview questions and then continued with codes inductively identified within the data. Each coding was then categorized and refined.

Results

Task Completion

The success rate for all tasks in the study was 93.75%. Attempts were deemed "successful" if the participant was able to correctly enter his or her provided destination when given three tries, using either the voice user interface (VUI) or graphical user interface (GUI). All but one participant used the VUI exclusively. This one participant attempted to use the GUI for one task attempt but switched mid-attempt to the VUI. One participant initiated the stop process but elected to have the vehicle continue to its destination. All participants elected to complete the tutorial and one participant repeated it. In-vehicle time attempting the tasks ranged from 28 to 41 minutes.

General Opinion of System Usability

The mean SUS score for all participants, on a 0 to 100 scale, was 87.62 (SD = 10.95, range = 52.5 to 100, mode = 85, 100, median = 88.75). The mean SUS score for low vision participants was 86.87 (SD = 5.93, range = 75 to 92.5, mode = 92.5, 90, median = 88.75) whereas the mean score for blind participants was 88.12 (SD = 13.57, range = 52.5 to 100, mode = 100). Based on the research of de Winter [118] and Fritz,

Morris and Richler [130], who have shown that the sample size required for the t-test is a function of statistical power and effect size, independent samples t-tests were conducted to compare mean SUS scores between the blind and low vision groups and between male and female participants. No significant difference was observed in the mean scores of the blind and low vision groups, $t(18) = 0.2437$, $p = 0.8102$, $d = 0.1148$. Given the small sample size an effect of degree of vision loss would have likely been reflected in a Cohen's D greater than 0.2 [131]. No significant difference was observed in the mean scores of the male ($M = 88.61$, SD = 6.26) and female ($M = 86.81$, SD = 13.96) participants, $t(18) = 0.3556$, $p = 0.7263$, $d = -0.167$. Given the small sample size an effect of gender would have likely been reflected in a Cohen's D greater than 0.2 [131]. On an adjective rating scale (12.5 = "Worst Imaginable" to 90.9 = "Best Imaginable"); all five scores fell within the range of "Excellent" (85.6 to 90.8).

Interview Results

All participants made at least one positive comment regarding the system; positive comments outnumbered negative comments by more than 3 to 1. Fifty eight percent of comments that focused on the usability of the system praised the voice user interface for its simplicity. Participants responded favorably to the ability to state a destination (ex. "Find Kmart in Ocala, Florida") and in turn be presented with a list of options:

> I like the simplicity of being able to just say where I want to go, and say the name, and then it would look for the address for me. I like that (P2)

> It was very easy to use. And it was very interesting that you only had to give minimal information, and the system asked you questions to go along with it. (P14)

Several participants also praised the usability of the system relative to other speech-based systems they had used in the past as expressed by one participant:

> It seemed to pick up on the voices pretty well. You know what I mean? I could talk, and it would catch it right away. I'm used to using an Alexa, a lot, and so… It was much smarter than Alexa. (P4)

Nearly half of participants commented on the system's situational awareness features. Nearly all of those commenting indicated satisfaction with the system's situational awareness cues:

> Oh. Well, I was impressed with … how the Atlas gave descriptions with landmarks…when we were uhm / there was a point of interest …you were given certain landmarks and things that were around you as we were coming or going from one / one spot to another. I thought that was good. (P6)

> Yeah, I liked how it said on the left and right what buildings were kind of there. Like there was a church. (P7)

> I liked that it was telling you a little bit about what was going on, while you're travelling from one place to another. Cars on the roads, what you're passing, even the speed the car was going. It makes you a little bit more comfortable while you're riding in the car. (P9)

Negative comments regarding the system were uttered by less than half of participants (45%). Those commenting negatively regarding system features focused primarily on issues with the system's speech recognizer and the perceived inability to speak freely while in the vehicle. Two participants expressed concern that the system was unable to clearly understand their speech:

> … you have to make sure you speak clearly. (P1)

> Hm uh A couple times we had to say it over. Like you had to raise your voice for them not to get it. You know what I mean? (P12)

Two participants questioned the inability to speak freely in the vehicle during the scenario. In order to make the scenario as realistic as possible, participants were asked at the beginning of the scenario to minimize their interaction with the Interaction Wizard unless they had a safety related question or concern. Both participants interpreted this as

a shortcoming of the system and identified this as an aspect of the system that they dislike.

Situational Awareness

On a seven-item Likert scale (1 = "Strongly Disagree" to 7 = "Strongly Agree"), participants were asked to indicate their agreement or disagreement with the statement that the ATLAS system was helpful in making them aware of their surroundings and location during the scenario. The most frequently selected response was "strongly agree" (75%), followed by "mostly agree" (20%); no participant "strongly disagreed" with this statement. It was reasoned that the ability of some low vision participants to observe the vehicle's exterior environment and compare it with the visual and audible cues of the system would perhaps impact participant perception of the situational awareness features. When responses to this question were analyzed based on degree of vision loss, 75% of low vision participants "strongly agreed" with the contention that the system's situational awareness feature were effective, while 83.3% of blind participants "strongly agreed". The response mean was 6.55 (SD = 0.887, range 1 to 7).

Location Verification

On a seven-item Likert scale (1 = "Strongly Disagree" to 7 = "Strongly Agree"), participants were asked to indicate their agreement or disagreement with the statement that the ATLAS system was effective in helping them to verify their arrival at the correct location. The most frequently selected response was "strongly agree" (80%), followed by "mostly agree" (10%); one participant "somewhat disagreed" with this statement. When analyzed based on degree of vision loss, 87.5% of low vision participants "strongly agreed" with this statement, while 75% of blind participants "strongly agreed". The response mean was 6.55 (SD = 1.099, range 1 to 7).

Familiarity with the Testing Area

In order to show that participants' positive perception of the situational awareness features of the system were not correlated with their familiarity with the area, a correlation analysis was conducted. Participants were read the statement, "I am familiar with the roads and landmarks in the immediate vicinity of the Florida Center for the Blind," and asked to indicate their agreement or disagreement on a seven-item Likert scale (1 = "strongly disagree" to 7 = "strongly agree"). The most frequently selected response was seven or "strongly agree" (45%). The response mean was 5.45 (SD = 1.98, range 1 to 7). A nonparametric procedure, the Spearman's rank order correlation coefficient (i.e., Spearman's rho) was conducted, and no statistically significant correlation could be found between familiarity with the testing area and either participants' stated satisfaction with the prototype's situational awareness features used during the scenario ($r_s = -0.34342$, $p = 0.138$) or satisfaction with the prototype's location verification features ($r_s = -0.04201$, $p = 0.8604$).

Self-Driving Car Acceptance Scale

Perceived reliability of automation/trust

Participants were presented with three statements related to their perception of the reliability of self-driving vehicles and their general trust in the technology. They were then asked to indicate their agreement or disagreement with each statement on a seven-item Likert scale (1 = "strongly disagree" to 7 = "strongly agree").

In responding to statement one, "Self-driving vehicles are safe", the most frequently selected response of all participants prior to interacting with the prototype was four or "neither agree nor disagree" (50%), followed by six or "mostly agree" (30%), which was true also for blind participants (41.6% "neither agree nor disagree", 33.3%

“mostly agree”) and for low vision participants (62.5% “neither agree nor disagree”, 25% “mostly agree”). Participants responding to statement one following their interaction with the ATLAS prototype selected seven or “strongly agree” most frequently (50%), followed by six or “mostly agree” (15%). This was also true when analyzed according to participants’ degree of vision loss with seven or “strongly agree” most frequently selected by both blind participants (75%) and low vision participants (50%). Figure 8-7 illustrates participant agreement and disagreement with the statement, “self-driving cars are safe”, accounting for all variations of “agreement” (“slightly”, “mostly” and “strongly”), “neither agree nor disagree” and all variations of “disagreement (“slightly”, “mostly” and “strongly”); results pre and post interaction with the ATLAS prototype are shown.

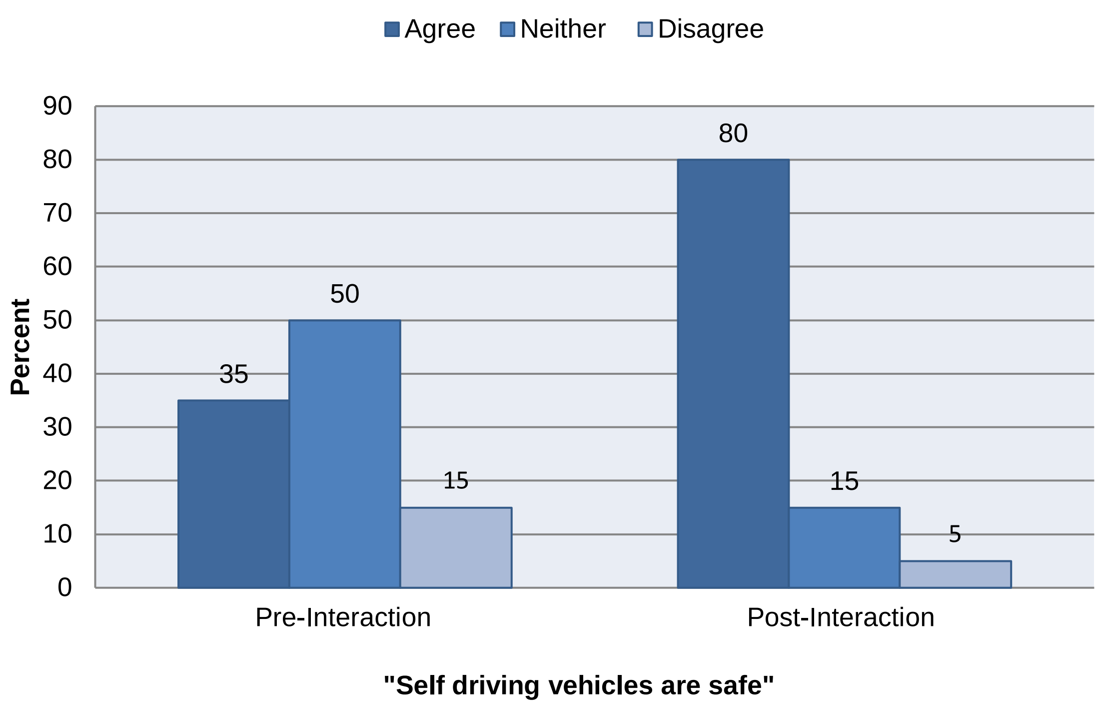


Figure 8-7. Percentage of participants agreeing and disagreeing with statement one preand post interaction with the ATLAS prototype.

In responding to the statement two, “I would trust a self-driving car to get me to my destination”, the most frequently selected response of all participants prior to interacting with the prototype was “neither agree nor disagree” (60%), followed by “strongly agree” (50%). For blind participants, “neither agree nor disagree”, “mostly agree” and “strongly agree” were selected with the same frequency (25%). For low vision participants, “neither agree nor disagree” was the most frequently selected option (37.5%). Participants responding following their interaction with the ATLAS prototype selected “strongly agree” most frequently (70%), followed by “mostly agree” (15%). This was also true when analyzed according to participants’ degree of vision loss with “strongly agree” most frequently selected by both blind participants (66.6%) and low vision participants (75%). Figure 8-8 illustrates participant agreement and disagreement with the statement, “I would trust a self-driving car to get me to my destination”, accounting for all variations of “agreement” (“slightly”, “mostly” and “strongly”), “neither agree nor disagree” and all variations of “disagreement (“slightly”, “mostly” and “strongly”); results pre and post interaction with the ATLAS prototype are shown.

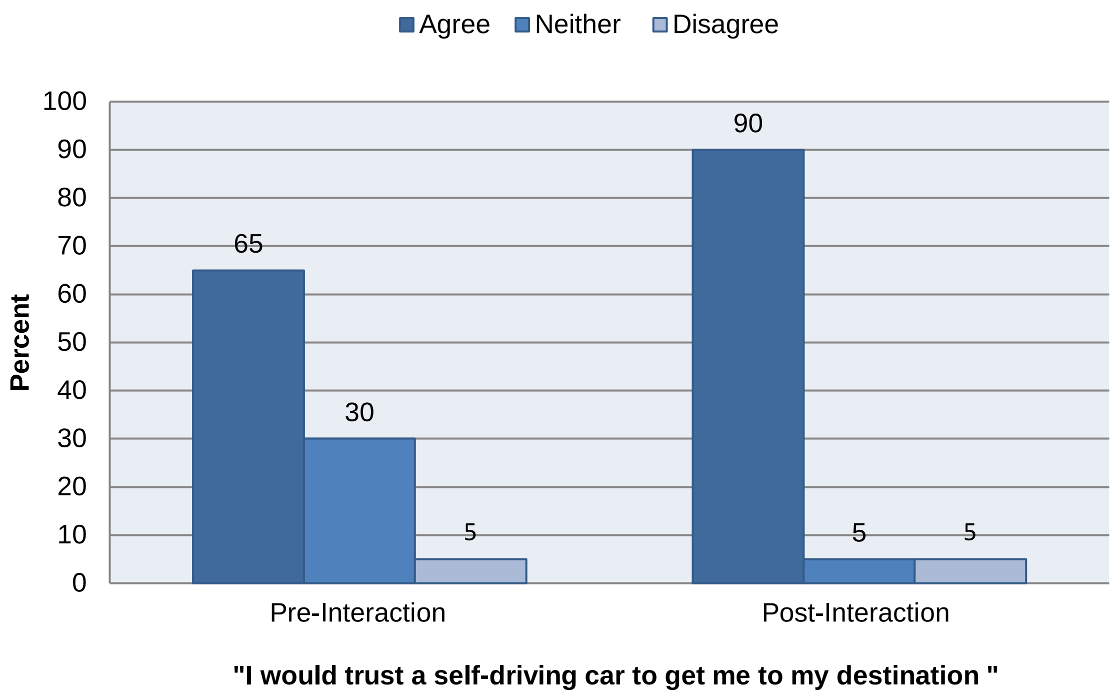


Figure 8-8. Percentage of participants agreeing and disagreeing with statement two pre and post interaction with the ATLAS prototype.

In responding to the statement three, “People will need to watch self-driving cars closely to be sure the computers don’t make mistakes”, for all participants “neither agree nor disagree”, “slightly agree” and “mostly” were selected with the same frequency (25%). For blind participants, “slightly agree” was the most frequently selected response (33.3%). For low vision participants “neither agree nor disagree” and “mostly agree” were selected with the same frequency (37.5%). Participants responding following their interaction with the ATLAS prototype selected “strongly disagree” and “slightly disagree” with the same frequency (20%). For blind participants the most frequently selected response was “strongly agree” (37.5%), while for low vision participants the most frequently selected responses were “slightly disagree” and “strongly disagree”, which were selected with the same frequency (25%). Figure 8-9 illustrates participant agreement and disagreement with the statement, “People will need to watch self-driving

cars closely to be sure the computers don't make mistakes". The data illustrated accounts for all variations of "agreement" ("slightly", "mostly" and "strongly"), "neither agree nor disagree" and all variations of "disagreement ("slightly", "mostly" and "strongly"); results pre and post interaction with the ATLAS prototype are shown.

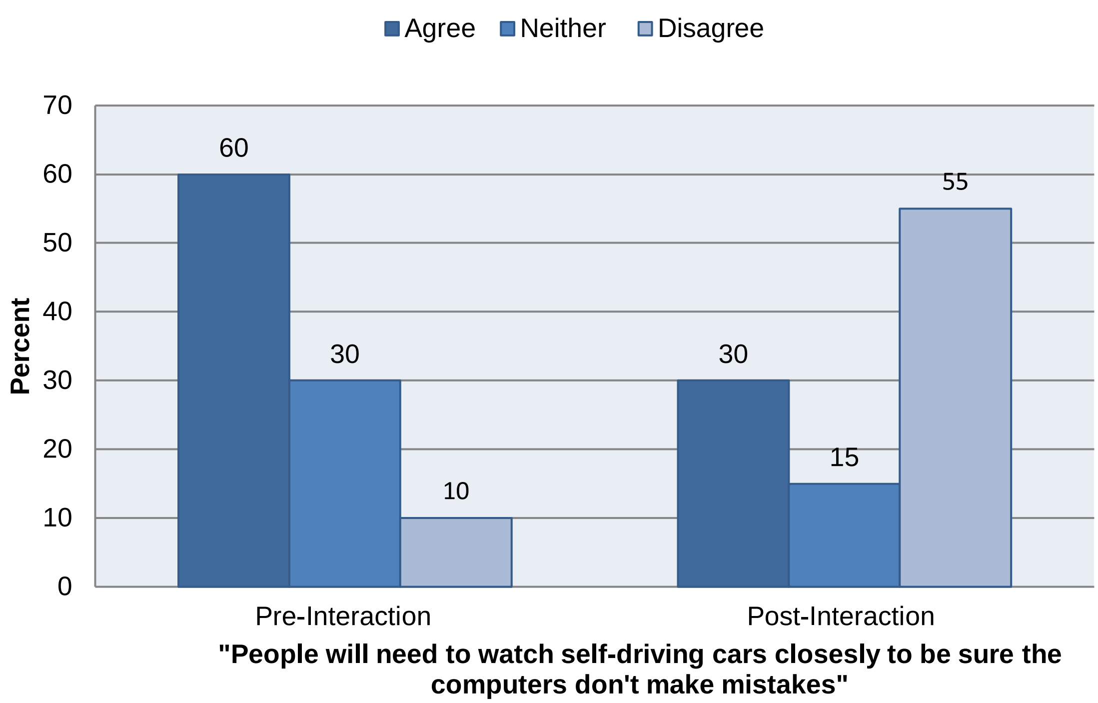


Figure 8-9. Percentage of participants agreeing and disagreeing with statement three pre and post interaction with the ATLAS prototype.

Figure 8-10 illustrates the mean response to statements one through three, pre and post interaction with the ATLAS prototype. Paired t-tests were conducted to compare mean responses of all participants pre and post interaction. For the statement, "self-driving cars are safe", a significant difference was observed between the mean response for the pre-interaction (M = 4.6, SD = 1.23) and post interaction (M = 5.9, SD = 1.33) conditions; t(19) = 4.211, p = 0.0005. Post-interaction, participants' stated perception that

self-driving cars are safe improved by 28.26%. For the statement, “I would trust a self-driving car to get me to my destination”, a significant difference was observed between the mean response for the pre-interaction (*M* = 5.3, SD = 1.41) and post interaction (*M* = 6.35, SD = 1.30) conditions; t(19) = 3.0529, p = 0.0065. Post-interaction, participants’ stated perception that they would trust a self-driving car to deliver them to their destination increased by 20.75%. For the statement, “People will need to watch self-driving cars closely to be sure the computers don't make mistakes”, a significant difference was observed between the mean response for the pre-interaction (*M* = 4.75, SD = 1.52) and post interaction (*M* = 3.60, SD = 2.11) conditions; t(19) = -2.9297, p = 0.0086. Post-interaction, participants’ stated perception that they would need to closely monitor a self-driving car for errors decreased by 24.22%.

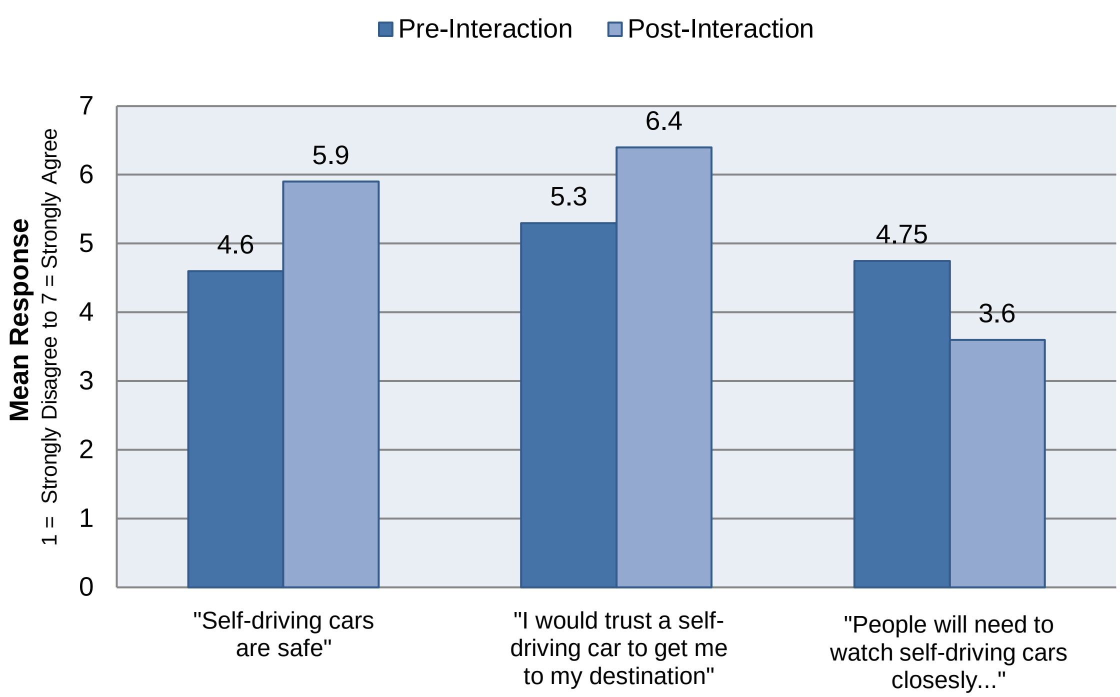


Figure 8-10. Mean participant response to statements one through three, pre and post interaction with the ATLAS prototype.

Cost of automation

Participants were presented with three statements related to their willingness to pay for a self-driving car and perception of the value of such a vehicle compared to its associated costs. They were then asked to indicate their agreement or disagreement with each statement on a seven-item Likert scale (1 = “strongly disagree” to 7 = “strongly agree”).

In responding to the statement four, “I would be willing to pay more for a self-driving car compared to what I would pay for a traditional car”, “strongly agree” and “mostly agree” were selected with the same frequency (35%). For blind participants “mostly agree” (30%) was the most frequently selected response (50%), whereas for low vision participants “strongly agree” was the most frequently selected response (62.5%). Participants responding to the statement four following their interaction with the ATLAS prototype selected seven or “strongly agree” most frequently (55%). This was also true when analyzed according to participants’ degree of vision loss with seven or “strongly agree” most frequently selected by both blind participants (58.3%) and low vision participants (50%). Figure 8-11 illustrates participant agreement and disagreement with the statement, “I would be willing to pay more for a self-driving car compared to what I would pay for a traditional car”, accounting for all variations of “agreement” (“slightly”, “mostly” and “strongly”), “neither agree nor disagree” and all variations of “disagreement (“slightly”, “mostly” and “strongly”); results pre and post interaction with the ATLAS prototype are shown.

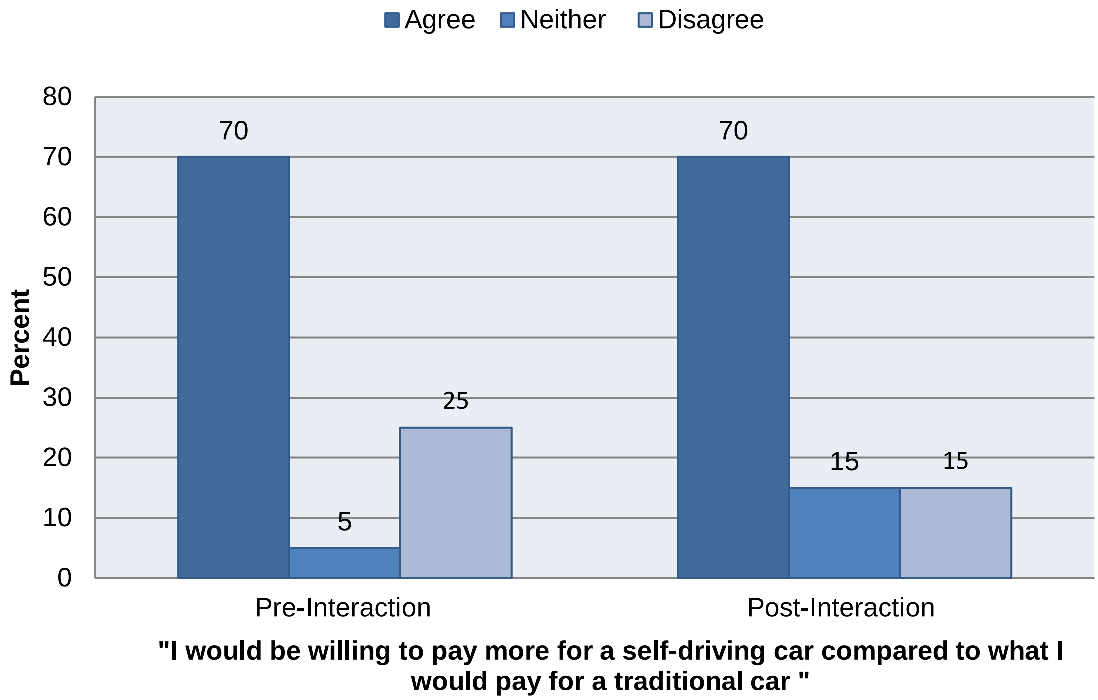


Figure 8-11. Percentage of participants agreeing and disagreeing with statement four pre and post interaction with the ATLAS prototype.

In responding to statement five, “The benefits of a self-driving car would outweigh the amount of money it would cost”, the most frequently selected response of all participants prior to interacting with the prototype was “strongly agree” (40%), followed by six or “mostly agree” (20%). This was also observed for blind participants (50% “strongly agree”) but diverged from the responses of low vision participants (50% “mostly agree”). Participants responding to statement five following their interaction with the ATLAS prototype selected seven or “strongly agree” most frequently (80%). This was also true when analyzed according to participants’ degree of vision loss with seven or “strongly agree” most frequently selected by both blind participants (83.3%) and low vision participants (75%). Figure 8-12 illustrates participant agreement and disagreement with the statement, “The benefits of a self-driving car would outweigh the amount of

money it would cost”, accounting for all variations of “agreement” (“slightly”, “mostly” and “strongly”), “neither agree nor disagree” and all variations of “disagreement (“slightly”, “mostly” and “strongly”); results pre and post interaction with the ATLAS prototype are shown.

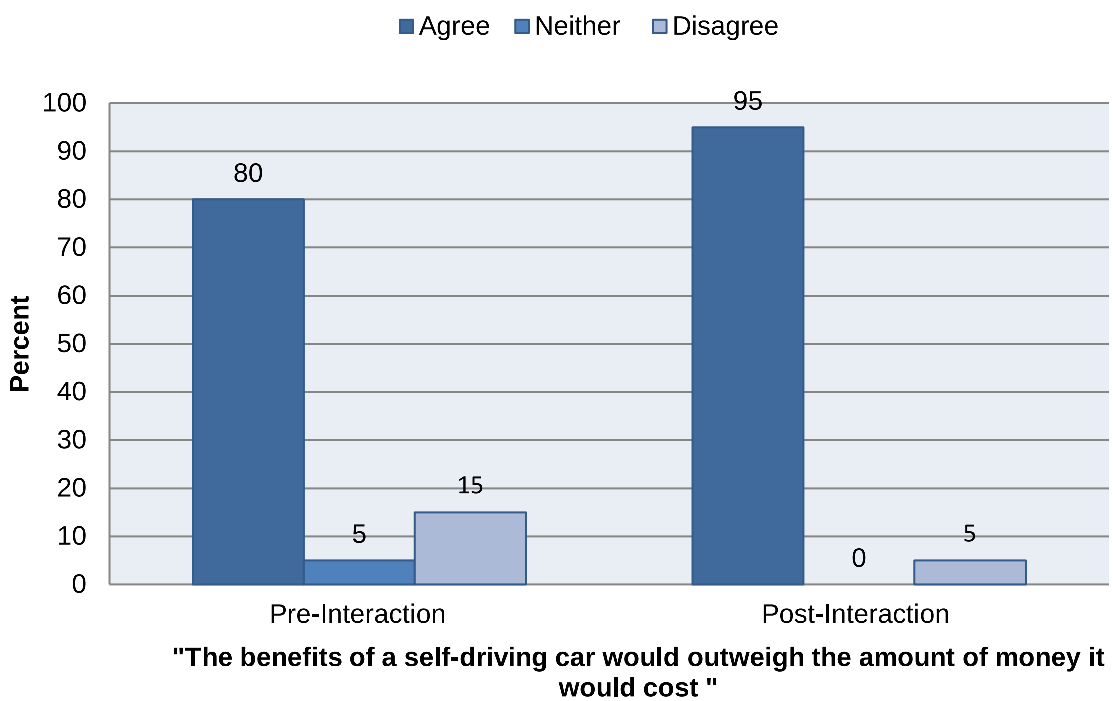


Figure 8-12. Percentage of participants agreeing and disagreeing with statement five pre and post interaction with the ATLAS prototype.

In responding to statement six, “The cost of a self-driving car would be the most important thing I would consider before purchasing one,” the most frequently selected response of all participants prior to interacting with the prototype was two or “slightly disagree” (25%), which was true also for blind participants (33.33%). The frequently selected response for low vision participants however was “mostly agree” (37.5%). Participants responding to statement six following their interaction with the ATLAS prototype selected seven or “strongly agree” most frequently (25%), which was true as

well for low vision participants (25%). For blind participants however, “strongly disagree” was the most frequently selected response (50%). Figure 8-13 illustrates participant agreement and disagreement with statement six, accounting for all variations of “agreement” (“slightly”, “mostly” and “strongly”), “neither agree nor disagree” and all variations of “disagreement (“slightly”, “mostly” and “strongly”); results pre and post interaction with the ATLAS prototype are shown.

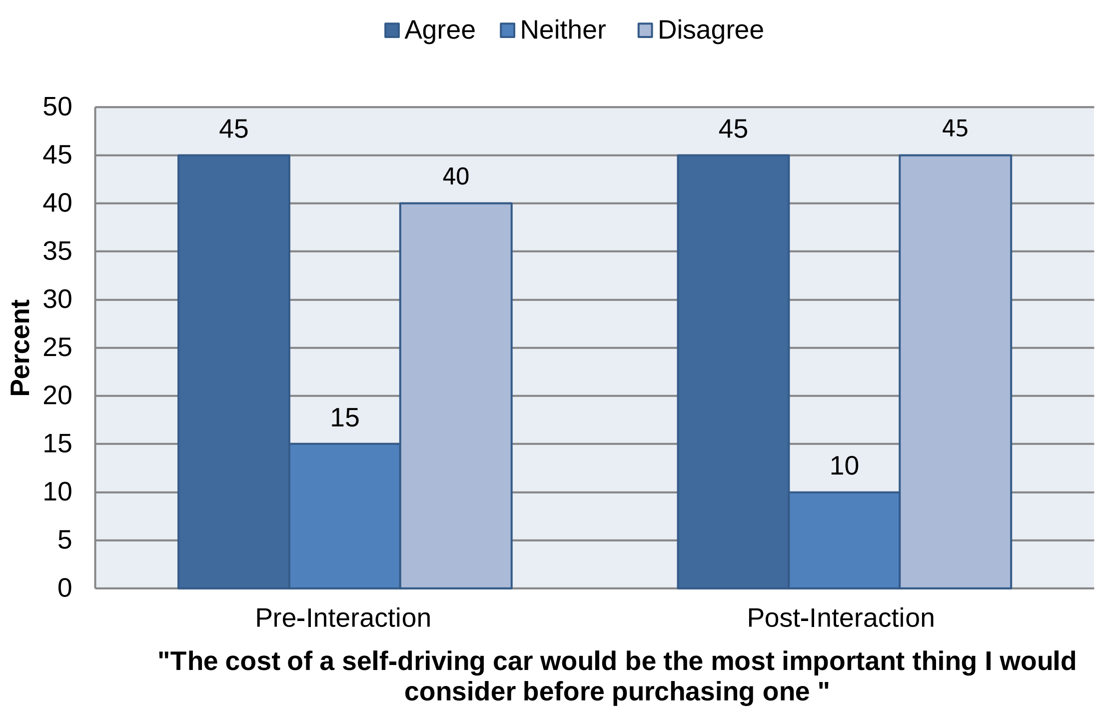


Figure 8-13. Percentage of participants agreeing and disagreeing with statement six pre and post interaction with the ATLAS prototype.

Figure 8- 14 illustrates the mean response to statements four through six, pre and post interaction with the ATLAS prototype. Paired t-tests were conducted to compare mean responses of all participants pre and post interaction. For the statement, “I would be willing to pay more for a self-driving car compared to what I would pay for a traditional

car", the difference between the mean response for the pre-interaction (*M* = 5.3, SD = 2.00) and post interaction (*M* = 5.55, SD = 1.93) conditions was found to be statistically insignificant; t(19) = 0.839, p = 0.4120. For the statement, "The benefits of a self-driving car would outweigh the amount of money it would cost", a significant difference was observed between the mean response for the pre-interaction (*M* = 5.45, SD = 1.90) and post interaction (*M* = 6.60, SD = 0.88) conditions; t(19) = 3.217, p = 0.0045. Post-interaction, participants' stated perception that the benefits of a self-driving car would outweigh the amount of money it would cost increased by 21.1%. For the statement, "The cost of a self-driving car would be the most important thing I would consider before purchasing one", the difference between the mean response for the pre-interaction (*M* = 4.2, SD = 2.19) and post interaction (*M* = 4.0, SD = 2.38) conditions was found to be statistically insignificant; t(19) = -0.7215, p = .4794.

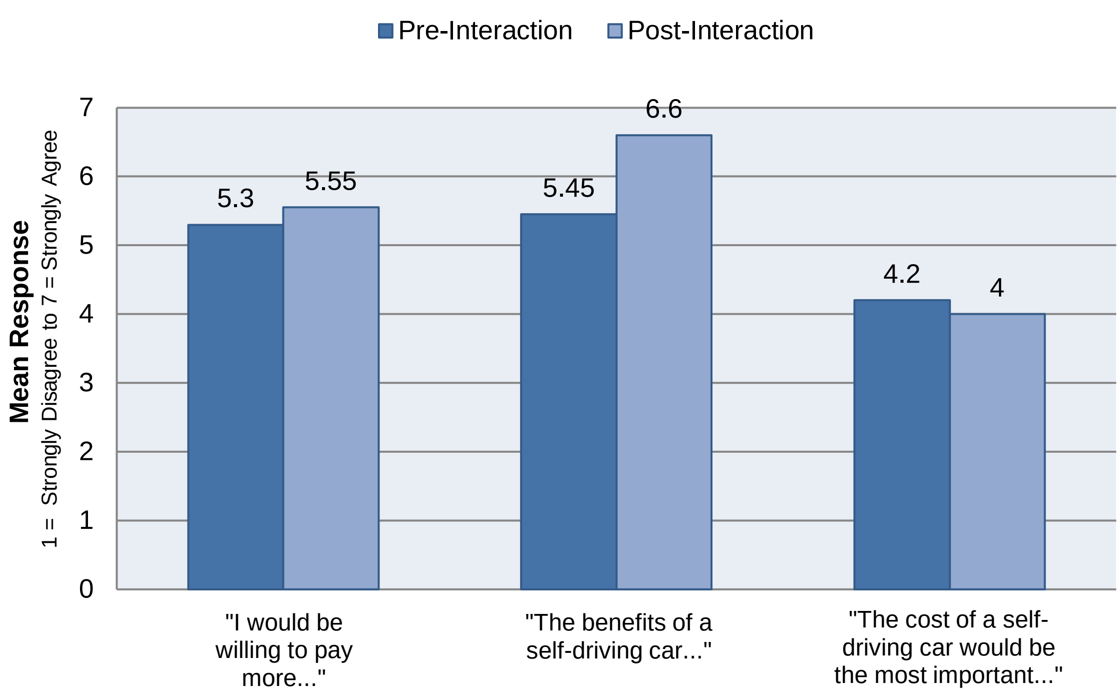


Figure 8- 14. Mean participant response to statements four through six, pre and post interaction with the ATLAS prototype.

Appropriateness and compatibility of automation

Participants were presented with three statements related to their general perception of the appropriateness of vehicular automation. They were then asked to indicate their agreement or disagreement with each statement on a seven-item Likert scale (1 = “strongly disagree” to 7 = “strongly agree”).

In responding to the statement seven, “I do not think computers should be driving cars”, the most frequently selected response of all participants prior to interacting with the prototype was one or “strongly disagree” (45%), which was true also for blind participants (50%). For low vision participants two or “mostly disagree” and one or “strongly disagree” were selected with equal frequency (37.5%). Participants responding to statement seven following their interaction with the ATLAS prototype selected one or “strongly disagree” most frequently (70%), followed by two or “mostly disagree” (15%). This was also true when analyzed according to participants’ degree of vision loss with one or “strongly disagree” most frequently selected by both blind participants (66.66%) and low vision participants (75%). Figure 8-15 illustrates participant agreement and disagreement with statement seven accounting for all variations of “agreement” (“slightly”, “mostly”, and “strongly”), “neither agree nor disagree” and all variations of “disagreement (“slightly”, “mostly” and “strongly”); results pre and post interaction with the ATLAS prototype are shown.

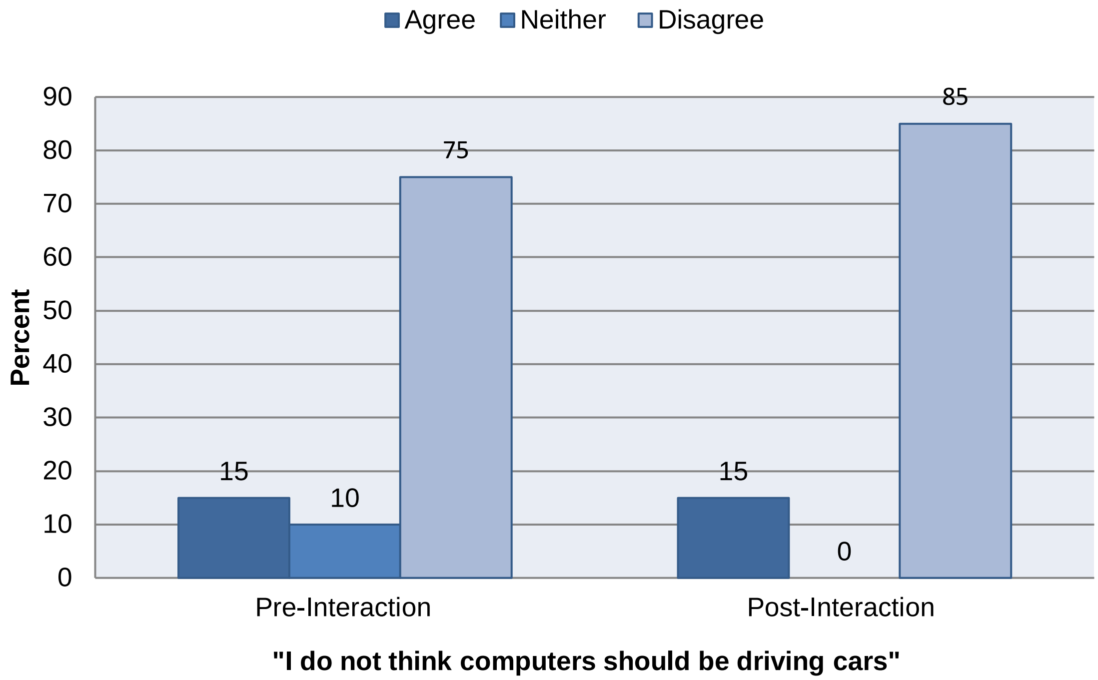


Figure 8-15. Percentage of participants agreeing and disagreeing with statement seven pre and post interaction with the ATLAS prototype.

In responding to statement eight, “It is important for a human to be able to take back control from a self-driving car”, the most frequently selected response of all participants prior to interacting with the prototype was “neither agree nor disagree” (35%), which was true also for blind participants (50%). For low vision participants however, six or “mostly agree” was the most frequently selected response (25%). Participants responding to statement eight following their interaction with the ATLAS prototype selected “slightly agree” most frequently (25%), which was also true for blind participants (25%). Low vision participants however selected “slightly agree” (25%) with the same frequency as “strongly disagree” (25%). Figure 8-16 illustrates participant agreement and disagreement with statement eight, “It is important for a human to be able to take back control from a self-driving car”, accounting for all variations of “agreement”

("slightly", "mostly" and "strongly"), "neither agree nor disagree" and all variations of "disagreement ("slightly", "mostly" and "strongly"); results pre and post interaction with the ATLAS prototype are shown.

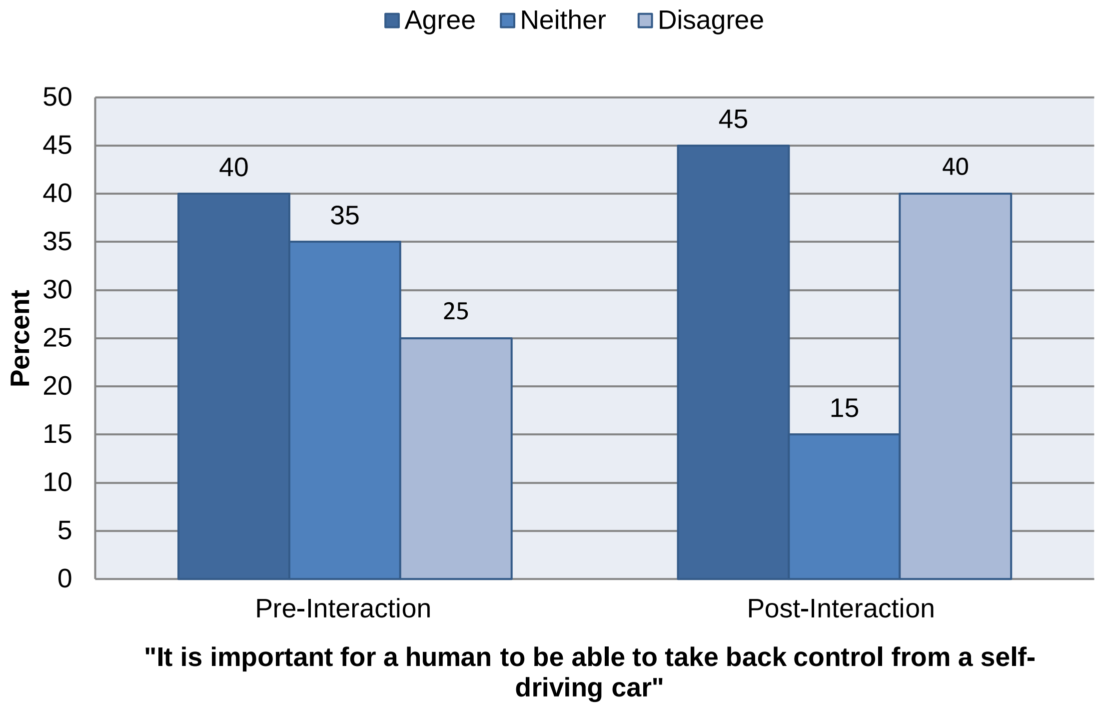


Figure 8-16. Percentage of participants agreeing and disagreeing with statement eight pre and post interaction with the ATLAS prototype.

In responding to statement nine, "There are some driving scenarios that will be too difficult for a self-driving car to handle", the most frequently selected response of all participants prior to interacting with the prototype was six or "mostly agree" (25%). For blind participants, six or "mostly agree" and four or "neither agree nor disagree" were selected with equal frequency (25%). For low vision participants "strongly agree", "mostly agree", and "slightly agree" were selected with equal frequency (25%). Participants responding to statement nine following their interaction with the ATLAS prototype selected "neither agree nor disagree" most frequently (30%), which was also

true for blind participants (33.33%) specifically. Low vision participants selected “neither agree nor disagree”, “slightly disagree”, “mostly disagree” and “strongly disagree” with equal frequency (25%). Figure 8-17 illustrates participant agreement and disagreement with statement nine, “There are some driving scenarios that will be too difficult for a self-driving car to handle”, accounting for all variations of “agreement” (“slightly”, “mostly” and “strongly”), “neither agree nor disagree” and all variations of “disagreement (“slightly”, “mostly” and “strongly”); results pre and post interaction with the ATLAS prototype are shown.

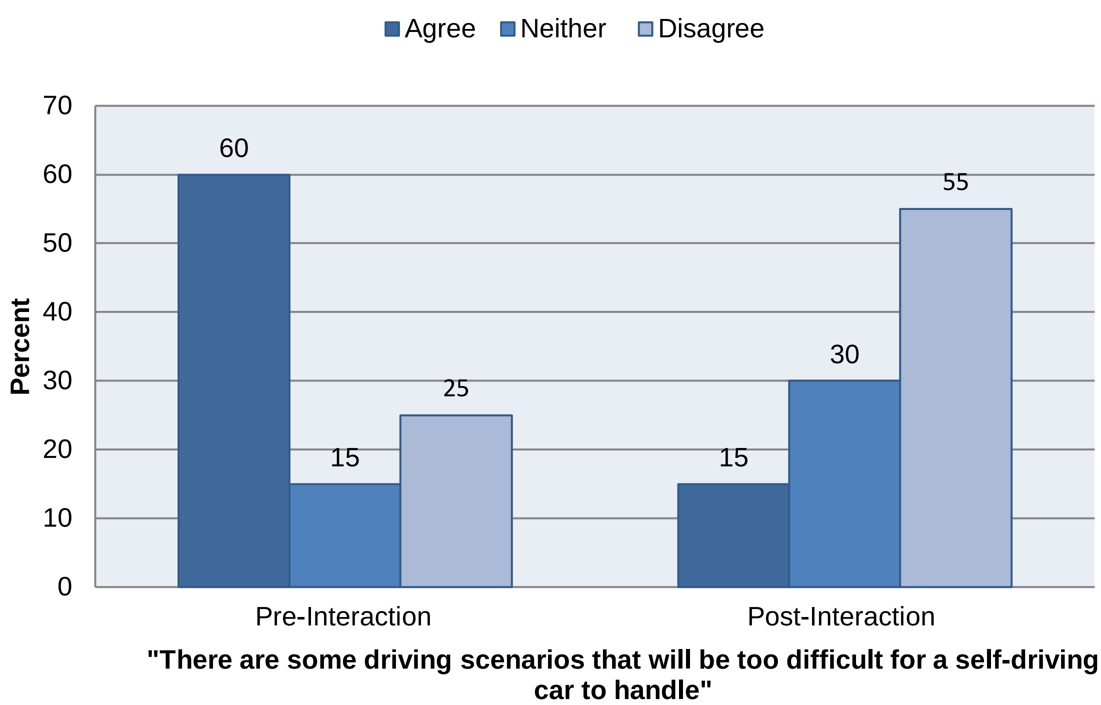


Figure 8-17. Percentage of participants agreeing and disagreeing with statement nine pre and post interaction with the ATLAS prototype.

Figure 8-18 illustrates the mean response to statement seven through nine, pre and post interaction with the ATLAS prototype. Paired t-tests were conducted to compare mean responses to all statements pre and post interaction. For statement seven, “I do not

think that computers should be driving cars”, the difference between the mean response for the pre-interaction (M = 2.25, SD = 1.62) and post interaction (*M* = 1.85, SD = 1.69) conditions was found to be statistically insignificant; t(19) = -2.0268, p = 0.0569. For statement eight, “It is important for a human to be able to take back control from a self-driving car”, a significant difference was observed between the mean response for the pre-interaction (*M* = 4.35, SD = 1.9) and post interaction (*M* = 3.85, SD = 2.01) conditions; t(19) = -2.7033, p = 0.0141. Post-interaction, participants’ stated perception of the importance for a human to be able to take back control from a self-driving car decreased by 11.49%. For statement nine, “There are some driving scenarios that will be too difficult for a self-driving car”, a significant difference was observed between the mean response for the pre-interaction (*M* = 4.65, SD = 1.87) and post interaction (*M* = 3.0, SD = 1.56) conditions; t(19) = -3.6762, p = 0.0016. Post-interaction, participants’ stated opinion that there are some driving scenarios that will be too difficult for a self-driving car decreased by 35.48%.

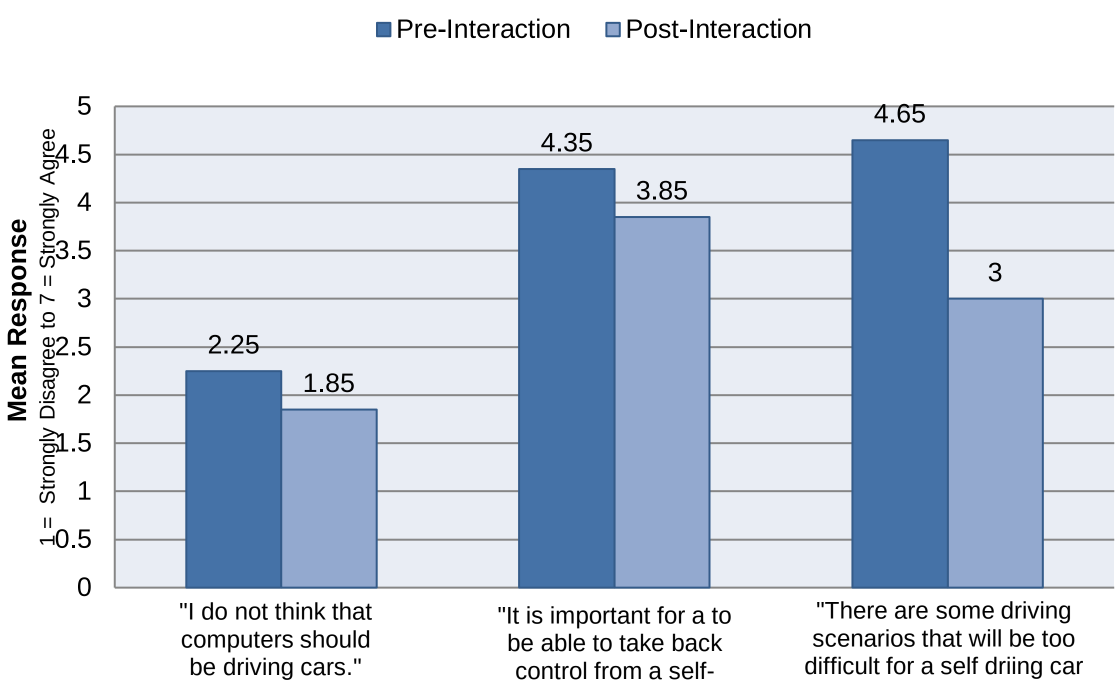


Figure 8-18. Mean participant response to statements seven through nine, pre and post interaction with the ATLAS prototype.

Enjoyment

Participants were presented with three statements related to their enjoyment of driving and desire to ride in an automobile. They were then asked to indicate their agreement or disagreement with each statement on a seven-item Likert scale (1 = “strongly disagree” to 7 = “strongly agree”).

In responding to statement 10, “I would enjoy driving a car”, the most frequently selected response of all participants prior to interacting with the prototype was “strongly agree” (80%), which was true also for blind participants (58.33%) and for low vision participants (100%). Participants responding to statement 10 following their interaction with the ATLAS prototype selected “strongly agree” most frequently (75%). This was also true when analyzed according to participants’ degree of vision loss with “strongly agree” most frequently selected by both blind participants (58.33%) and low vision participants (100%). Figure 8-19 illustrates participant agreement and disagreement with the statement 10 accounting for all variations of “agreement” (“slightly”, “mostly” and “strongly”), “neither agree nor disagree” and all variations of “disagreement (“slightly”, “mostly” and “strongly”); results pre and post interaction with the ATLAS prototype are shown.

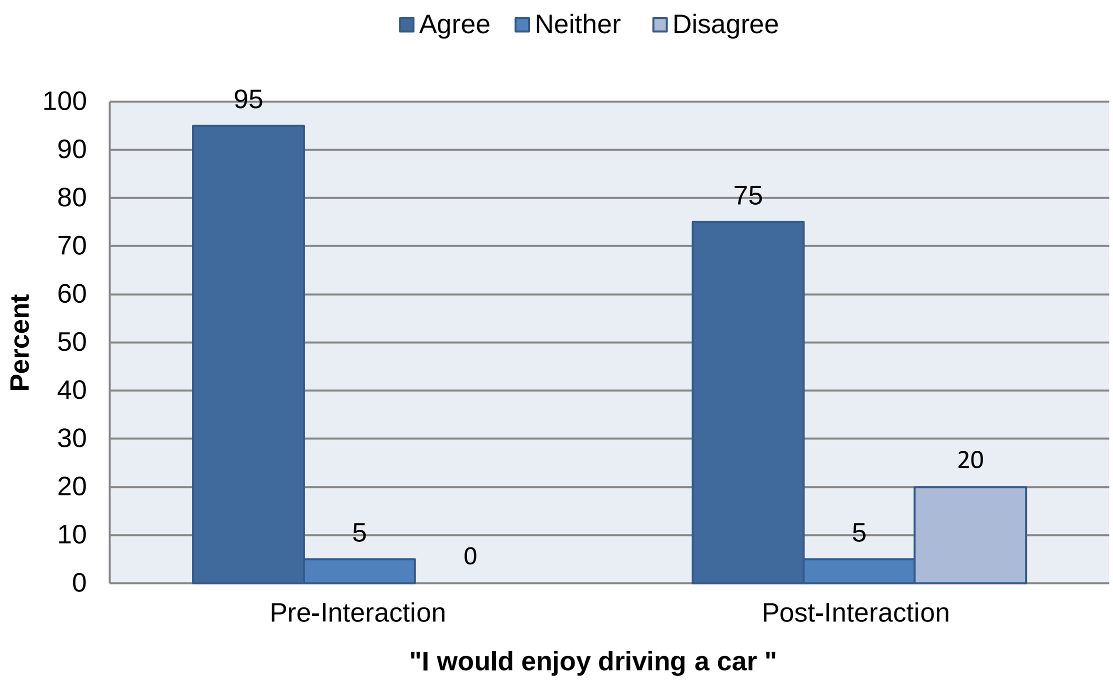


Figure 8-19. Percentage of participants agreeing and disagreeing with statement 10 pre and post interaction with the ATLAS prototype.

In responding to the statement 11, “I would prefer to be the driver rather than the passenger”, the most frequently selected response of all participants prior to interacting with the prototype was “strongly agree” (55%), which was true also for blind participants (50%) and low vision participants (62.5%). Participants responding to the statement 11 following their interaction with the ATLAS prototype selected “strongly agree” most frequently (45%), which was also true for blind participants (50%). Low vision participants however selected “strongly agree” and “neither agree nor disagree” with equal frequency. Figure 8-20 illustrates participant agreement and disagreement with the statement 11 accounting for all variations of “agreement” (“slightly”, “mostly” and “strongly”), “neither agree nor disagree” and all variations of “disagreement (“slightly”,

“mostly” and “strongly”); results pre and post interaction with the ATLAS prototype are shown.

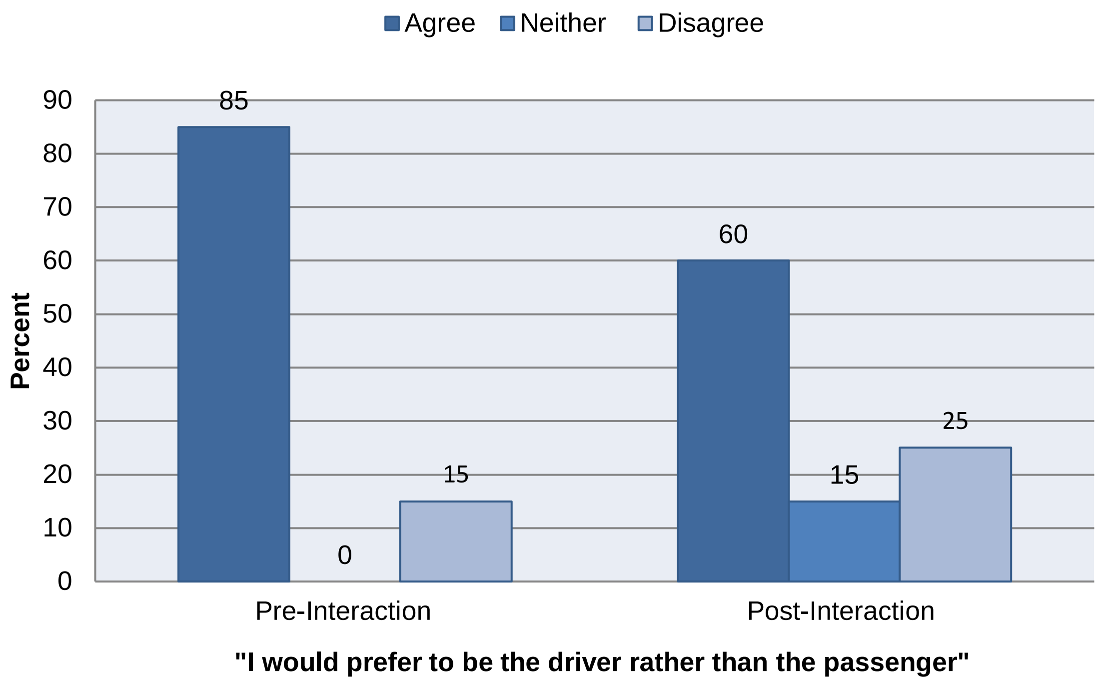


Figure 8-20. Percentage of participants agreeing and disagreeing with statement 11 pre and post interaction with the ATLAS prototype.

In responding to the statement 12, “I enjoy cruising or going for joy rides”, the most frequently selected response of all participants prior to interacting with the prototype was seven or “strongly agree” (60%), which was true also for blind participants (58.33%) and for low vision participants (62.5%). Participants responding to statement 12 following their interaction with the ATLAS prototype selected “strongly agree” most frequently (80%). This was also true when analyzed according to participants’ degree of vision loss with “strongly agree” most frequently selected by both blind participants (83.33%) and low vision participants (75%). Figure 8-21 illustrates participant agreement and disagreement with statement 12, “I enjoy cruising or going for joy rides”, accounting

for all variations of “agreement” (“slightly”, “mostly” and “strongly”), “neither agree nor disagree” and all variations of “disagreement (“slightly”, “mostly” and “strongly”); results pre and post interaction with the ATLAS prototype are shown.

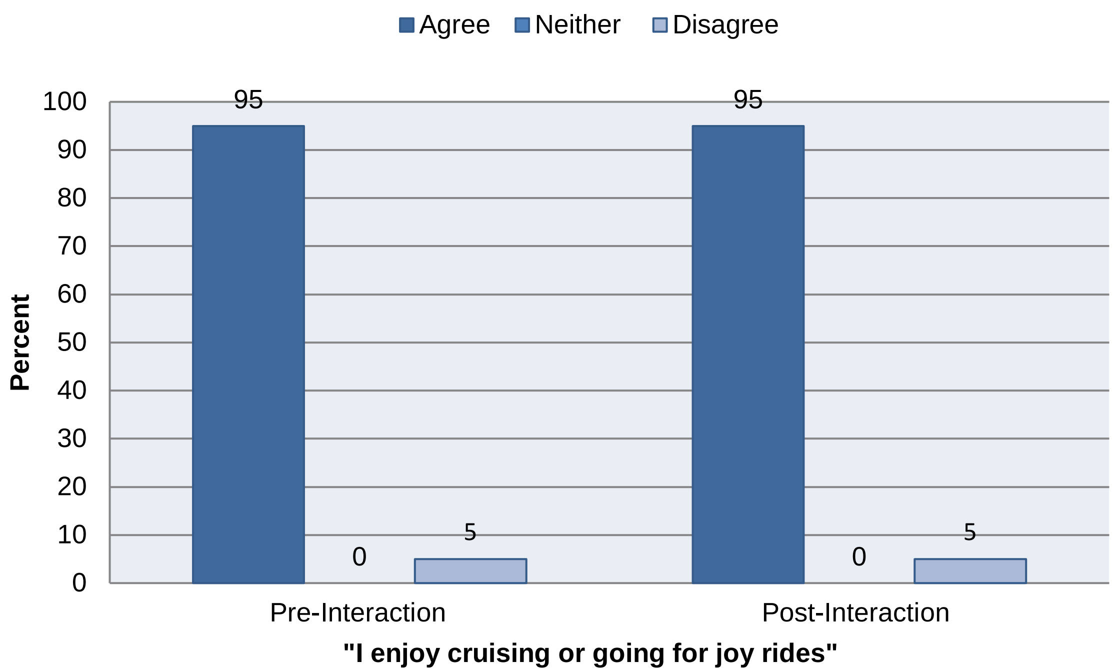


Figure 8-21. Percentage of participants agreeing and disagreeing with statement 12 pre and post interaction with the ATLAS prototype.

Figure 8-22 illustrates the mean response to statements 10 through 12, pre and post interaction with the ATLAS prototype. Paired t-tests were conducted to compare mean responses to all statements pre and post interaction. For statement 10, “I would enjoy driving a car”, a significant difference was observed between the mean response for the pre-interaction (M = 6.65, SD = 0.81) and post interaction (M = 5.7, SD = 2.39) conditions; t(19) = -2.2979, p = 0.0331. Post-interaction, participants’ stated enjoyment of driving a conventional automobile decreased by 14.28%. For statement 11, “I would prefer to be the driver rather than the passenger”, a significant difference was observed

between the mean response for the pre-interaction (*M* = 5.85, SD = 1.3) and post interaction (*M* = 4.95, SD = 2.39) conditions; t(19) = -2.099, p = 0.0493. Post-interaction, participants' stated preference for being the driver rather than the passenger in an automobile decreased by 15.38%. For statement 12, "I enjoy cruising or going for joy rides", the difference between the mean response for the pre-interaction (*M* = 6.3, SD = 1.22) and post interaction (*M* = 6.5, SD = 1.24) conditions was found to be statistically insignificant; t(19) = 1.453, p = 0.1625.

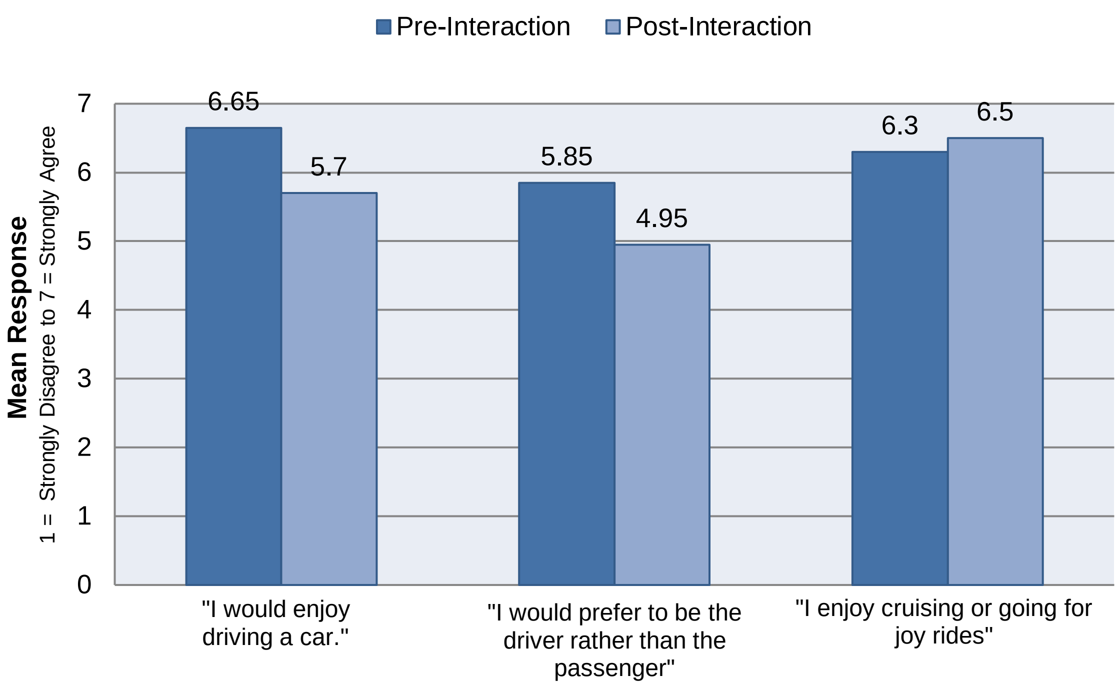


Figure 8-22. Mean participant response to statements 10 through 12, pre and post interaction with the ATLAS prototype.

Perceived usefulness

Participants were presented with three statements related to the potential usefulness of self-driving vehicles. They were then asked to indicate their agreement or disagreement with each statement on a seven-item Likert scale (1 = "strongly disagree" to 7 = "strongly agree").

In responding to statement 13, “A self-driving car would allow me to be more productive”, the most frequently selected response of all participants prior to interacting with the prototype was “strongly agree” (70%), which was true also for blind participants (75%) and for low vision participants (41.66%). Participants responding to statement 13 following their interaction with the ATLAS prototype selected “strongly agree” most frequently (95%). This was also true when analyzed according to participants’ degree of vision loss with “strongly agree” most frequently selected by both blind participants (100%) and low vision participants (87.5%). Figure 8-23 illustrates participant agreement and disagreement with statement 13, “A self-driving car would allow me to be more productive”, accounting for all variations of “agreement” (“slightly”, “mostly” and “strongly”); results pre and post interaction with the ATLAS prototype are shown.

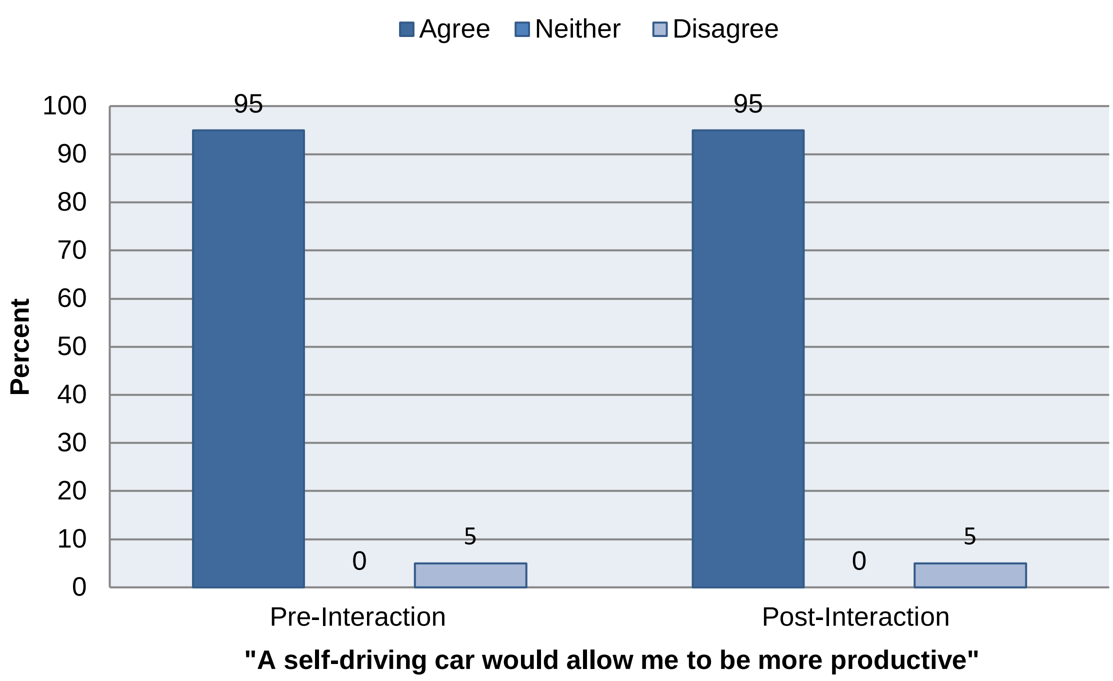


Figure 8-23. Percentage of participants agreeing and disagreeing with statement 13 pre and post interaction with the ATLAS prototype.

In responding to the statement 14, “A self-driving car would allow me to be more safe while in the car”, the most frequently selected response of all participants prior to interacting with the prototype was “slightly agree”. Blind participants selected “mostly agree” and “neither agree nor disagree” with the same frequency (33.33%). Low vision participants selected “slightly disagree” with the greatest frequency (50%). Participants responding to statement 14 following their interaction with the ATLAS prototype selected “strongly agree” most frequently (50%). Blind participants selected “neither agree nor disagree” with the greatest frequency (41.66%) whereas low vision participants selected “strongly agree” most frequently (75%). Figure 8-24 illustrates participant agreement and disagreement with the statement, “A self-driving car would allow me to be more safe while in the car”, accounting for all variations of “agreement” (“slightly”, “mostly” and “strongly”), “neither agree nor disagree” and all variations of “disagreement (“slightly”, “mostly” and “strongly”); results pre and post interaction with the ATLAS prototype are shown.

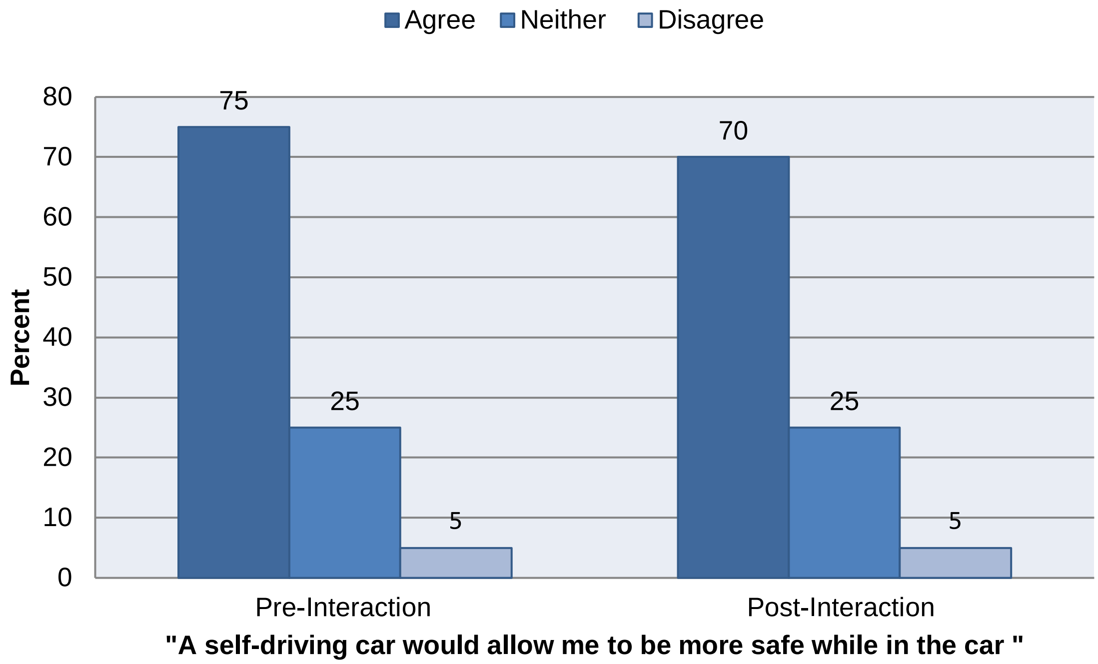


Figure 8-24. Percentage of participants agreeing and disagreeing with statement 14 pre and post interaction with the ATLAS prototype.

In responding to statement 15, “Self-driving cars will reduce traffic problems,” the most frequently selected response of all participants prior to interacting with the prototype was “neither agree nor disagree” (35%). When analyzed by degree of vision loss blind participants selected “neither agree nor disagree” most frequently whereas low vision participants selected “mostly agree” and “slightly agree” with equal frequency (37.5%). Participants responding to statement 15 following their interaction with the ATLAS prototype selected “mostly agree” most frequently (54%), followed by “strongly agree” (25%). This was also true when analyzed according to participants’ degree of vision loss with “mostly agree” most frequently selected by both blind participants (41.6%) and low vision participants (50%). Figure 8-25 illustrates participant agreement and disagreement with the statement, “Self-driving cars will reduce traffic problems”,

accounting for all variations of “agreement” (“slightly”, “mostly” and “strongly”), “neither agree nor disagree” and all variations of “disagreement (“slightly”, “mostly” and “strongly”); results pre and post interaction with the ATLAS prototype are shown.

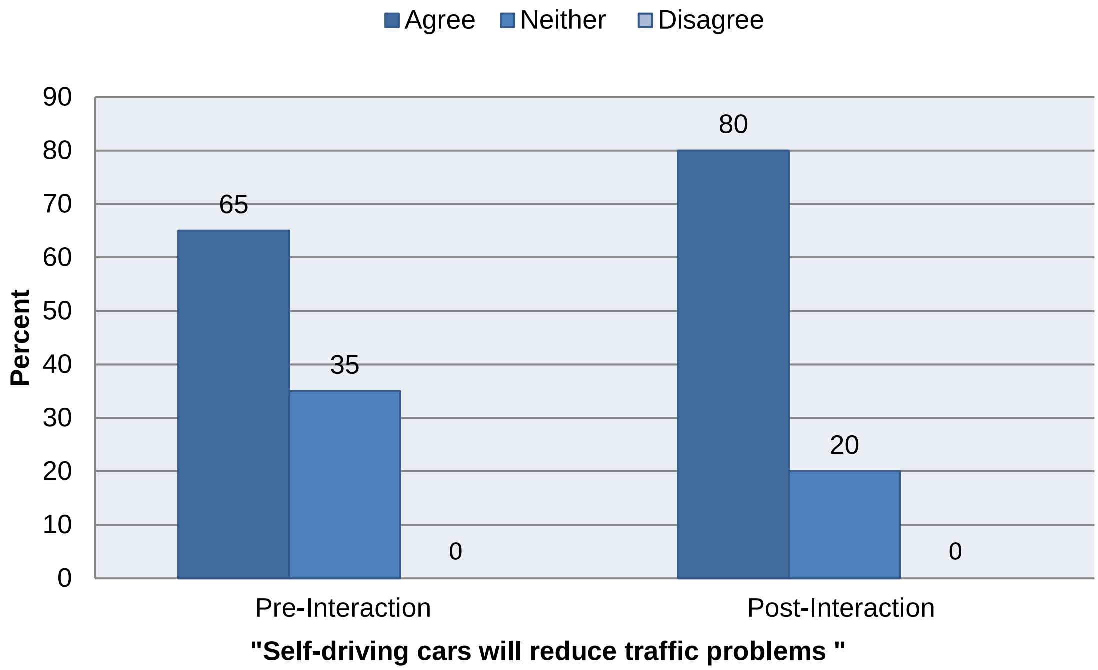


Figure 8-25. Percentage of participants agreeing and disagreeing with statement 15 pre and post interaction with the ATLAS prototype.

Figure 8-26 illustrates the mean response to statements 13 through 15, pre and post interaction with the ATLAS prototype. Paired t-tests were conducted to compare mean responses to all statements pre and post interaction. For statement 13, “A self-driving car would allow me to be more productive”, a significant difference was observed between the mean response for the pre-interaction (M = 6.50, SD = 1.15) and post interaction (M = 6.75, SD = 1.12) conditions; t(19) = 2.5166, p = 0.0210. Post-interaction, participants’ stated opinion that a self-driving car would help them to be more productive increased by 3.84%. For statement 14, “A self-driving car would allow me to

be more safe while in the car", the difference between the mean response for the pre-interaction (M = 5.25, SD = 0.97) and post interaction (M = 5.75, SD = 1.45) conditions was found to be statistically insignificant; t(19) = 1.3924, p = 0.1799. For statement 15, "Self-driving cars will reduce traffic problems", a significant difference was observed between the mean response for the pre-interaction (M = 5.15, SD = 1.04) and post interaction (M = 5.75, SD = 1.07) conditions; t(19) = 2.4495, p = 0.0242. Post-interaction, participants' belief in the contention that self-driving cars would help to improve traffic problems increased by 11.65%.

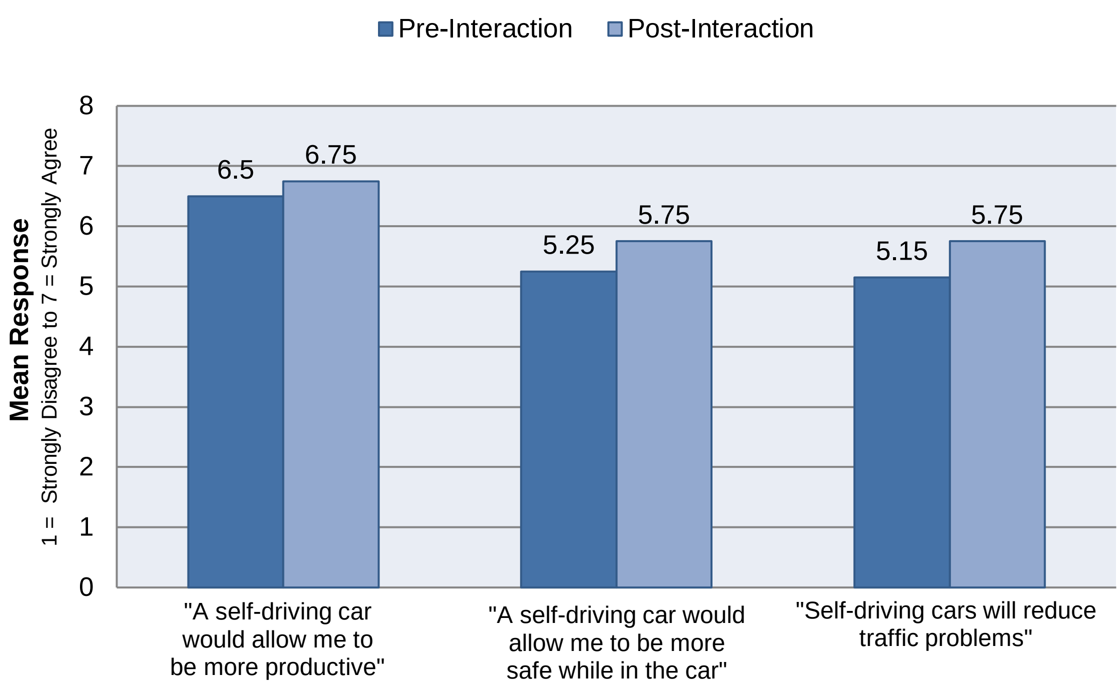


Figure 8-26. Mean participant response to statements 13 through 15, pre and post interaction with the ATLAS prototype.

Perceived ease of use

Participants were presented with three statements related to the perceived ease of use of self-driving cars. They were then asked to indicate their agreement or

disagreement with each statement on a seven-item Likert scale (1 = “strongly disagree” to 7 = “strongly agree”).

In responding to statement 16, “Self-driving cars will be easy to use”, the most frequently selected response of all participants prior to interacting with the prototype was “slightly agree” (30%), followed by “mostly agree” (25%). which was true also for blind participants (33.33%). For low vision participants however, “strongly agree” was the most frequently selected response (37.5%). Participants responding to statement 16 following their interaction with the ATLAS prototype selected “strongly agree” most frequently (60%), followed by “mostly agree” (25%). This was also true when analyzed according to participants’ degree of vision loss with “strongly agree” most frequently selected by both blind participants (58.33%) and low vision participants (62.5%). Figure 8-27 illustrates participant agreement and disagreement with statement 16, “Self-driving cars will be easy to use”, accounting for all variations of “agreement” (“slightly”, “mostly” and “strongly”), “neither agree nor disagree” and all variations of “disagreement (“slightly”, “mostly” and “strongly”); results pre and post interaction with the ATLAS prototype are shown.

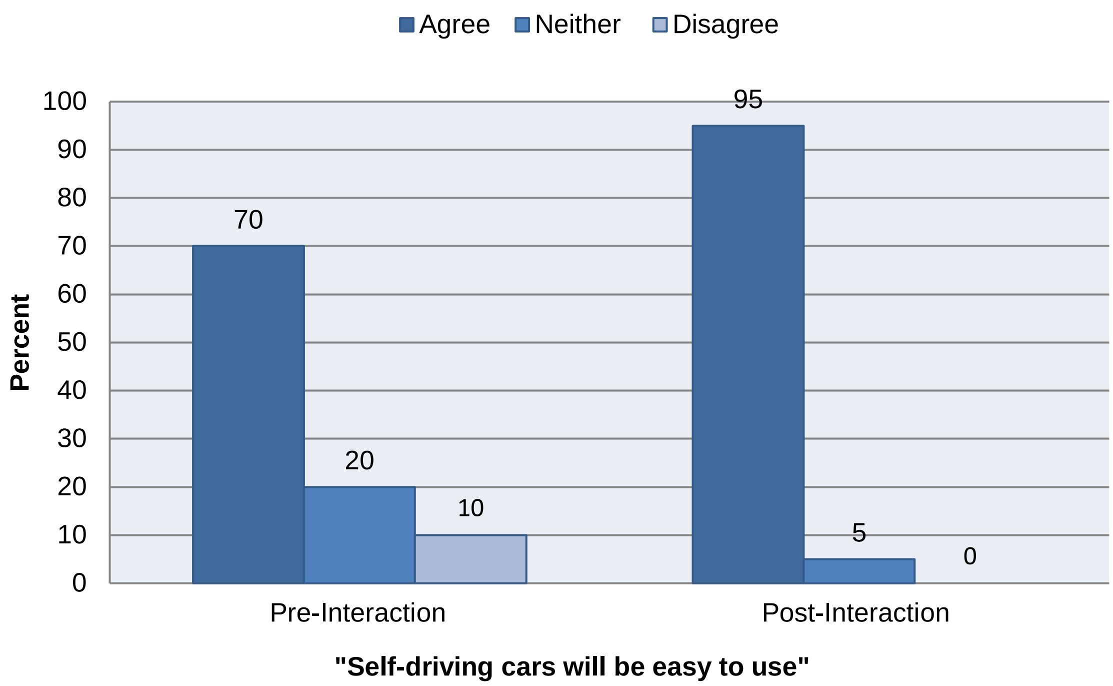


Figure 8-27. Percentage of participants agreeing and disagreeing with statement 16 pre and post interaction with the ATLAS prototype.

In responding to statement 17, “It will be a lot of work to figure out how to use a self-driving car”, “neither agree nor disagree” and “mostly disagree” were selected with equal frequency (30%). For blind participants, “neither agree nor disagree” was the most frequently selected response (33.33%) whereas for low vision participants “mostly disagree” was the most frequently selected (37.5%). Participants responding to the statement 17 following their interaction with the ATLAS prototype selected “strongly disagree” most frequently (65%). This was also true when analyzed according to participants’ degree of vision loss with “strongly disagree” most frequently selected by both blind participants (75%) and low vision participants (50%). Figure 8-28 illustrates participant agreement and disagreement with the statement, “It will be a lot of work to figure out how to use a self-driving car”, accounting for all variations of “agreement”

(“slightly”, “mostly” and “strongly”), “neither agree nor disagree” and all variations of “disagreement (“slightly”, “mostly” and “strongly”); results pre and post interaction with the ATLAS prototype are shown.

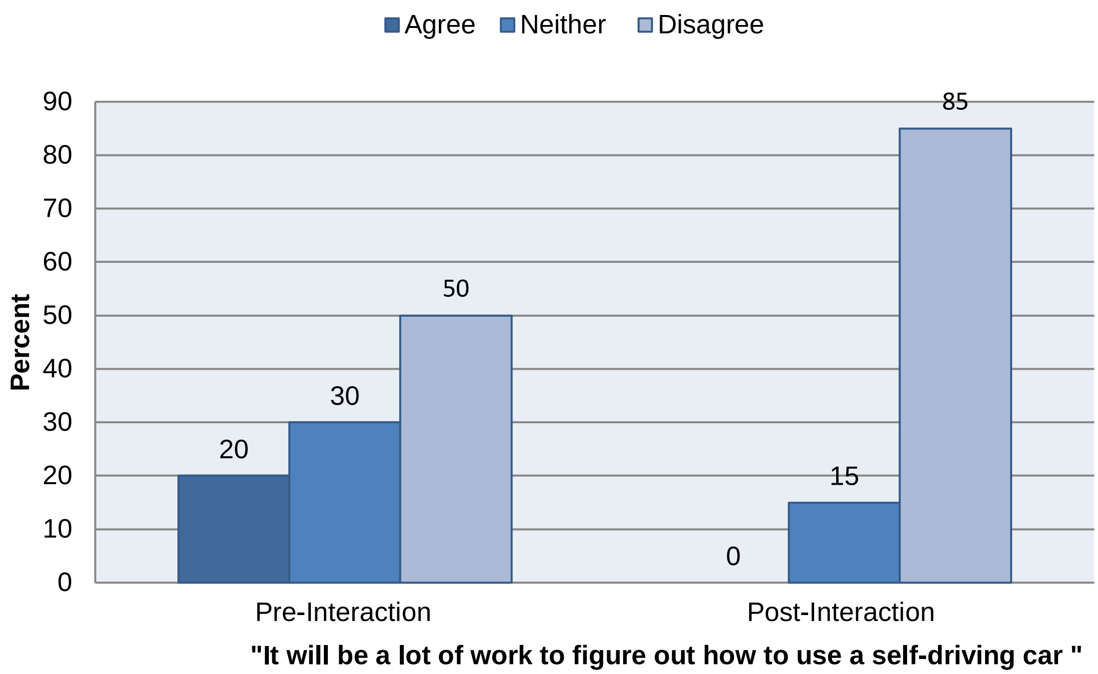


Figure 8-28. Percentage of participants agreeing and disagreeing with statement 17 pre and post interaction with the ATLAS prototype.

In responding to statement 18, “It would take me a long time to figure out how to use a self-driving car”, the most frequently selected response of all participants prior to interacting with the prototype was “slightly disagree” (30%). Blind participants selected “strongly disagree” most frequently (33.33%) whereas low vision participants selected “slightly disagree” most frequently (37.5%). This was also true when analyzed according to participants’ degree of vision loss with “strongly disagree” most frequently selected by both blind participants (75%) and low vision participants (62.5%). Figure 8-29 illustrates participant agreement and disagreement with the statement, “It would take me a long time

to figure out how to use a self-driving car", accounting for all variations of "agreement" ("slightly", "mostly" and "strongly"), "neither agree nor disagree" and all variations of "disagreement ("slightly", "mostly" and "strongly"); results pre and post interaction with the ATLAS prototype are shown.

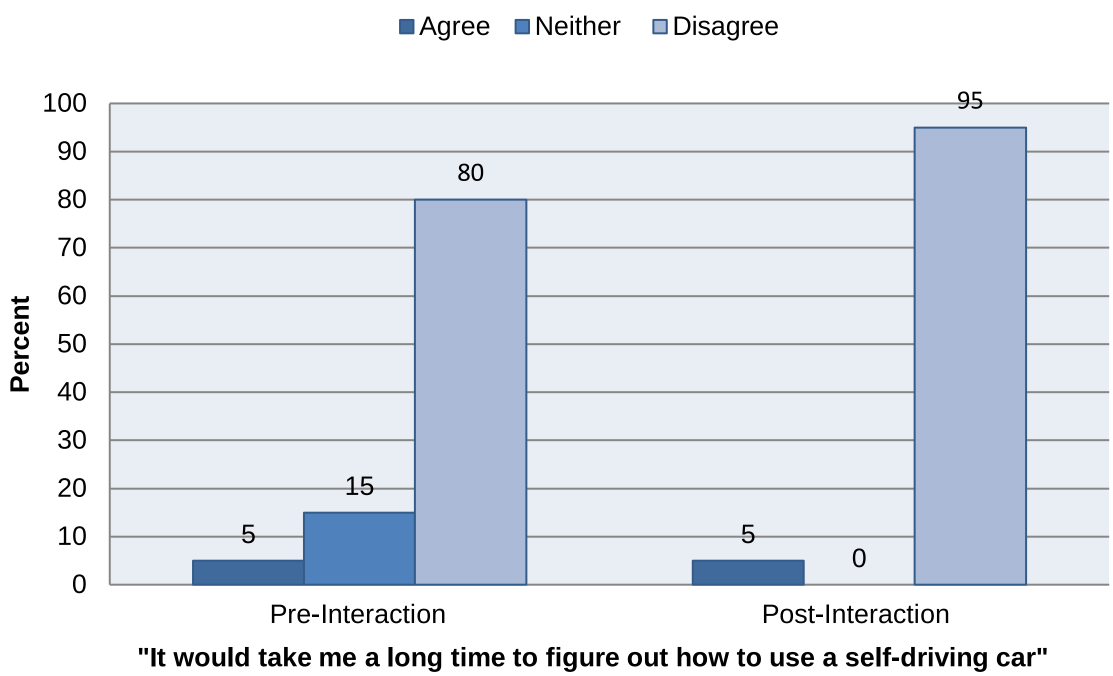


Figure 8-29. Percentage of participants agreeing and disagreeing with statement 18 pre and post interaction with the ATLAS prototype.

Figure 8-30 illustrates the mean response to statements 16 through 18, pre and post interaction with the ATLAS prototype. Paired t-tests were conducted to compare mean responses to all statements pre and post interaction. For statement 16, "Self-driving cars will be easy to use", a significant difference was observed between the mean response for the pre-interaction (*M* = 5.05, SD = 1.43) and post interaction (*M* = 6.40, SD = 0.88) conditions; t(19) = 3.9428, p = 0.0009. Post-interaction, participants' stated perception that self-driving cars would be easy to use increased by 26.73%. For statement 17, "It

will be a lot of work to figure out how to use a self-driving car", a significant difference was observed between the mean response for the pre-interaction (*M* = 3.50, SD = 1.61) and post interaction (*M* = 1.7, SD = 1.13) conditions; t(19) = -5.0024, p = 0.0001. Post-interaction, participants' stated opinion that it would be a lot of work to figure out how to use a self-driving car decreased by 51.42%. For statement 18, "It would take me a long time to figure out how to use a self-driving vehicle", the difference between the mean response for the pre-interaction (*M* = 2.50, SD = 1.19) and post interaction (*M* = 1.6, SD = 1.39) conditions was found to be statistically insignificant; t(19) = -1.894, p = 0.0735.

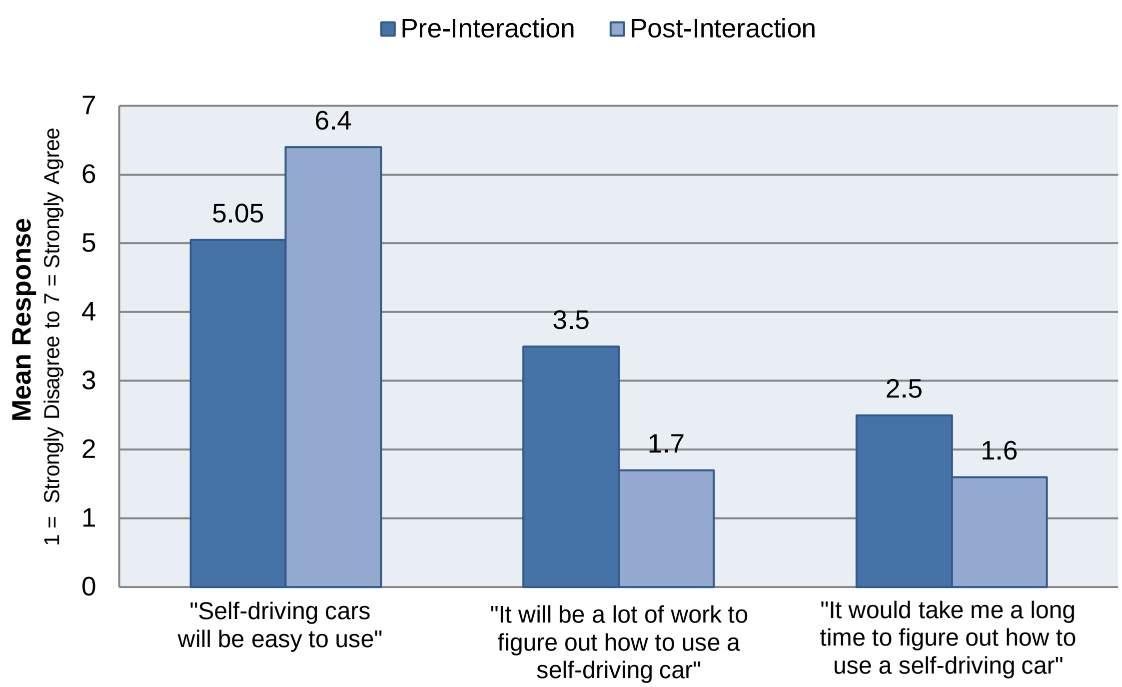


Figure 8-30. Mean participant response to statements 16 through 18, pre and post interaction with the ATLAS prototype.

Experience with automation

Participants were presented with three statements related to their experiences with technology and opinion of automation. They were then asked to indicate their agreement

or disagreement with each statement on a seven-item Likert scale (1 = “strongly disagree” to 7 = “strongly agree”).

In responding to statement 19, “I like to use technology to make tasks easier for me, the most frequently selected response of participants generally prior to interacting with the prototype was strongly agree (80%), which was true also for blind participants (83.33%) and for low vision participants (75%”). Participants responding to statement 19 following their interaction with the ATLAS prototype selected “strongly agree” most frequently (85%). This was also true when analyzed according to participants’ degree of vision loss with “strongly agree” most frequently selected by both blind participants (83.33%) and low vision participants (87.5%). Figure 8-31 illustrates participant agreement and disagreement with the statement, “I like to use technology to make tasks easier for me”, accounting for all variations of “agreement” (“slightly”, “mostly” and “strongly”), “neither agree nor disagree” and all variations of “disagreement (“slightly”, “mostly” and “strongly”); results pre and post interaction with the ATLAS prototype are shown.

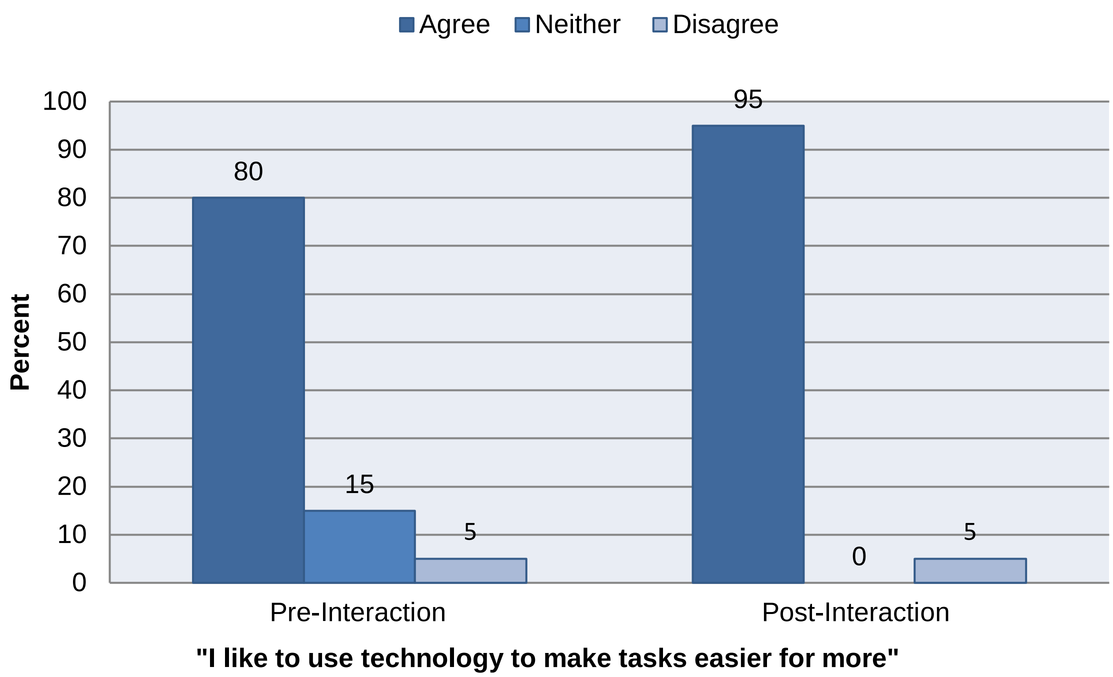


Figure 8-31. Percentage of participants agreeing and disagreeing with statement 19 pre and post interaction with the ATLAS prototype.

In responding to statement 20, “I have bad experiences when I try too use new technology instead of doing things the old fashioned way”, “mostly disagree” and “strongly disagree” were the most frequently selected responses and were selected with equal frequency (40%). This was also true for blind and low vision participants who selected “mostly disagree” and “strongly disagree” with 41.6% frequency and 37.5% frequency respectively. Participants responding to the statement 20 following their interaction with the ATLAS prototype selected “strongly disagree” most frequently (65%). This was also true when analyzed according to participants’ degree of vision loss with “strongly disagree” most frequently selected by both blind participants (58.33%) and low vision participants (75%). Figure 8-32illustrates participant agreement and disagreement with the statement, “I have bad experiences when I try too use new

technology instead of doing things the old-fashioned way", accounting for all variations of "agreement" ("slightly", "mostly" and "strongly"), "neither agree nor disagree" and all variations of "disagreement ("slightly", "mostly" and "strongly"); results pre and post interaction with the ATLAS prototype are shown.

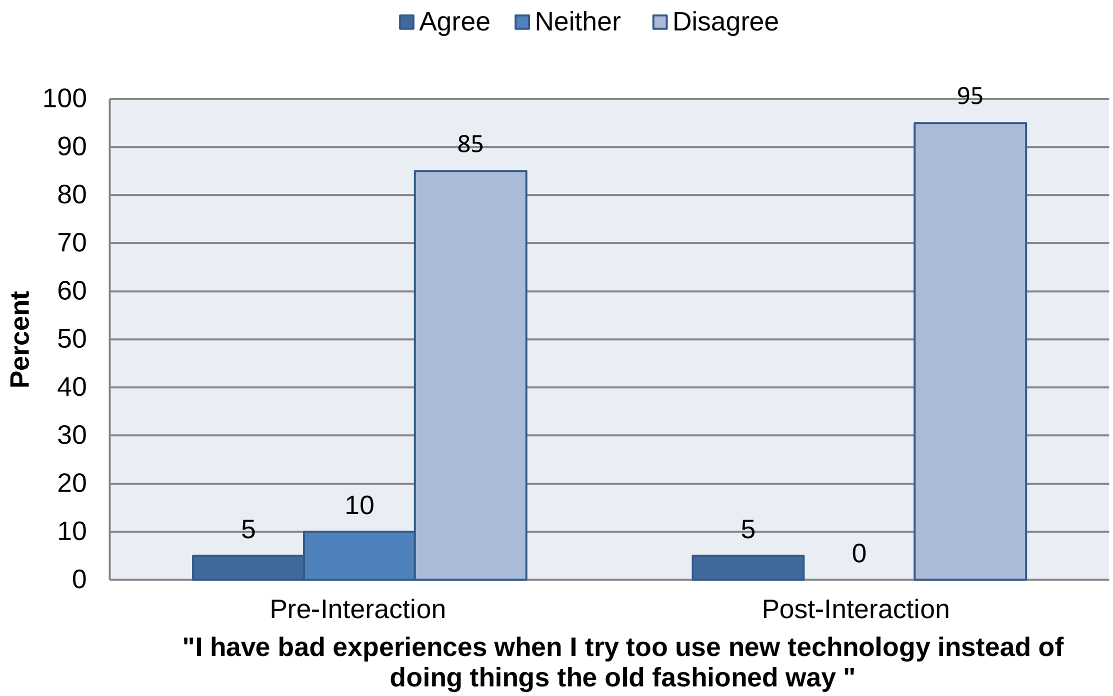


Figure 8-32. Percentage of participants agreeing and disagreeing with statement 20 pre and post interaction with the ATLAS prototype.

In responding to statement 21, "There are tasks in my life that have been made easier by computers doing the work for me", the most frequently selected response of all participants prior to interacting with the prototype was seven or "strongly agree" (75%), which was true also for blind participants (91.66%). For low vision participants "strongly agree" and "mostly agree" were selected with equal frequency (50%). Participants responding to statement 21 following their interaction with the ATLAS prototype selected "strongly agree" most frequently (85%). This was also true when analyzed

according to participants' degree of vision loss with "strongly agree" most frequently selected by both blind participants (83.33%) and low vision participants (87.5%). illustrates participant agreement and disagreement with the statement, "There are tasks in my life that have been made easier by computers doing the work for me", accounting for all variations of "agreement" ("slightly", "mostly" and "strongly"), "neither agree nor disagree" and all variations of "disagreement ("slightly", "mostly" and "strongly"); results pre and post interaction with the ATLAS prototype are shown.

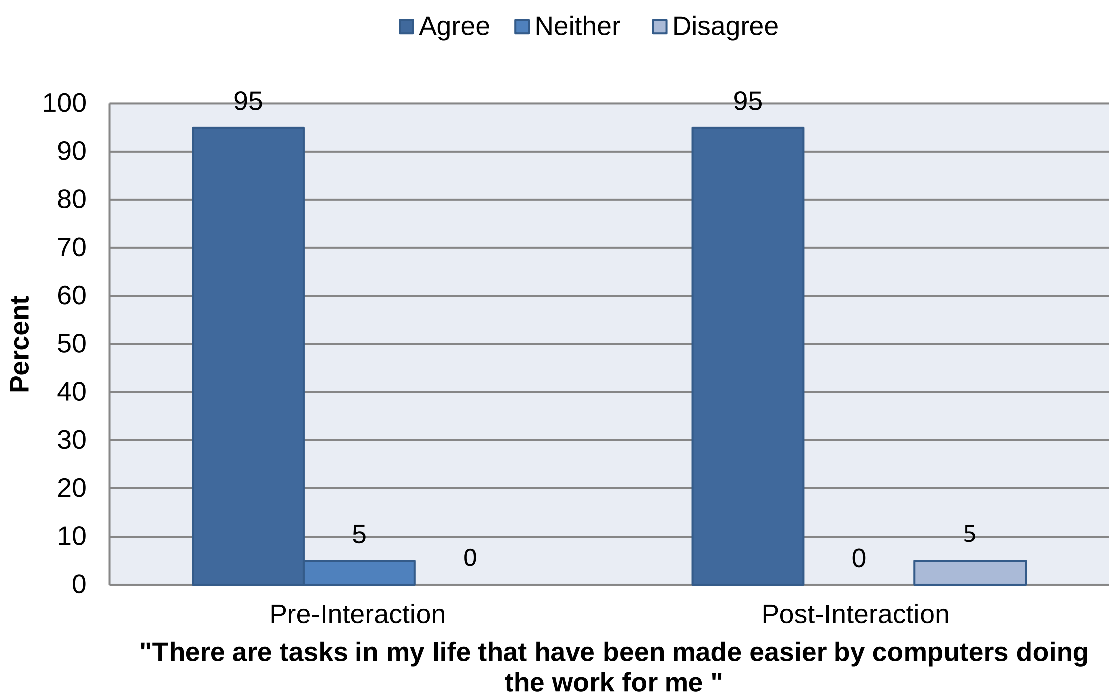


Figure 8-33. Percentage of participants agreeing and disagreeing with statement 21 pre and post interaction with the ATLAS prototype.

Figure 8-34 illustrates the mean response to statements 19 through 21, pre and post interaction with the ATLAS prototype. Paired t-tests were conducted to compare mean responses to all statements pre and post interaction. For statement 19, "I like to use technology to make tasks easier for more", the difference between the mean response for

the pre-interaction (M = 6.6, SD = 1.14) and post interaction (M = 6.7, SD = 0.80) conditions was found to be statistically insignificant; t(19) = 0.8094, p = 0.4283. For statement 20, “I have bad experiences when I try too use new technology instead of doing things the old fashioned way”, the difference between the mean response for the pre-interaction (M = 2.0, SD = 1.17) and post interaction (M = 1.6, SD = 1.35) conditions was found to be statistically insignificant; t(19) = -1.094, p = 0.2876. For statement 21, “There are tasks in my life that have been made easier by computers doing the work for me”, the difference between the mean response for the pre-interaction (M = 6.65, SD = 0.75) and post interaction (M = 6.55, SD = 1.39) conditions was found to be statistically insignificant; t(19) = -0.4904, p = 0.6295.

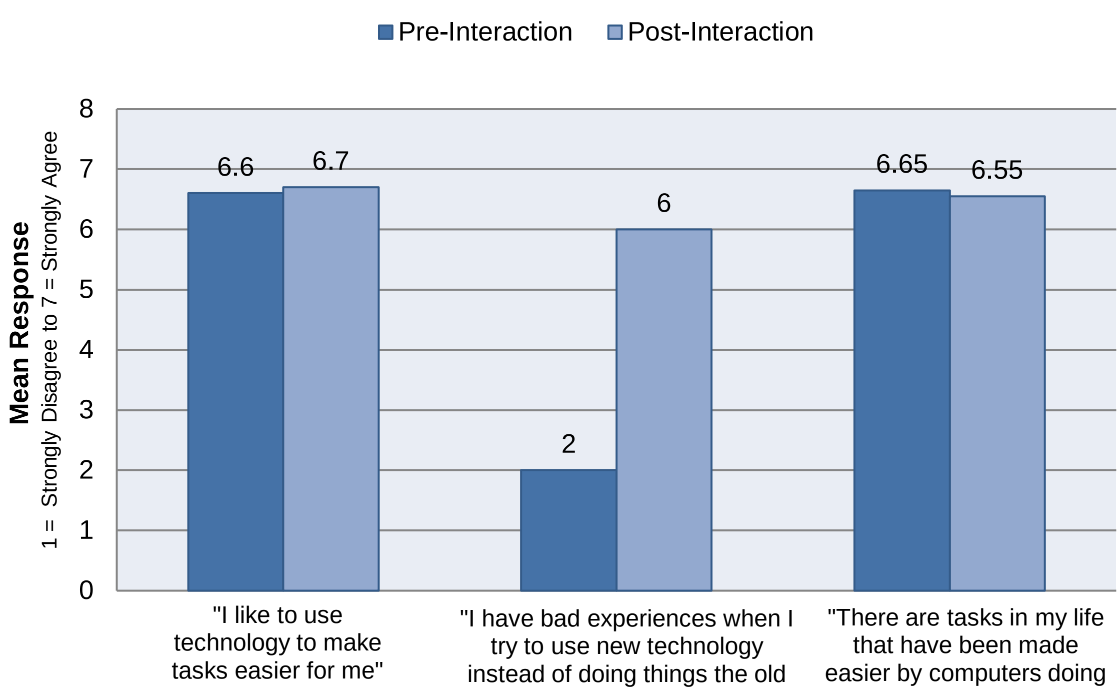


Figure 8-34. Mean participant response to statements 19 through 21, pre and post interaction with the ATLAS prototype.

Intention to use

Participants were presented with three statements related to their intention to use self-driving vehicles. They were then asked to indicate their agreement or disagreement with each statement on a seven-item Likert scale (1 = “strongly disagree” to 7 = “strongly agree”).

In responding to statement 22, “I would like to own a self-driving car”, the most frequently selected response of participants generally prior to interacting with the prototype was seven or “strongly agree” (55%), which was true also for blind participants (75%). For low vision participants however, “mostly agree” was the most frequently selected response (50%). Participants responding to statement 22 following their interaction with the ATLAS prototype selected “strongly agree” most frequently (90%). This was also true when analyzed according to participants’ degree of vision loss with “strongly agree” most frequently selected by both blind participants (83.33%) and low vision participants (100%). Figure 8-35 illustrates participant agreement and disagreement with the statement, “I would like to own a self-driving car”, accounting for all variations of “agreement” (“slightly”, “mostly” and “strongly”), “neither agree nor disagree” and all variations of “disagreement (“slightly”, “mostly” and “strongly”); results pre and post interaction with the ATLAS prototype are shown.

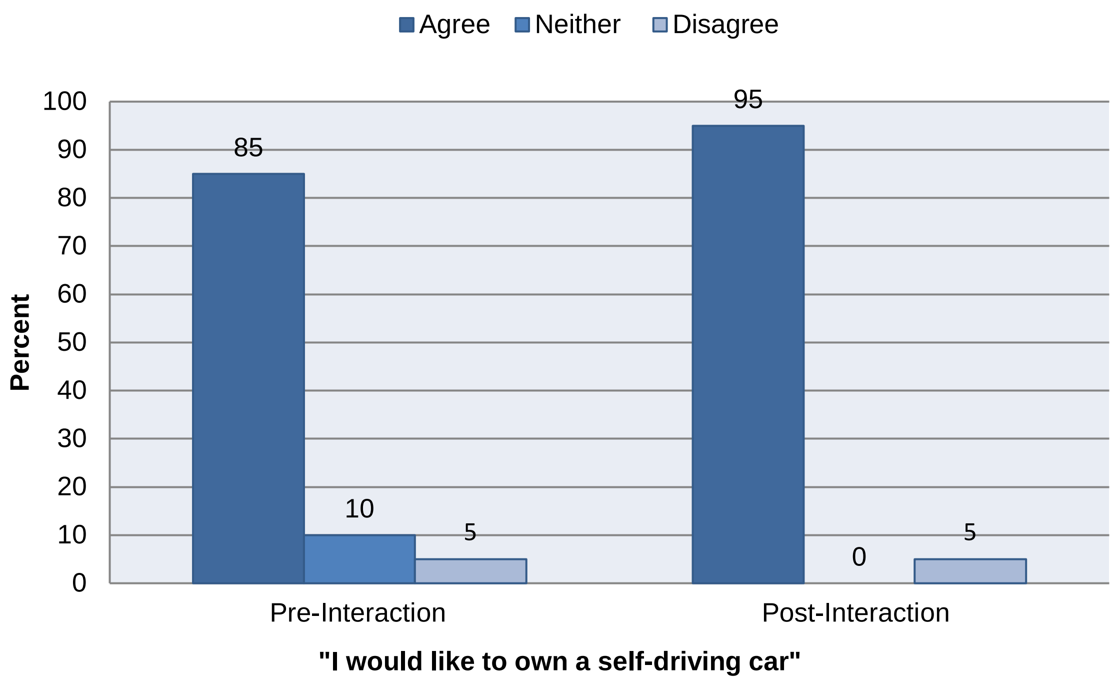


Figure 8-35. Percentage of participants agreeing and disagreeing with statement 22 pre and post interaction with the ATLAS prototype.

In responding to statement 23, “Even if I had a self-driving car, I would still want to drive myself most of the time”, “strongly disagree” was the most frequently selected response (30%). This was also true for blind participants who selected “strongly disagree” with 41.6% frequency. For low vision participants the most response frequency was shared between “strongly agree”, five or “slightly agree” and “mostly disagree” (25%). Participants responding to the statement 22 following their interaction with the ATLAS prototype selected one or “strongly disagree” most frequently (55%). This was also true when analyzed according to participants’ degree of vision loss with “strongly disagree” most frequently selected by both blind participants (66.66%) and low vision participants (37.5%). Figure 8-36 illustrates participant agreement and disagreement with the statement 23, “Even if I had a self-driving car, I would still want to drive myself most

of the time", accounting for all variations of "agreement" ("slightly", "mostly" and "strongly"), "neither agree nor disagree" and all variations of "disagreement ("slightly", "mostly" and "strongly"); results pre and post interaction with the ATLAS prototype are shown.

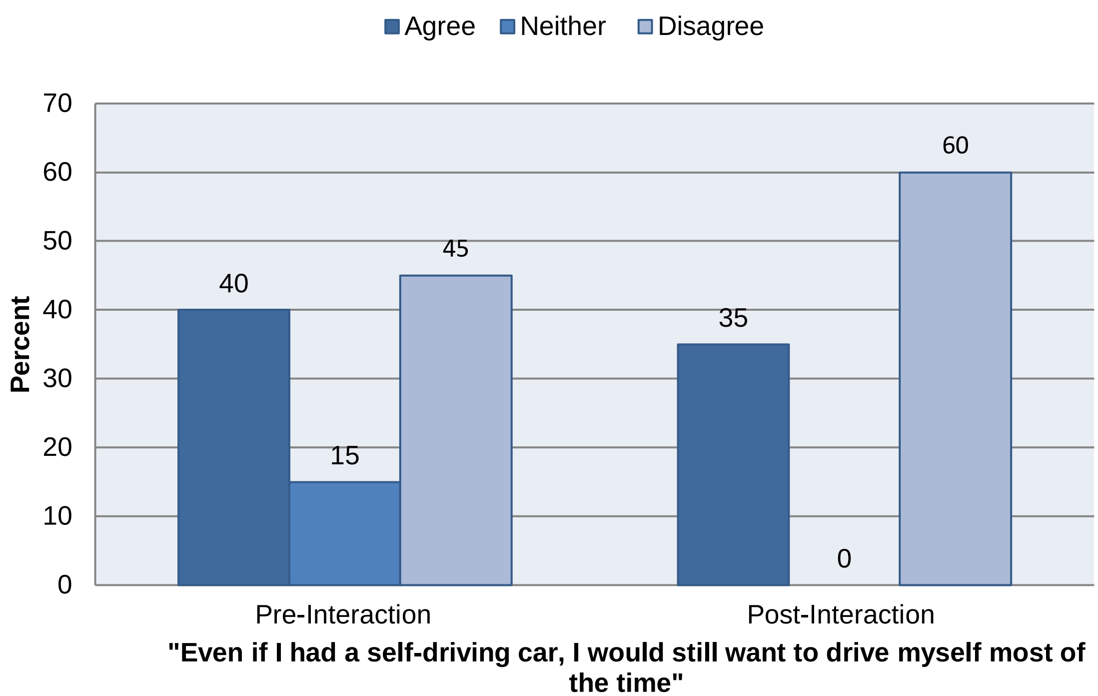


Figure 8-36. Percentage of participants agreeing and disagreeing with statement 23 pre and post interaction with the ATLAS prototype.

In responding to statement 24, "In a self-driving car, it will be important to me to have the option to turn off the computer and drive myself", the most frequently selected response of all participants prior to interacting with the prototype was "strongly disagree" (45%), which was true also for blind participants (35%). For low vision participants "strongly disagree" and "mostly disagree" and "slightly disagree" were selected with equal frequency (25%). Participants responding to statement 24 following their interaction with the ATLAS prototype selected "strongly disagree" most frequently

(45%). This was also true when analyzed according to participants' degree of vision loss with "strongly disagree" most frequently selected by both blind participants (50%) and low vision participants (37.5%). Figure 8-37. Percentage of participants agreeing and disagreeing with statement 24 pre and post interaction with the ATLAS prototype.

Figure 8-37 illustrates participant agreement and disagreement with the statement, "In a self-driving car, it will be important to me to have the option to turn off the computer and drive myself", accounting for all variations of "agreement" ("slightly", "mostly" and "strongly"), "neither agree nor disagree" and all variations of "disagreement ("slightly", "mostly" and "strongly"); results pre and post interaction with the ATLAS prototype are shown.

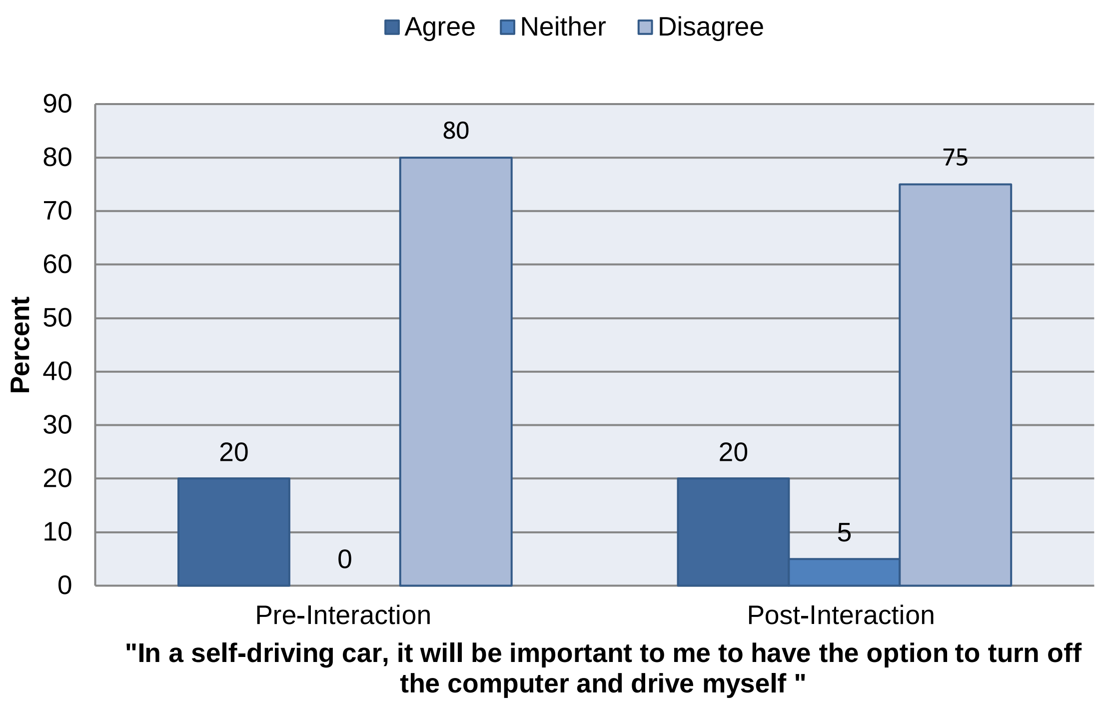


Figure 8-37. Percentage of participants agreeing and disagreeing with statement 24 pre and post interaction with the ATLAS prototype.

Figure 8-38 illustrates the mean response to statements 22 through 24, pre and post interaction with the ATLAS prototype. Paired t-tests were conducted to compare mean responses to all statements pre and post interaction. For statement 22, “I would like to own a self-driving car”, a significant difference was observed between the mean response for the pre-interaction (M = 6.1, SD = 1.52) and post interaction (M = 6.8, SD = 0.70) conditions; t(19) = 2.8961, p = 0.0093. Post-interaction, participants’ stated desire to own a self-driving car increased by 11.47%. For statement 23, “Even if I had a self-driving car, I would still want to drive myself most of the time”, the difference between the mean response for the pre-interaction (M = 3.7, SD = 2.43) and post interaction (M = 3.25, SD = 2.75) conditions was found to be statistically insignificant; t(19) = -0.9407, p = 0.3586. For statement 24, “In a self-driving car, it will be important to me to have the option to turn off the computer and drive myself”, the difference between the mean response for the pre-interaction (M = 2.45, SD = 1.99) and post interaction (M = 2.7, SD = 2.18)

conditions was found to be statistically insignificant; $t(19) = 0.6413$, $p = 0.5290$.

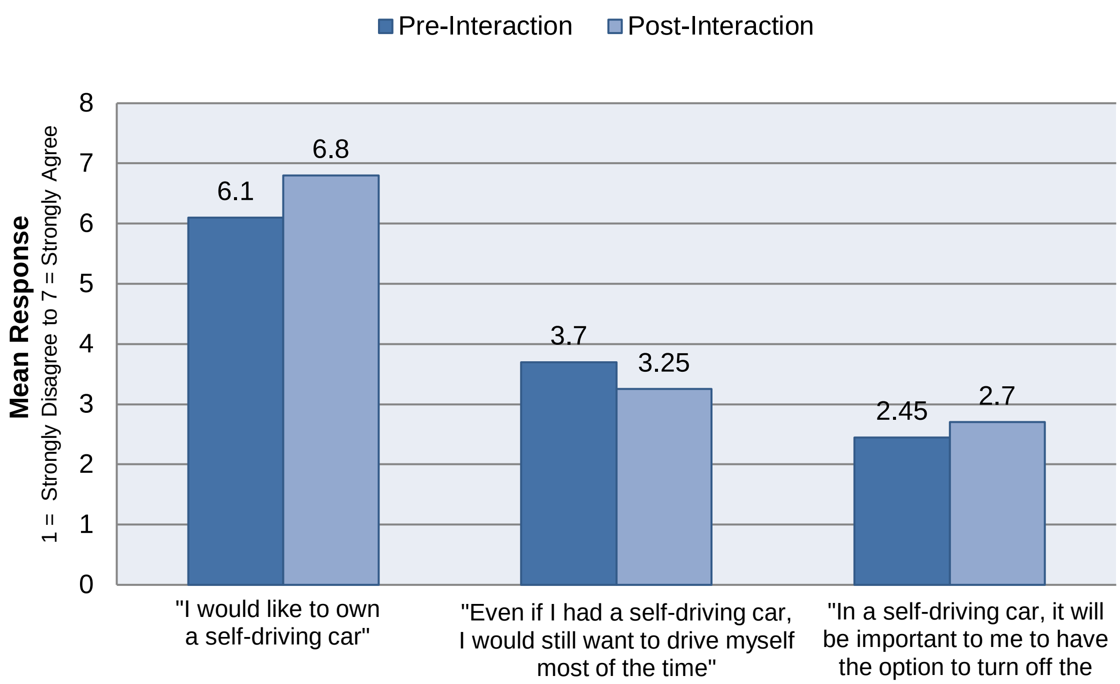


Figure 8-38. Mean participant response to statements 22 through 24, pre and post interaction with the ATLAS prototype.

Discussion

Overall Perception of the ATLAS System

Overall, participants expressed a decidedly positive view of the usability of the ATLAS prototype. Participants on average rated the usability of the system as “Excellent” as measured on the SUS, with no statistical differences observed between the perceptions of male, female, blind and low vision participants. Based on these findings the null hypotheses, H_{01} is rejected and the alternate hypothesis H_{A1} is accepted. Participants also expressed significant satisfaction with the situational awareness and location verification features of the prototype. When asked whether ATLAS satisfied their situational awareness and location verification needs, the mean response to both

questions was 6.55 (between “mostly” and “strongly” agree) with variations in standard deviation observed. A comparison of the pre and post scenario responses to the Self-Driving Car Acceptance Scale also provides guidance regarding participant’s perception of the system’s usability. Following interaction with the system, participants’ stated perception that self-driving cars will be easy to use increased by 26.73% while the belief that it would be “a lot of work” to learn how to use a self-driving car decreased by 51.42%. Based on these findings, the null hypotheses, H_{02} is rejected and the alternate hypothesis H_{A2} is accepted.

Further comparisons of the pre and post scenario responses of the Self-Driving Car Acceptance Scale also provide guidance as to participant perception of the safety of self-driving vehicles. Following their interaction with the prototype, participants’ perception of the safety of the technology improved by 28.26%, stated trust in the technology increased by 20.75% while the belief in the need to closely monitor a self-driving vehicle for errors decreased by 24.22%. Participants’ belief in the need for features that would allow them to take back control from the automated system decreased by 11.49% while participant perception that there are some driving scenarios that will be too difficult for a self-driving vehicle decreased by 35.48%. These findings are indicative of a general increase in the perception of safety and trust in the technology and based on these findings the null hypothesis, H_{03} is rejected and the alternate hypothesis H_{A3} is accepted. Study findings relative to trust provide additional support to the findings of a qualitative study conducted by Intel where users expressed a greater degree of comfort with self-driving vehicle technology after having a first-hand experience with it. The findings of the Intel study have questionable generalizability given the small number of participants involved (10). These findings are significant for two reasons. The present

study suggests that even an interaction with a Wizard-of-Oz'd self-driving vehicle, where participants are overtly told that a licensed driver is in the driver's seat, may ameliorate feelings of concern and apprehension that users have regarding this technology. These results are perhaps even more significant when viewed in the context of consumer adoption broadly. Studies have consistently found that consumers generally are afraid to ride in self-driving vehicles [132] and are significantly concerned about the potential for dangerous equipment failures [55], [57]. A recent AAA study for instance found that 75% of respondents indicated that they were afraid to ride in a self-driving vehicle [132]. The present study provides additional support to the contention that increased user interaction with the technology, simulated or otherwise, may effectively address this issue.

My findings suggest that interaction with the ATLAS prototype also increased participant comfort with the concept of being a passenger as opposed to an active driver. Participants' stated enjoyment of driving a conventional vehicle post-interaction decreased by 14.28% while the stated preference for being the driver rather than the passenger decreased by 15.38%. Given that the stated enjoyment of being in a vehicle generally did not change significantly, these findings imply a changing interpretation of participants' relationship to personal transportation post-interaction with the prototype.

The earlier, formative research of this dissertation suggested that while visually impaired users generally are relatively optimistic about self-driving vehicles, this optimism is driven largely by a belief that the technology will improve personal mobility and productivity. While participants of the present study began with a generally positive perception of the technology, post-interaction this perception relative to a belief in increased personal productivity improved by 3.84%. While it cannot be stated

definitively whether this increase was driven by interaction with what participants believed to be a self-driving vehicle or interaction with the ATLAS system specifically, the latter contention is supported by the 90% of participants who indicated that they would purchase a self-driving vehicle with the ATLAS system if cost were not a factor. Post interaction, participants' stated desire to own a self-driving vehicle increased by 11.47% while belief that benefits of a self-driving car would outweigh the amount of money it would cost increased by 21.1%. These findings stand in contrast with much of the literature, which has suggested that while consumers have a generally favorable view of the *concept* of vehicular automation, most consumers would not actually pay more to have access to it [57], [60].

Viewed collectively, the findings suggest that the features of the ATLAS system, borne of a lengthy process of investigation, development, and refinement, are promising in satisfying the experiential needs of visually impaired persons in interacting with self-driving vehicles.

Limitations

The most apparent limitation of the presentation study is a limitation that is characteristic of all studies using a Wizard-of-Oz approach; that being the wizards themselves. Given that human are not computers it is physically demanding for human to attempt to mimic the responses of a computer for any considerable length of time. A human, acting as a computer, is also prone to errors and variations in mimicked computer behavior. To minimize the impact of these factors in the present study a single researcher served as the "driver" wizard in an attempt to reduce the variations in driving style between trials. Trials were also scheduled apart as necessary to allow a rest period of approximately 30 minutes for the driver to reduce fatigue.

A secondary limitation was the introduction of the two-question Situational Awareness-Location Verification questionnaire. The general validity of the questionnaire was not evaluated prior to its use in the present study.

CHAPTER 9
POLICY PROPOSAL

In any discussion regarding self-driving vehicles and their accessibility, a key consideration must be the legal and regulatory environment of their use. What is learned from investigations similar to those described in Chapters 3, 4, 6 and 8 may be for naught if the requisite legal and regulatory environment either restricts the operation of self-driving vehicle technology to licensed drivers or fails to require features that support accessibility. The present chapter 1) provides and overview of existing regulations regarding self-driving vehicles, 2) examines how accessibility is addressed in existing laws and guidelines, and 3) concludes with recommendations for improvements to federal and state regulations to address self-driving vehicle accessibility concerns.

Federal and State Regulatory Roles

Vehicles operating on public roads in the United States are subject to both Federal and State jurisdiction. The federal government, via the National Highway Transportation Safety Administration (NHTSA) of the U.S. Department of Transportation (DOT), is responsible for regulating motor vehicles and motor vehicle equipment [133]. The DOT, through the through the Federal Highway Administration (FHWA) is also involved in the safety, evaluation, planning, and maintenance of the U.S. highway system and regulation of interstate motor carriers and commercial vehicle drivers. Individual states are responsible for regulating the driver (e.g. vehicle licensing), vehicle registration, traffic laws, enforcement, and all aspects of motor vehicle insurance and liability.

Federal Role

At the Federal level there is an absence of enacted legislation that has been written with the intent to specifically address automated vehicles. As a result, the bulk of guidance regarding automated vehicles is the result of interpretations of existing statutes

by the DOT and NHTSA. The National Highway Transportation Safety Administration has a legislative mandate under Title 49 of the U.S. Code, Chapter 301, Motor Vehicle Safety, to issue Federal Motor Vehicle Safety Standards (FMVSS) [134]. As the agency responsible for both setting and enforcing FMVSSs, absent any specific legislation NHTSA has interpreted their mandate to include the ability to remove any vehicle, to include automated vehicles, from the public roadways if it is deemed a risk to public safety. Given that manufacturers must also certify their compliance with the FMVSS prior to selling their vehicles in the United States, NHTSA is a de facto gatekeeper of automated vehicles on public roadways despite the lack of formal legislation in this regard. To this end, NHTSA published the *Federal Automated Vehicle Policy* [135] in September 2016, which has since been replaced by *A Vision for Safety* 2.0 [133] in September 2017.

The DOT has issued Vehicle Performance Guidance for Automated Vehicles (VPGAV) [136] that outlines best practices for pre-deployment design, development and testing of this technology prior to commercial sale or operation on public roads. The VPGAV applies primarily to SAE level 5 fully autonomous vehicles, with some aspects applying to SAE levels 3 and 4 technologies. It is intended to include all classes of motor vehicles, while covering any organization testing, operating, or deploying automated vehicles. The VPGAV includes a 15-item safety assessment (Table 9-1) where manufacturers and developers are asked to explain how they are satisfying each topic area. The VPGAV was rescinded by federal authorities in 2017 with the introduction of *A Vision for Safety 2.0* under the argument that such guidance was “speculative in nature” and outside the scope of NHTSA’s authority.

Table 9-1. Description of topic areas within the VPGAV vehicle safety assessment.

Topic area	Description
Operational Design Domain	How and where the highly automated vehicle is supposed to function and operate
Object and Event Detection and Response	Perception and response functionality of the highly automated vehicle system
Fall Back (Minimal Risk Condition)	Response and robustness of the highly automated vehicle upon system failure
Validation Methods	Testing, validation, and verification of an highly automated vehicle system
Registration and Certification	Registration and certification to NHTSA of an highly automated vehicle system
Data Recording and Sharing	Highly automated vehicle system data recording for information sharing, knowledge building and for crash reconstruction purposes
Post-Crash Behavior	Process for how an highly automated vehicle should perform after a crash and how automation functions can be restored
Privacy	Privacy considerations and protections for users
System Safety	Engineering safety practices to support reasonable system safety
Vehicle Cyber security	Approaches to guard against vehicle hacking risks;
Human-Machine Interface	Approaches for communicating information to the driver, occupant and other road users
Crashworthiness	Protection of occupants in crash situations
Consumer Education and Training	Education and training requirements for users of highly automated vehicles
Ethical Considerations	How vehicles are programmed to address conflict dilemmas on the road; and
Federal, State, and Local Laws	How vehicles are programmed to comply with all applicable traffic laws.

Beyond the VPGAV, much of what has been done at the Federal level has involved establishing guidelines and best practices designed to provide guidance to the states and provide commonality to state laws. In *A Vision for Safety 2.0,* NHTSA proposes a set of guidelines for state legislatures related broadly to safety related issues involving partially, highly or fully automated vehicles while discouraging states from regulating safety and performance aspects of this technology (e.g. topics covered in the

VPGAV). To summarize, NHTSA’s legislative guidance encourages states to:

- Provide a technology neutral environment: states should avoid limiting the ability to develop automated vehicles technology to companies with existing motor vehicle manufacturing capability. All companies meeting Federal and State requirements for testing and deployment should have the ability to operate in the state.

- Provide licensing and registration procedures: Procedures should be developed to facilitate the licensing and registration of automated vehicles.

- Provide reporting and communications methods for Public Safety Officials: Developing communication mechanisms coordinated with public safety agencies within a state may enable the monitoring of the safe operation of automated vehicles.

- Review traffic laws and regulations that may serve as barriers to the operation of automated vehicles: Vehicle codes and traffic laws should be reviewed to determine if unnecessary regulatory barriers exist that would prevent the deployment and testing of automated vehicles within a state.

NHTSA has also established best practices for state highway safety officials. Generally, highway safety authority is used within each state to establish highway safety programs addressing driver education, testing, licensing, pedestrian safety, law enforcement, vehicle registration, crash prevention, and a number of other services. NHTSA’s guidance to highway safety focuses on:

- Administration: States are encouraged to identify a lead agency responsible for deliberations regarding any automated vehicle testing. Through this lead agency establish an internal process for approving or deny automated vehicle testing within the state.

- Application for testing: It is recommended that applications for automated vehicle testing remain at the state level as opposed to local jurisdictions. Characteristics of the business entity (e.g. the financial ability to satisfy a judgment), training provided to employees or contractors and the ability to identify each operator may be appropriate decision criteria.

- Permission to test on public roadways: The state’s lead agency should involve law enforcement prior to responding to a request to test on public roadways. If permission is granted, it should be suspended if a failure to comply with insurance or driver requirements is identified.

- Automated vehicle drivers and operators: As applicable states should request a summary of training for drivers/operators involved in testing. SAE level 3 or lower automated vehicles should require a licensed driver whereas SAE levels 4 and 5 (e.g. fully automated vehicles) should not.

- Consideration for registration and titling: States should consider identifying the presence of automated capabilities on a vehicle's title or registration depending upon the level of automation.

- Public safety officials: Public safety officials should be trained to understand the operation of automated vehicles and should begin to develop policies on human operator behavior.

- Liability and insurance: States should begin the process of determining how to allocate liability in the event of an automated vehicle accident and determine who should be required to carry motor vehicle insurance (e.g. the manufacturer, operator, passenger, etc.).

Beyond regulatory efforts and policy guidance by the DOT and NHTSA, legislative efforts at the Federal level to pass and enact legislation that specifically address automated vehicles have been limited and largely recent. The SELF DRIVE Act (SDA) [137] and the AV START Act (ASA) [138], for instance, both introduced in 2017, are the first major U.S. legislative efforts intended to establish policies for regulating SAE level 4 and 5 automated vehicles. The SDA passed the U.S. House of Representatives in September 2017 and is intended to officially give the National Highway Transportation Safety Administration the power to regulate the design, construction and performance of automated vehicles. The legislation requires NHTSA to develop rules regarding specific safety criteria and specific performance standards within 24 months. The Senate version of the bill, ASA has yet to pass.

State Role

States have begun the process of passing legislation concerning automated driving technology to include self-driving vehicles. As of 2018, 33 states have introduced legislation concerning self-driving vehicles specifically [139]. Twenty states introduced

legislation in 2016. Twenty-one states have passed legislation related to self-driving vehicles and governors in six states have issued executive orders related to autonomous vehicles (Figure 9-1). While Nevada was the first to enact autonomous vehicle legislation, the states of California, Michigan, Florida and Tennessee have enacted the most legislation pertaining to automated vehicles.

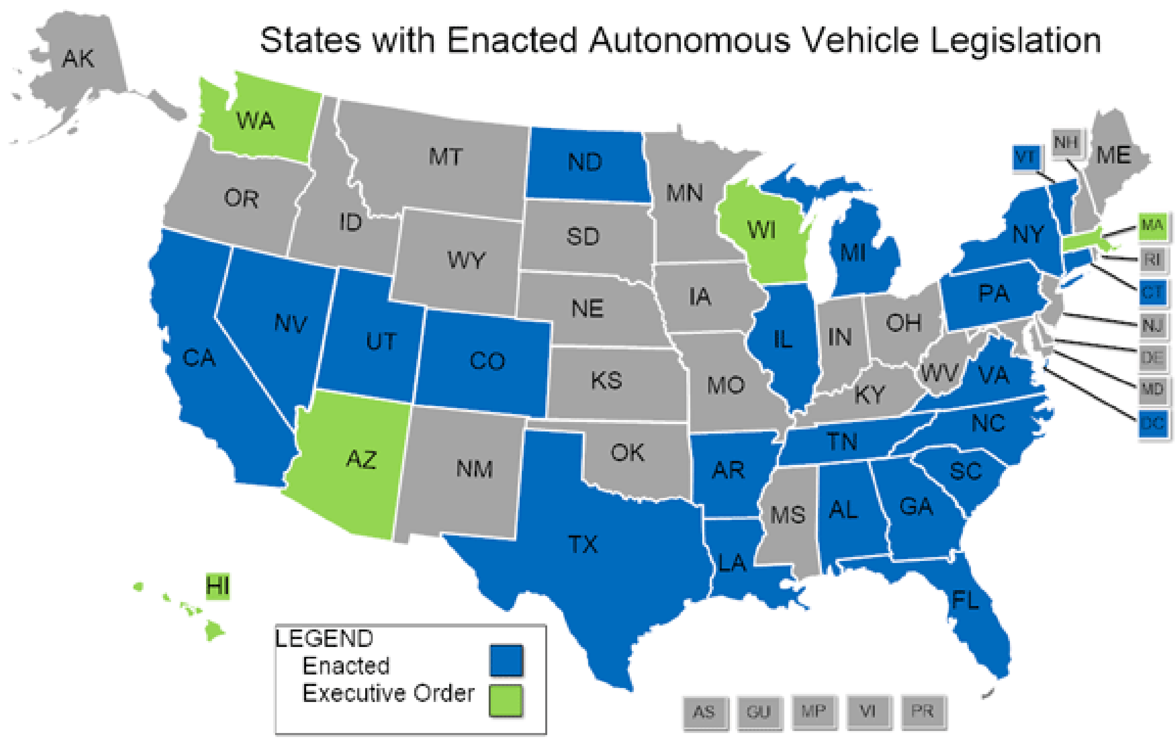


Figure 9-1. Illustration of U. S. States with enacted legislation related to AV technology or existing executive orders from the National Conference of State Legislatures [139].

Noteworthy state legislation: Nevada's AB 511 (2011) [140] authorized the operation of autonomous vehicles on public roads in the state, created a driver's license endorsement for operators, defined "autonomous vehicle" and directed the state Department of Motor Vehicles to adopt rules for licensing, operation, insurance and

testing. SB 140 (2011) [141] prohibited the use of handheld wireless devices while driving unless by an operator in a legally operating autonomous vehicle; this user is not deemed to be operating a motor vehicle for the purposes of the law.

California's SB 1298 (2012) [142] required the Department of California Highway Patrol to adopt safety standards and performance requirements for autonomous vehicles operation and permitted the operation of such vehicles on public roads in the state. Bill AB 1592 [143] permitted the testing of autonomous vehicles without driver controls (e.g. steering wheel, brake pedal, etc.) in specific locations. Bill AB 669 (2017) [144] extended the sunset date of a law allowing vehicle platooning and prohibits the operation of a platooned vehicle by someone without a valid driver's license. Bill AB 1444 (2017) [145] extended the testing of autonomous vehicles without driver controls. Bill SB 145 (2017) [146] repealed the requirement that the California Department of Motor Vehicles notify the legislature of receipt of an application seeking approval to test an SAE Level 5 autonomous vehicle on public roads.

In 2013 SB 169 [147] established definitions for "automated technology", "automated vehicle" and "automated vehicle operator" in Michigan state law. This law also permitted the testing of automated vehicles under certain conditions and addressed the liability of the vehicle manufacturer. Bill SB 663 [148] limited the liability of automated vehicle manufacturers. Bill SB 998 (2016) [149] exempted mechanics and repair shops from liability for repairing automated vehicles. Bill SB 997 (2016) [150]defined an "automated driving system" and permitted the creation of testing center for automated vehicle technology. Bill SB 995 (2016) [151] expanded the conditions for autonomous vehicle testing and operation and specified a minimum following distance of

500 feet. Bill SB 996 (2016) [152, p. 996] permitted testing of autonomous vehicles without a person in the vehicle.

Florida's HB 1207 (2012) [153] defined "autonomous vehicle" and "autonomous technology" and declared that the state does not prohibit or specifically regulate autonomous technology testing. The bill also authorized persons in possession of a valid driver's license to operate an autonomous vehicle and identified that individual as the operator. Bill HB 7027 (2016) [154, p. 7] expanded operation of autonomous vehicles on public roads by individuals with a valid driver's license and removed the requirement that a driver be present in the vehicle. Bill HB 7061 (2016) [155] further defined "autonomous technology" and "driver-assistive truck platooning technology" and required a study on the latter.

Tennessee's SB 598 (2015) [156] prohibited local governments from banning motor vehicles equipped with autonomous vehicle technology. Bill SB 1561 (2016) [157] redefined "autonomous technology" and defined "driving mode" and "dynamic driving task". Bill SB 2333 (2016) [158] permitted a vehicle to be equipped with an integrated electronic display visible to the operator provided the vehicle's is capable of operating autonomously. Bill SB 676 (2017) [159]permitted the testing of vehicle platooning capabilities on the public roadways. Tennessee's "Automated Vehicle Act" (2017), SB 151 [160], redefined a host of terms related to vehicle automation, preempted local regulation of autonomous vehicles, permitted driverless operation under certain conditions and modified laws related to crash reporting and seat belts.

Accessibility and Existing Laws and Guidelines

The concepts of accessibility and soliciting input from the disabled community in the design of autonomous vehicles are covered in a very limited fashion in existing

Federal and state laws and guidelines. In the *Federal Automated Vehicle Policy* [135] document for instance issues related to disabled persons are briefly mentioned; the word "disabled" specifically appears twice. In the more than 11,000 words of its 2017 replacement [133], "disabled" appears once and the discussion of disabled persons is similarly limited. In both instances, Federal guidance to the states suggests soliciting feedback from representatives of the aging and disabled communities in establishing highway safety guidelines. Neither of these documents makes specific mention of the inclusion of or consideration of disabled persons in the actual design of autonomous technology.

Within the VPGAV, that outlines best practices for the safe design and development of automated vehicles, accessibility is also a largely ignored topic. While the 15-item outline stresses the need for manufacturers to address issues like privacy, vehicle cyber security, ethical considerations and the human-machine interface, no specific mention is made of accessibility.

At the state level, issues around accessibility have also been largely ignored in legislation.

Policy Recommendations

Perhaps the most apparent conclusion that one may draw from a review of federal and state autonomous vehicles guidelines within the context of an accessibility discussion is the apparent absence of any meaningful legislation or guidance related directly to accessibility. It is not simply that accessibility guidance is weak or unenforceable; the guidance is essentially non-existent. This largely laissez faire approach to autonomous vehicle development taken by NHTSA has been championed by proponents in industry [161]. They argue that a voluntary approach that lightly encourages manufacturers to

continuously improve the technology minimizes the likelihood that burdensome regulations might stifle innovation and slow time to market. This approach to regulating the technology may make sense at the state level given that states are responsible for regulating the driver (e.g. vehicle licensing), vehicle registration, traffic laws and enforcement. It is the federal government however that retains the authority to regulate self-driving vehicle technology directly and by failing to directly do so may perhaps inadvertently create conditions that will encourage inaccessibility.

In an attempt to strike a balance between the recognition that: 1) AV technology is still in its infancy, 2) stifling of new technology through regulation is an area of real concern, and 3) there are significant accessibility concerns regarding self-driving vehicles for consumers with a range of disabilities, I propose the following:

- A reintroduction and revision of the Vehicle Performance Guidance for Automated Vehicles;
- The inclusion of a dedicated section on accessibility within *A Vision for Safety* 3.0, anticipated in 2018 [162].

Perhaps an immediate step that can be taken to encourage self-driving vehicle manufacturers to begin directly addressing accessibility is a reintroduction of a revised VPGAV. The original guidance directly addressed the human-machine interface but failed to address general accessibility in a meaningful way. Given that the VPGAV was intended to serve as a collection of best practices, I argue that including accessibility as a topic area may spur greater emphasis on accessibility without regulating any specific technical approach. The reintroduction of the VPGAV could be supported through the inclusion of a dedicated section on accessibility within version 3.0 of the federal AV guidance, *A Vision for Safety*. By NHTSA raising the profile of accessibility through its emphasis in federal guidance, manufacturers, fearful of regulation, might begin to more

directly address the needs and concerns of disabled persons in the development of AV technology. The implied threat of regulation has been used previously to spur technology companies to take action in other industries. Most recently, the threat of legislation has spurred Facebook to address potential political manipulation in its online advertising [163] and Twitter to address “hate speech” on its platform [164].

Notably absent from my policy recommendation is a call for a Section 508-esque (Section 508 of the Rehabilitation Act of 1973 [23]) accessibility law for AV technology. I argue that the technology is currently too immature for such a law and that doing so at this early stage *may*, in unforeseen ways, inhibit the development of the technology. Prior to this research, it could be argued that such a law would be appropriate; one that directly dictated the manner with which the accessibility challenges of disabled persons as it relates to self-driving vehicles should be addressed. I argue that this dissertation demonstrates that there are multiple technical approaches that may be taken to address these accessibility issue and that given the immaturity of the technology a relatively rigid approach may prove burdensome and unwarranted.

CHAPTER 10
CONCLUSION

This dissertation began with formative research that indicated that visually impaired persons had high hopes for the benefits of self-driving vehicles. Participants were particularly optimistic regarding the prospect of increased independence through access to a technology that could, properly implemented, transport them from place to place unaided. Participants were pessimistic regarding the likelihood of the initial accessibility of the technology and were concerned that the technology being developed would be difficult to use or generally inaccessible. These specific concerns were explored in detail in a series of focus groups and through interviews conducted with individuals with a range of vision loss; from moderate low vision to total blindness. The potential to create a more accessible self-driving vehicle for visually impaired users was subsequently explored through a series of participatory design sessions. This design activity culminated with the development of the *Accessible Technology Leveraged for Autonomous vehicles System* or ATLAS. Quasi-naturalistic testing of ATLAS showed that the system was promising satisfying the accessibility and experiential needs of visually impaired users while generally improving their trust in the technology and belief in its potential benefits.

Contributions of this Dissertation

This dissertation has contributed what are arguably the first formal studies of the needs, preferences and concerns of visually impaired consumers regarding self-driving vehicles. It has collectively explored questions of accessibility regarding a potentially life changing technology that have previously remained unexplored within the existing scientific literature.

In the study described in Chapter 3, visually impaired respondents were asked to provide their general opinions regarding self-driving vehicles, their concerns, their

willingness to pay for this technology and their opinions regarding key issues related to visual impairment and blindness. My findings suggest that while the opinions and concerns of blind and visually impaired consumers may broadly parallel the opinions and concerns of consumers generally, there are key differences that may impact how these consumers approach and interact with this technology. This research has contributed what is arguably the first formal survey of the sentiment of visually impaired consumers regarding L5 self-driving vehicle technology and has been accepted for publication in the *Journal of Technology and Persons with Disabilities* in 2018.

The study discussed in Chapter 4 was designed to more deeply explore the issues uncovered through the online survey. Focus group participants were asked to comment on their general opinions regarding self-driving vehicles conceptually, their hopes for the technology, their major concerns, and their preferences regarding modes of interaction, among other topics. My findings suggest that blind and low vision consumers may view self-driving vehicles more favorably than consumers generally but have questions about their ability to effectively interact with and control the technology. This research has contributed what is arguably the first published focus group study of visually impaired consumers regarding self-driving vehicles and has been been published in the proceedings of the ACM SIGACCESS Conference on Computers and Accessibility [165].

The persona creation process described in Chapter 5 was intended to formalize a method of constructing personas with disabilities for use as a methodological tool to inform the design of accessible automotive systems. While the literature on persona creation is vast, there is little existing literature that demonstrates a practical process for constructing domain-specific personas with disabilities. Chapter 5 is effectively a

demonstration of applied user-centered design that may ultimately aide practitioners in the development of accessible automotive technologies. This research has been accepted for publication in the proceedings of the 9th Applied Human Factors and Ergonomics International Conference in 2018.

The design and implementation of the ATLAS system, described in chapters 6 and 7, demonstrates the use of participatory design in the development of a system designed for accessibility and serves as a practical demonstration of the use of persona as a methodological tool. The research is the first demonstration of the use of a persona driven participatory design process in the development of an accessible automotive technology for visually impaired persons and is an invited submission to a special issue of the journal *ACM Transactions on Accessible Computing (TACCESS)*.

The quasi-naturalistic study of the ATLAS system, described in Chapter 8, is one of the few but growing formal studies that has investigated the user experience in self-driving vehicles. My research is differentiated from the related research however in its focus on operators with visual impairments. My findings suggest that the features implemented within the ATLAS system are promising in terms of their ability to satisfy the experiential needs of visually impaired self-driving vehicle operators. My findings further suggest that interaction with even a simulated self-driving vehicle under real world conditions may ameliorate concerns regarding the use of such technology. These findings are significant given the unexplored nature of this issue in the scientific literature. The research described in Chapter 8 is currently under review for publication in a special issue of the *International Journal of Human-Computer Interaction.*

Future Work

While this dissertation has included foundational research on self-driving vehicles and persons with visual impairments, the topic of self-driving vehicle accessibility is broad and requires much additional research. Given that the user study of the derived system occurred in a simulated self-driving vehicle, additional research would be helpful in supporting the ecological validity of the study's findings. A logical next step in that regard would be a study of the system in an actual self-driving vehicle under naturalistic conditions. Satisfying operators' accessibility needs in this context will require more than simply satisfying the experiential needs of visually impaired persons. Those with hearing loss, physical and cognitive disabilities are also likely consumers of self-driving vehicles and may face challenges that have been unexplored by the current dissertation. My future research will investigate accessibility from the perspective of operators with a variety of disabilities with the goal of arriving at a set of features that will support the goal of a universally accessible self-driving vehicle.

Final Remarks

This dissertation documents my investigation of the needs, preferences, and concerns of visually impaired persons regarding self-driving vehicles. In presenting this research, this dissertation has attempted to demonstrate the following thesis:

> An accessible self-driving vehicle human-machine interface, designed to support the spatial abilities of visually impaired persons, can enable visually impaired operators to effectively interact with and control self-driving vehicles.

Given that true self-driving vehicle technology is still in its infancy, the technological landscape of this technology has changed considerably during the course of this research. As the technology rushes towards its apparently inevitable commercial availability it will likely continue to evolve further and at an increasing pace.

Unaddressed, the problems that visually impaired persons face regarding this technology will become increasingly apparent as self-driving vehicles make their way into the hands of consumers. What this research demonstrates, however, is promosing solutions to these challenges may be developed through the use of user-centered design.

APPENDIX A
ONLINE SURVEY OF VISUALLY IMPAIRED CONSUMERS

Survey questions adapted from Schoettle and Sivak (2014)

Opinions Concerning Autonomous and Self-Driving Vehicles

We are conducting a survey of opinions about autonomous and self-driving vehicles. A general explanation of what is meant by autonomous and self-driving vehicles will be shown on the next page. Please take a moment to read that description carefully before continuing with the survey.

Autonomous vehicles are those in which at least some aspects of a safety-critical control (such as steering, throttle, or braking) operate without direct driver input. Vehicles that provide safety warnings to drivers (for example, a forward-crash warning) but do not take control of the vehicle are not considered autonomous.

Autonomous vehicles may use on-board sensors, cameras, GPS, and telecommunications to obtain information in order to make decisions regarding safety-critical situations and act appropriately by taking control of the vehicle at some level. Examples of autonomous-vehicle technologies range from those that take care of basic functions such as cruise control, to completely self-driving vehicles with no human driver required.

1) Had you ever heard of autonomous and/or self-driving vehicles before participating in this survey?
    a) Yes
    b) No
2) What is your general opinion regarding autonomous and self-driving vehicles? *Even if you had never heard of autonomous or self-driving vehicles before participating in this survey, please give us your opinion based on the description you just heard.*
    a) Very positive
    b) Somewhat positive
    c) Neutral
    d) Somewhat negative
    e) Very negative
3) How concerned would you be about riding in a vehicle that is fully autonomous as the primary operator? A fully autonomous vehicle is one that takes complete control of all critical driving functions for the entire trip and monitors the roadway.
    a) Very concerned
    b) Moderately concerned
    c) Slightly concerned
    d) Not at all concerned
4) How concerned would you be about riding in a vehicle that is partially autonomous as the primary operator? A partially autonomous vehicle takes complete control of all critical driving functions under certain conditions but requires the driver to take control as needed.

a) Very concerned
b) Moderately concerned
c) Slightly concerned
d) Not at all concerned

5) How concerned would you be about your ability to operate a self-driving car if one was made available to you?
    a) Very concerned
    b) Moderately concerned
    c) Slightly concerned
    d) Not at all concerned

How likely do you think it is that the following benefits will occur when using completely self-driving vehicles?

6) Fewer crashes
    a) Very likely
    b) Somewhat likely
    c) Somewhat unlikely
    d) Very unlikely
7) Reduced Severity of Crashes
    a) Very likely
    b) Somewhat likely
    c) Somewhat unlikely
    d) Very unlikely
8) Improved emergency response to crashes
    a) Very likely
    b) Somewhat likely
    c) Somewhat unlikely
    d) Very unlikely
9) Less traffic congestion
    a) Very likely
    b) Somewhat likely
    c) Somewhat unlikely
    d) Very unlikely
10) Shorter travel time
    a) Very likely
    b) Somewhat likely
    c) Somewhat unlikely
    d) Very unlikely
11) Lower vehicle emissions
    a) Very likely
    b) Somewhat likely

c) Somewhat unlikely
d) Very unlikely

12) Better fuel economy
a) Very likely
b) Somewhat likely
c) Somewhat unlikely
d) Very unlikely

13) Lower insurance rates
a) Very likely
b) Somewhat likely
c) Somewhat unlikely
d) Very unlikely

How concerned are you about the following issues related to completely self-driving vehicles (Level 4)?

14) Safety consequence of equipment failure or system failure
a) Very concerned
b) Moderately concerned
c) Slightly concerned
d) Not at all concerned

15) Legal liability for drivers or owners
a) Very concerned
b) Moderately concerned
c) Slightly concerned
d) Not at all concerned

16) System security (from hackers)
a) Very concerned
b) Moderately concerned
c) Slightly concerned
d) Not at all concerned

17) Data privacy (location and destination tracking)
a) Very concerned
b) Moderately concerned
c) Slightly concerned
d) Not at all concerned

18) Interacting with non self-driving vehicles
a) Very concerned
b) Moderately concerned
c) Slightly concerned
d) Not at all concerned

19) Interacting with pedestrians and bicycles
a) Very concerned
b) Moderately concerned
c) Slightly concerned

27) Public transportation such as buses that are completely self-driving
    a) Very concerned
    b) Moderately concerned
    c) Slightly concerned
    d) Not at all concerned
28) Taxis that are completely self-driving
    a) Very concerned
    b) Moderately concerned
    c) Slightly concerned
    d) Not at all concerned

New Question:

29) How interested would you be in having a completely self-driving vehicle (Level 4) as the vehicle you own or lease?
    a) Very interested
    b) Moderately interested
    c) Slightly interested
    d) Not at all interested
30) How much EXTRA would you be willing to pay to have completely self-driving technology (Level 4) on a vehicle you own or lease in the future? *Please enter 0 if you would not be willing to pay extra for this technology.*
    a) Textbox for data entry
31) If you were to ride in a completely self-driving vehicle (Level 4), what do you think you would use the extra time doing instead of driving? Please select one response only.
    a) Text or talk with friends/family
    b) Read
    c) Sleep
    d) Watch movies/TV
    e) Play games
    f) Work
    g) Watch the road even though I would not be driving
    h) I would not ride in a completely self-driving vehicle
    i) Other (please specify): ___________________

Now we would like to know some basic background information about you.

32) What is your gender?
    a) Male
    b) Female
    c) Other
33) What is your age?
    a) 18 to 24

b) 25 to 29
c) 30 to 34
d) 35 to 39
e) 40 to 44
f) 45 to 49
g) 50 to 54
h) 55 to 59
i) 60 to 64
j) 65 to 69
k) 70 or older

34) What is the highest level of education you have completed?
a) Some High School
b) High School
c) Some College
d) Associate's Degree
e) Bachelor degree
f) Graduate degree

35) What is your current level of employment?
a) Employed full-time
b) Employed part-time
c) Not currently employed
d) Retired
e) Full-time student
f) Part-time student

36) What kind of vehicle do you drive or ride in most often?
a) Passenger car (any type or size)
b) Minivan / van / MPV (multipurpose vehicle)
c) Pickup truck
d) SUV (sport utility vehicle)
e) Motorcycle / scooter
f) Public transportation

37) How would you best describe the length of time that you have been blind?
a) All of my life
b) Most of my life
c) I recently became blind

38) As a person who is blind or visually impaired do you agree that your needs are being considered in the development of self-driving cars?
a) Strongly Agree
b) Moderately Agree
c) Neither agree or disagree
d) Moderately Disagree
e) Strongly Disagree

d) Not at all concerned

20) Learning to use self-driving vehicles
    a) Very concerned
    b) Moderately concerned
    c) Slightly concerned
    d) Not at all concerned
21) System performance in poor weather
    a) Very concerned
    b) Moderately concerned
    c) Slightly concerned
    d) Not at all concerned
22) Self driving vehicles getting confused by unexpected situation
    a) Very concerned
    b) Moderately concerned
    c) Slightly concerned
    d) Not at all concerned
23) Self driving vehicles not driving as well as human drivers in general
    a) Very concerned
    b) Moderately concerned
    c) Slightly concerned
    d) Not at all concerned

New Question:

How concerned are you about the following possible scenarios with completely self-driving vehicles (Level 4)?

24) Riding in a vehicle with no driver controls available (no steering wheel, no brake pedal, and no gas pedal/accelerator)
    a) Very concerned
    b) Moderately concerned
    c) Slightly concerned
    d) Not at all concerned
25) Self-driving vehicles moving by themselves from one location to another while unoccupied
    a) Very concerned
    b) Moderately concerned
    c) Slightly concerned
    d) Not at all concerned
26) Commercial vehicles such as heavy trucks or semitrailer trucks
    a) Very concerned
    b) Moderately concerned
    c) Slightly concerned
    d) Not at all concerned

39) How concerned are you about the prospect of laws being put in place to prevent people who are blind from operating self-driving cars?
    a) Very concerned
    b) Moderately concerned
    c) Slightly concerned
    d) Not at all concerned

Thank you for completing this survey about autonomous and self-driving vehicles!

APPENDIX B
FOCUS GROUP GUIDE

Focus Group Questions

Opinions Concerning Autonomous and Self-Driving Vehicles

We are conducting a focus group to gauge opinions about autonomous and self-driving vehicles. Autonomous vehicles are those in which at least some aspects of a safety-critical control (such as steering, throttle, or braking) operate without direct driver input. Vehicles that provide safety warnings to drivers (for example, a forward-crash warning) but do not take control of the vehicle are not considered autonomous.

Autonomous vehicles may use on-board sensors, cameras, GPS, and telecommunications to obtain information in order to make decisions regarding safety-critical situations and act appropriately by taking control of the vehicle at some level. Examples of autonomous-vehicle technologies range from those that take care of basic functions such as cruise control, to completely self-driving vehicles with no human driver required.

1. By show of hands how many of you have heard of autonomous vehicles or self driving cars?
2. Do you think you have a good understanding of what is meant by an autonomous vehicle or self driving car? What does the term autonomous vehicle mean to you?
3. Are there any features of autonomous vehicles as you understand them that you like?
4. What are the potential benefits of autonomous vehicles that you see?
5. Are there any features of autonomous vehicle that you dislike?
6. What are the potential pitfalls or downsides of autonomous vehicles as you see them?
7. Which features come to mind when you think about driving safety? Does the concept of an autonomous vehicle make you feel safe?
8. Are you concerned about the prospect of laws being put in place to prevent people who are blind from operating autonomous vehicles?
9. How would you describe your concerns about system security (e.g. from hackers) when thinking about autonomous vehicles?
10. Are there privacy issues that concern you with autonomous vehicles?
11. How concerned would you be about your ability to operate an autonomous vehicle if one was made available to you?
12. If you were able to purchase an autonomous vehicle tomorrow what types of things would you consider important in making a buying decision?
13. What do you think would be important for you to know before buying an autonomous vehicle?
14. How concerned about your ability to takeover control and drive an autonomous vehicle if something went wrong?

15. At some point while riding in an autonomous vehicle the vehicle may have to choose between a movement that may cause a potentially fatal accident (i.e. running into a tree) or hitting a pedestrian or animal. What do you think the vehicle should do and why?
16. Have we missed anyone's questions or forgotten to hear anyone's response?
17. Is there anything else that we should discuss?

APPENDIX C
SCENARIO TEMPLATE

1. Set the stage and introduce the product:

2. What is _______________ (the character) primary need from the self-driving vehicle?

3. The narrative for the primary need is:

4. What are ____________ (the character) needs from the human-machine interface?

5. The narrative from user needs is:

6. Conclude with a positive impact of the self-driving vehicle and HMI on the user's overall experience.

7. The complete scenario is:

APPENDIX D
CHARACTER INTRODUCTION VOICE SCRIPT FOR THE CASSIE PERSONA

"Hi, I'm Cassie. I'm a 24-year-old second year grad student in the Mass Communications department at the University of Florida. I live a pretty active lifestyle. I love art and music and I try to attend as many art shows and music events around town as I can. I find out about a lot of them at the last minute on social media. Most days I stop at my local coffee shop in the afternoons with one of my roommates to study. I also like to exercise; I take long walks through my neighborhood a few times a week while listening to music on my iPhone."

"My vision sometimes makes things hard for me but I manage. I have a form of retinitis pigmentosa that has affected the vision in both of my eyes since I was born. I'm really nearsighted, so I so use screen magnification that makes things larger when I use the computer. I also use the accessibility features on my iPhone."

"I commute to campus five days out of the week from my apartment. Sometimes I can get a ride from one of my roommates, they both have cars, but they have different schedules so I can't count on that. Normally I wait near the gate of my apartment complex for the bus, even if it's raining or it's really hot. I don't mind the bus. I see some of the same people and we talk sometimes, and riding the bus makes me feel like I'm helping the environment. But I'm pretty busy and the bus just isn't very fast or flexible. If I hear about a show at the last minute or if one of my friends wants to meet up, sometimes it's hard for me to get there since I can't drive a car. If I need to stop and pick something up from the store on the way home from campus I can't because the grocery store isn't on the bus route."

"I don't like asking my friends and classmates for rides all the time; sometimes they're unreliable. Missing a show or not being able to hang out isn't that big of a deal, but I've missed doctor's appointments and job interviews before because I was waiting for someone who was late picking me up or who promised and still forgot to drop me off. Because I can't legally drive public transportation is my only reliable and inexpensive option right now."

APPENDIX E
WIZARD OF OZ SCRIPT FOR LOW VISION GROUP 18-35

S = SYSTEM U = USER

Drive:

- U: Take me to the Oakmont mall and drop me off at JC Penny
- S: Ok, you want me to take you to the Oakmont mall in Gainesville, Florida. Is that correct?
- U: Yes
- S: Ok, the Oakmont mall is 5 miles away and it will take about 15 minutes to get there in normal traffic.

In transit

(Every minute - does this automatically)

- S: We are at the intersection of [street] and [street]. We will be passing [store] on the right in .5 miles.

(Does this when user asks)

- U: Where are we now? / What street are we on
- S: We are at the intersection of [street] and [street]. We will be passing [store] on the right in .5 miles.

Arrival:

- S: We have arrived at the Oakmont mall and we're at JC Penny's.
- U: Which direction do I walk in. / Tell me where the front door is / How many feet to the front door.
- S: When you get out of the car walk straight ahead. The door will be right in front of you. The door is 300 feet away from the vehicle.

(if user wants a description of outside environment)

- U: Describe what's outside to me / Tell me what other stores are around me
- S: [improvise]

Return

(Specialized key fob that has a button that lets you talk to the car)

- U: I'm finished shopping. Pick me up at the front door.
- S: I have arrived near the front door. I am 50 feet away to your left. (the key fob beeps as the user gets closer)

APPENDIX F
REVISED WIZARD OF OZ SCRIPT FOR LOW VISION GROUP 18-35

S = SYSTEM U = USER

Drive:

- U: Take me to the Oakmont mall and drop me off at JC Penny
- S: Ok, you want me to take you to the Oakmont mall in Gainesville, Florida. Is that correct?
- U: No
- S: I'm sorry I misunderstood, where do you want to go? You can say the place name or an address.
- U: Take me to the Oakmont mall and drop me off at JC Penny
- S: Ok, the Oakmont mall is 5 miles away and it will take about 15 minutes to get there in normal traffic.

In transit

(Every minute - does this automatically)

- S: We are traveling east on [improvise street] at the posted speed of 35 miles per hour. We will be passing [store] on the right in .5 miles. Traffic is light to moderate. Anticipated arrival in five minutes.

(Does this when user asks)

- U: Where are we now? / What street are we on
- S: We are at the intersection of [street] and [street]. We will be passing [point of interest] on the left in a quarter mile.

Arrival:

- S: We have arrived at the Oakmont mall and we are at JC Penny's. The weather is 72 degrees and sunny. The door is 300 feet away from the vehicle. I am sending walking directions to the entrance to your phone. Would you like me to park myself or wait here?
- U: Park yourself.
- S: OK, I will park myself. Press the return button on the key when you would like me to pick you up.

(if user wants a description of outside environment)

- U: Describe what's outside to me / Tell me what other stores are around me
- S: [improvise]

Return

(Specialized key fob that has a button that lets you talk to the car)

- U: I'm finished shopping. Pick me up at the front door.
- S: I have arrived near the front door. I am 50 feet away to your left. (the key fob beeps as the user gets closer)

APPENDIX G
CHARACTER INTRODUCTION VOICE SCRIPT FOR THE WALTER PERSONA

“Hello, I’m Walter. I’m a married, 48 year old father of three beautiful daughters. I’ve worked for seven years as a columnist and editor for an online financial magazine specializing in news about the technology industry. Before that, I worked for about 10 years in the financial services industry. Before *that* I was a student at the University of Maryland where I completed a bachelor’s degree in business. Outside of my job and my family I’m passionate about two things; sports and technology. I’m a big follower of my hometown Baltimore Orioles and I follow everything that has to do with science and technology. On most mornings before work I check out the sports scores and the latest tech trends on my iPhone while having my first of many cups of coffee for the day.”

“I’ve been blind since I was born so I can’t drive. I can sometimes recognize when a light is on in a room or when it’s light or dark out but I don’t have usable vision. My wife’s great. She would happily drop me off wherever I need to go, and she often does, but between getting the kids off to school and where we live it just wouldn’t make sense for her to drop me off at work. I work downtown, so for the past seven years I’ve been riding the bus an hour and a half into the city in the morning and an hour and a half back in the evenings. Don’t get me wrong, I appreciate that there’s a bus available, I don’t know how I would get to work without it, but I miss out on a lot because I can’t drive.”

“A few years ago I was offered a job as a reporter for a high-profile news website. I had to turn it down though when I found out I would have to provide my own transportation to interviews. That was bad, but it’s nothing compared to how I feel about the family time that I miss being stuck on a bus three hours a day. Those are hours that I miss being with my wife and my daughters. I’ve looked at other options, but we don’t make enough money to where using an Uber every day or hiring a private car service would make sense.”

“In most other aspects of my life I feel that technology has helped me to overcome the challenges that come with being blind. Using screen readers I can access most things online now without a problem, with my smartphone and apps walking around and doing most things isn’t a huge obstacle anymore. Transportation is one of the last big hurdles for me.”

APPENDIX H
WIZARD OF OZ SCRIPT FOR BLIND GROUP 18-54

S = SYSTEM U = USER

Drive:

- U: Atlas, take me to the Elsworth place mall. / Take me to the front door of the Elsworth place mall. / Take me to the Elsworth place mall, the entrance near the sports store / Can I have directions to the Elsworth place mall. / Atlas, take me to the Elsworth place mall in Baltimore, Maryland.
- S: Ok, you want me to take you to the Elsworth place in Baltimore, MD. / Which Elsworth place mall? The one in Baltimore Maryland?
- U: Yes
- S: Ok, I'll drive there now.

In transit

(Every minute **-** does this automatically)

- S: We are at the intersection of [street] and [street]. We will be passing [store] on the right in .5 miles.

(If it has to make an emergency maneuver)

- S: I'm sorry. I just had to make an emergency braking maneuver. A pedestrian walked into the street. / A car stopped abruptly.

(Does this when user asks)

- U: What is my location? / Where are we? / How close am I to [destination]
- S: We are at the intersection of [street] and [street]. We will be passing [store] on the right in .5 miles.

- U: How close am I to [destination]
- S: We are 1.5 miles away from the [destination] and we will be there in [minutes] in normal traffic

Arrival:

(probably want to use the smart key fob)

- S: We have arrived at the [destination].
- U: Could you give me directions to where the front door is?
- S: When you get out of the car walk straight ahead. The door will be right in front of you. The door is 300 feet away from the vehicle. The key fob will guide you to the front door.
- S: Would you like directions sent to your smartphone?

Parking

- U: Find a handicap parking space.
- S: There are no handicap parking spaces available. Would you like me to park in the closest parking space?
- U: Yes

(if user wants a description of outside environment)

- U: Can you describe my surroundings / Can you tell me where my location is
- S: [Vehicle describes what is looks like outside]

APPENDIX I
REVISED WIZARD OF OZ SCRIPT FOR BLIND GROUP 18-54

S = SYSTEM U = USER

Drive:

- U: Atlas, take me to the Elsworth place mall. / Take me to the front door of the Elsworth place mall. / Take me to the Elsworth place mall, the entrance near the sports store / Can I have directions to the Elsworth place mall. / Atlas, take me to the Elsworth place mall in Baltimore, Maryland.
- S: Ok, you want me to take you to the Elsworth place in Baltimore, MD. / Which Elsworth place mall? The one in Baltimore Maryland?
- U: Yes
- S: Ok, I'll drive there now.

In transit

(Every minute - does this automatically)

- S: We are heading on [street name], passing [point of interest] in [some distance]. Light vehicular traffic in both directions, no accidents reported for the next two miles. Light pedestrian traffic to your right.

(If it has to make an emergency maneuver)

- S: I'm sorry. I just had to make an emergency braking maneuver. A pedestrian walked into the street. / A car stopped abruptly.

(Does this when user asks)

- U: What is my location? / Where are we? / How close am I to [destination]
- S: We are at the intersection of [street] and [street]. We will be passing [store] on the right in .5 miles.

- U: How close am I to [destination]
- S: We are 1.5 miles away from the [destination] and we will be there in [minutes] in normal traffic

Arrival:

(probably want to use the smart key fob)

- S: We have arrived at the [destination]. The weather is 72 degrees and sunny. I observe cars, trees, a parking lot and a few vehicles. People are walking to your right. I have sent walking directions to the entrance of your final destination. Would you like me to park myself or hover?
- U: Park yourself

Parking

- U: Find a handicap parking space.
- S: There are no handicap parking spaces available. Would you like me to park in the closest parking space?
- U: Yes

(if user wants a description of outside environment)

- U: Can you describe my surroundings / Can you tell me where my location is
- S: [Vehicle describes what is looks like outside]

Miscellaneous

- U: What time is it?
- S: The current time is [give current time].

- U: What is the weather outside?
- S: It is 98 degrees outside and sunny.

- U: Is it raining outside?
- S: No, it is 98 degrees outside and sunny and there is a zero percent chance of rain

- U: How much gas is in the tanks?
- S: You have 100 miles worth of fuel

- U: Find the nearest or the cheapest gas station.

APPENDIX J
CHARACTER INTRODUCTION VOICE SCRIPT FOR THE HANNAH PERSONA

"Hi I'm Hannah. I'm 72 year's young, I'm retired and a grandmother. I start most days on the front porch where I drink my coffee. We live in a quiet neighborhood, me, my daughter and my granddaughter and I like the fresh air and the sounds in the morning as everyone heads off to work and to school. I've been retired for about twenty years and I've spent most of that time doing volunteer work at my church and at the community center."

"I'm not very good with computers but I do have a smartphone that I use a lot. Mostly I use it to listen to the news and to listen to audiobooks at night when I'm getting ready for bed. When I use a computer I use it with a screen reader but I like my smartphone better because I can talk to it."

"I use to travel a lot but that slowed down for me about eight years ago when my husband passed away. I have a retinal disease that has gotten worse over the years and now I'm legally blind. I can only see motions and bright lights now."

"Since my husband passed away, he could drive, getting around has gotten pretty difficult. My daughter works two jobs and she just doesn't have time to take me places. My granddaughter is only 14 so she can't drive yet. Where we live isn't on the bus route and you have to call a day before to schedule a trip on the shuttle. I take the shuttle when I can but a lot of times things come up at the last minute so takin' the shuttle isn't always possible. I have friends who don't mind giving me rides but I don't like asking people to make a special trip out here just to take me to the store. Most of the time I would rather wait until my daughter can take me. I feel more comfortable that way. I've missed quite a few doctor's appointments because I didn't have transportation and most of the time when they call me to reschedule I can't get there fast enough."

APPENDIX K
WIZARD OF OZ SCRIPT FOR BLIND GROUP 55+

S = SYSTEM U = USER

Drive:

- U: I have to go to Chesapeake General Hospital /
- U: Yes
- S: Ok, I'll drive there now.

- U: Take me to Chesapeake General Hospital at [address] or [city,state]. Take me to the emergency room entrance. Drop me off at the emergency room entrance. Go park yourself afterwards / You can leave after dropping me off.
- S: Ok, I will take you to Chesapeake General Hospital on [street address], [city, state]. Is that correct?
- U: Yes

In transit

(Every minute - 5 minutes - does this automatically)

- S: We are at the intersection of [street] and [street]. We will be passing [store] on the right in .5 miles.
- S: It's 98 degrees and sunny outside and the current weather is clear.
- S: The current traffic is clear (traffic conditions, accidents, etc.)

(If it has to make an emergency maneuver)

- S: I'm sorry. I just had to make an emergency braking maneuver. A pedestrian walked into the street. / A car stopped abruptly.

(Does this when user asks)

- U: Where am I / What is my location? / Where are we? / How close am I to [destination]
- S: We are at the intersection of [street] and [street]. We will be passing [store] on the right in .5 miles.

- U: Are we there yet? / Mileage and location please? / ETA / How close am I to [destination]
- S: We are 1.5 miles away from the [destination] and we will be there in [minutes] in normal traffic

Arrival:

(probably want to use the smart key fob)

- S: We have arrived at the [destination].
- U: Take me to the emergency room entrance (specify which entrance you want to go to)
- S: We have arrived at the emergency room entrance.
- U: Thank you. Please park in the closest available parking space / continue to your next destination

Miscellaneous Commands

U: What color are you?
S: [improvise]

U: Describe yourself?
S: I’m a 2020 Volvo XC90

U: Describe your features.
S: [improvise]

U: Describe your convenience controls.
S: [improvise]

U: Put my window down for me.
S: Ok, I am lowering the windows now

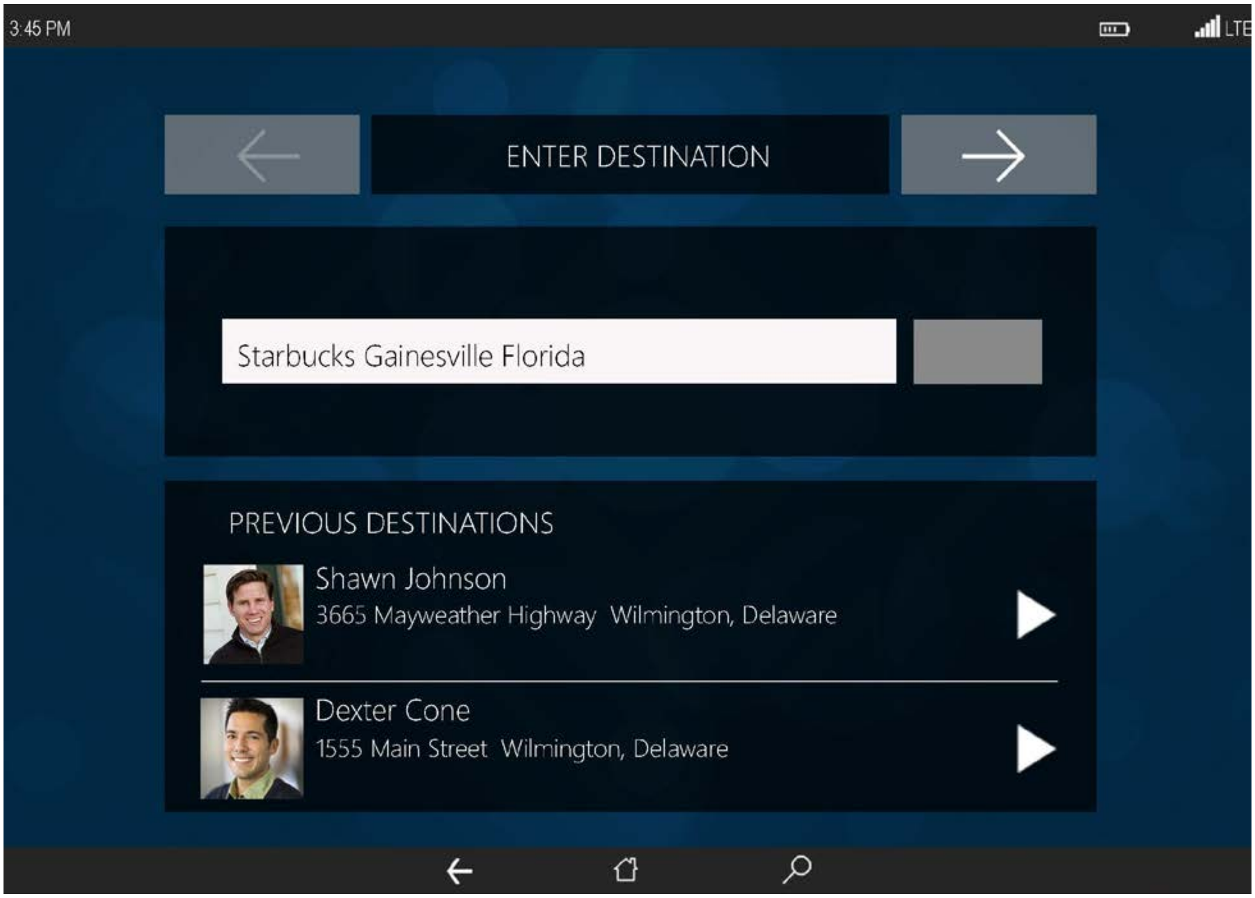
U: It’s too cold, make it warmer.
S: Ok, I am raising the temperature

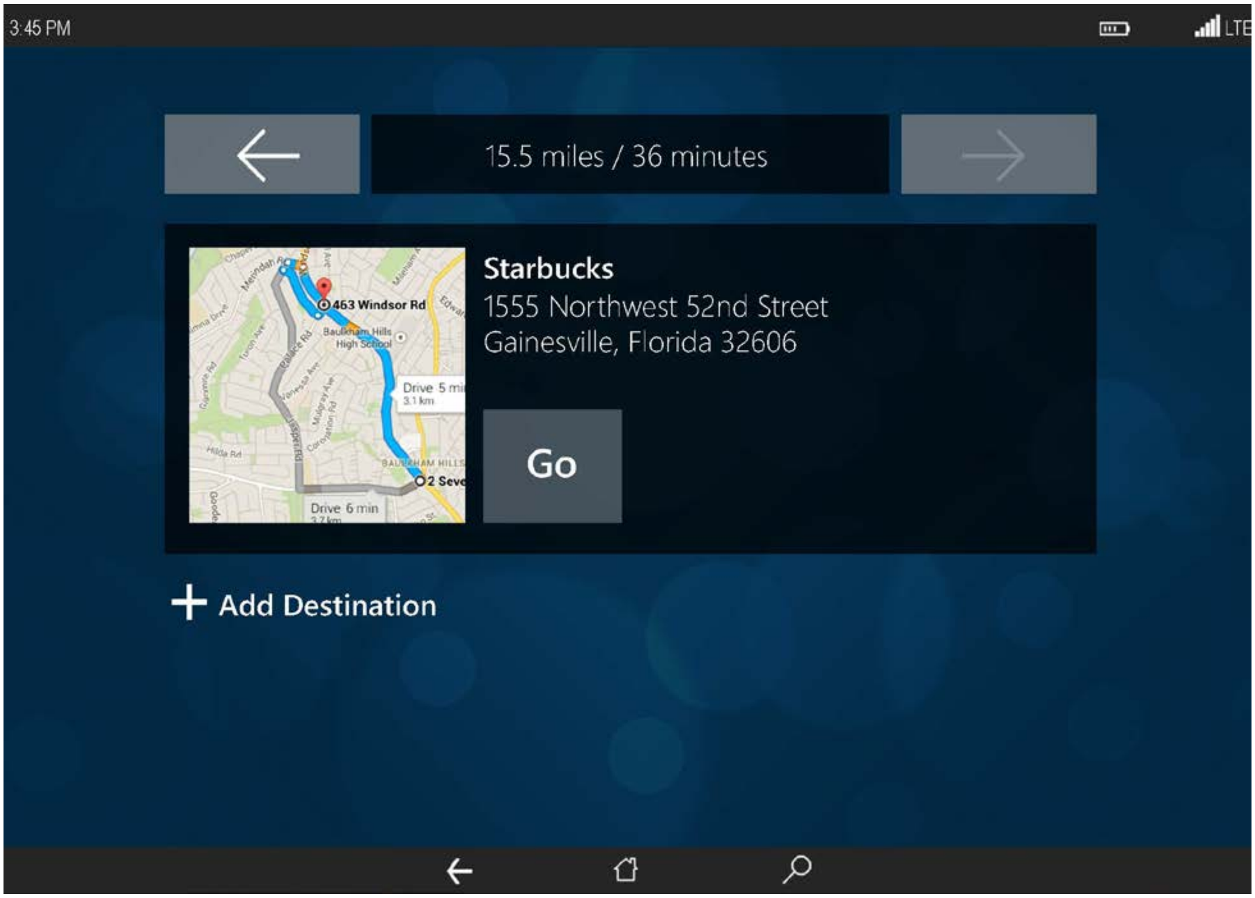
APPENDIX L
ATLAS TUTORIAL DIALOGUE

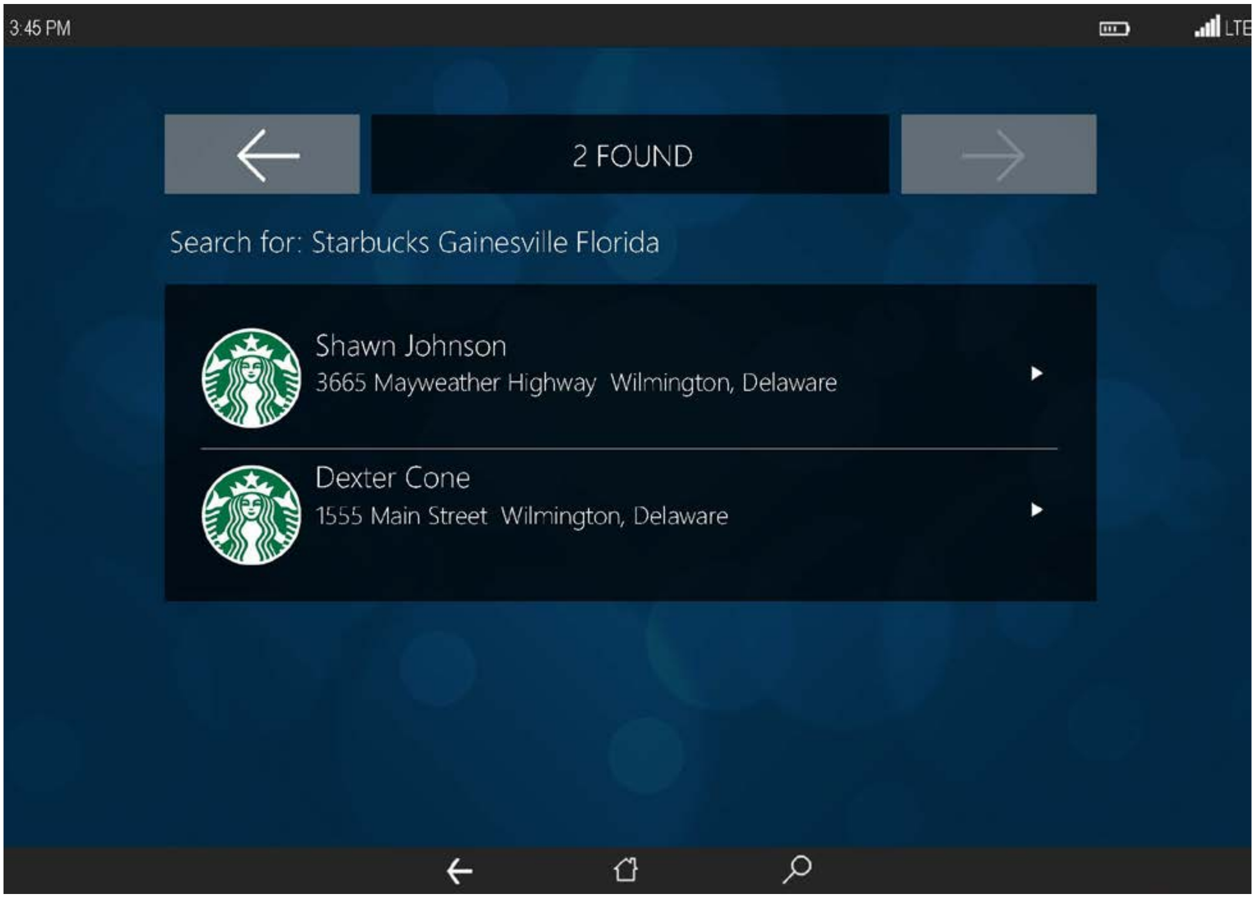
S = SYSTEM U = USER

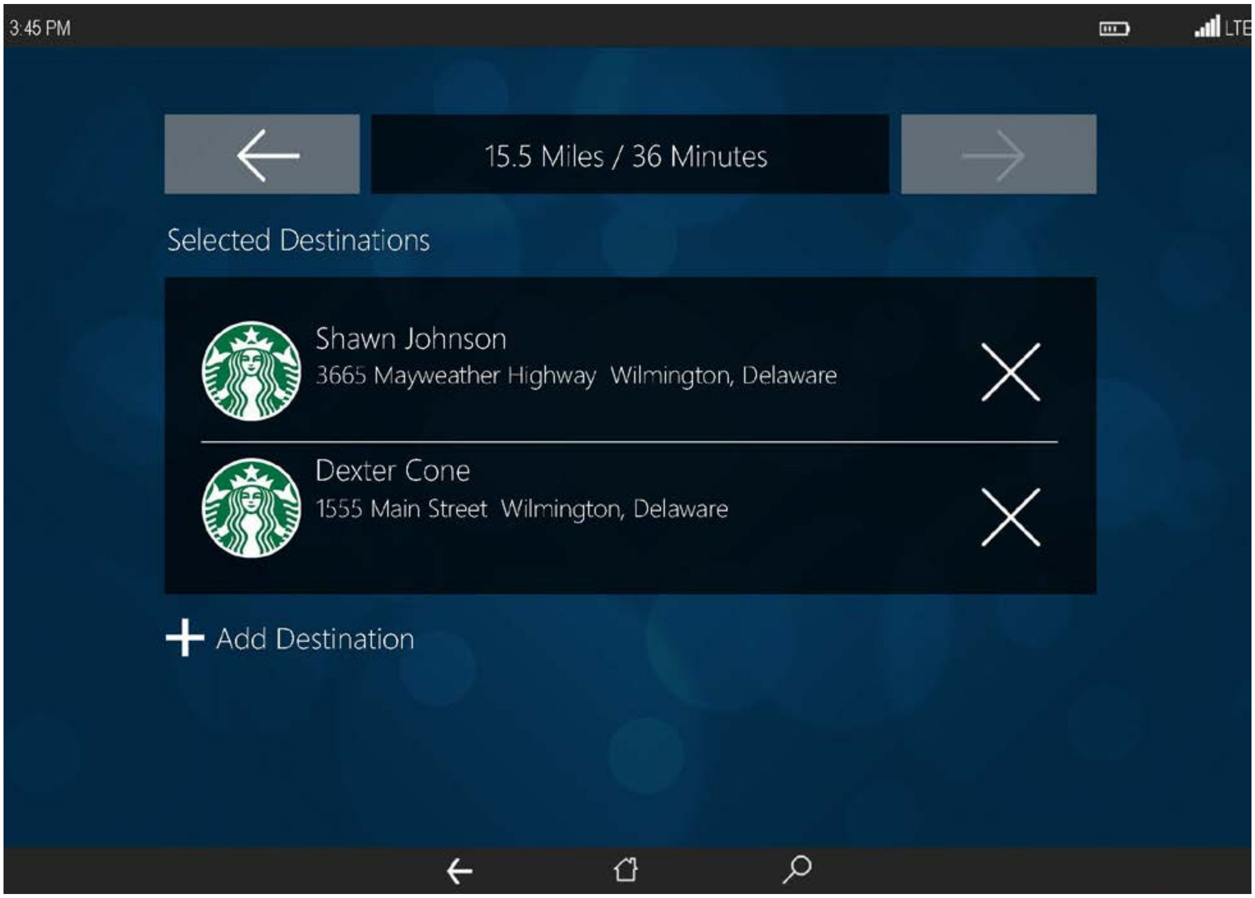
S: “Hello I’m ATLAS. I am here to help you with anything that you need while using this vehicle. With my help you can control most vehicle systems using just your voice. Let’s review the basics. Whenever you want me to do something just say my name, ATLAS, followed by your request. If I ask you a question and need a response I will play this sound…”
S: *beep*
S: “Please speak your response clearly after the beep. Let’s practice. After the beep, say ‘ATLAS what time is it?’”
U: “Atlas, what time is it?”
S: “Good job. The current time is [system time].”
S: “There are certain things that you can say without saying my name first. If you need help just say ‘Help’ and I will respond. If you have an emergency just say ‘Emergency’ to get my attention. Now let’s review vehicle control. To start a trip you can say ‘ATLAS, drive’. You can stop the vehicle at any time by saying ‘ATLAS, stop’. I will pull over as soon as it is safe to do so. When we arrive at your destination I will stop as close to the building as possible. If possible I will send walking directions to the entrance of your destination to any nearby mobile device. I can also park myself and will provide you with instructions on how to summon me when you are ready to leave. Those are the basics. I will provide additional tips and information as you begin to use the system. If you think you understand the basics, after the beep, say ‘I understand’. If you would like me to repeat the instructions, after the beep say, ‘repeat’”
U: “I understand.”
S: “Ok, I will standby for further instructions. Say ‘ATLAS, drive’ at any time to set a destination or press the drive button.”

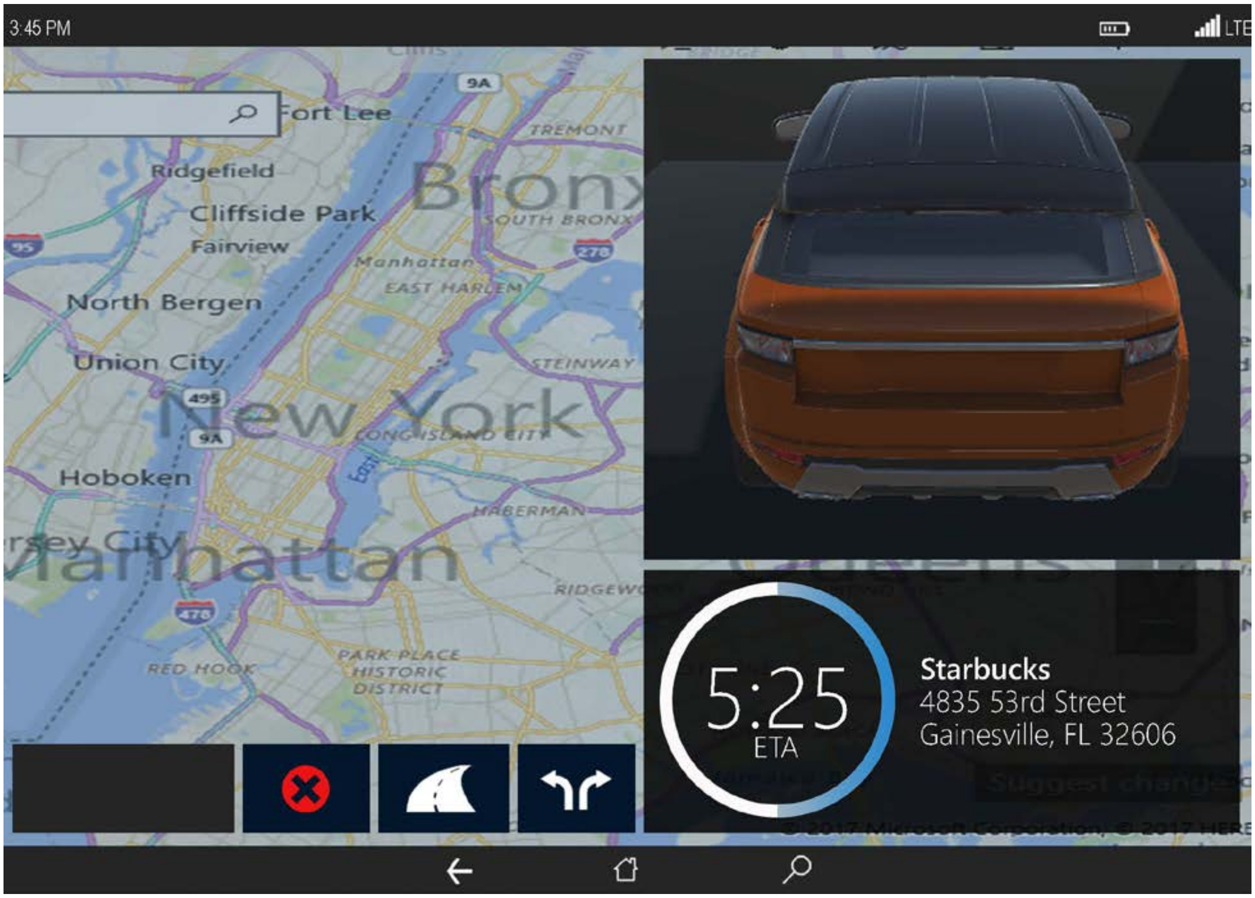
APPENDIX M
ATLAS USER INTERFACE MOCKUPS



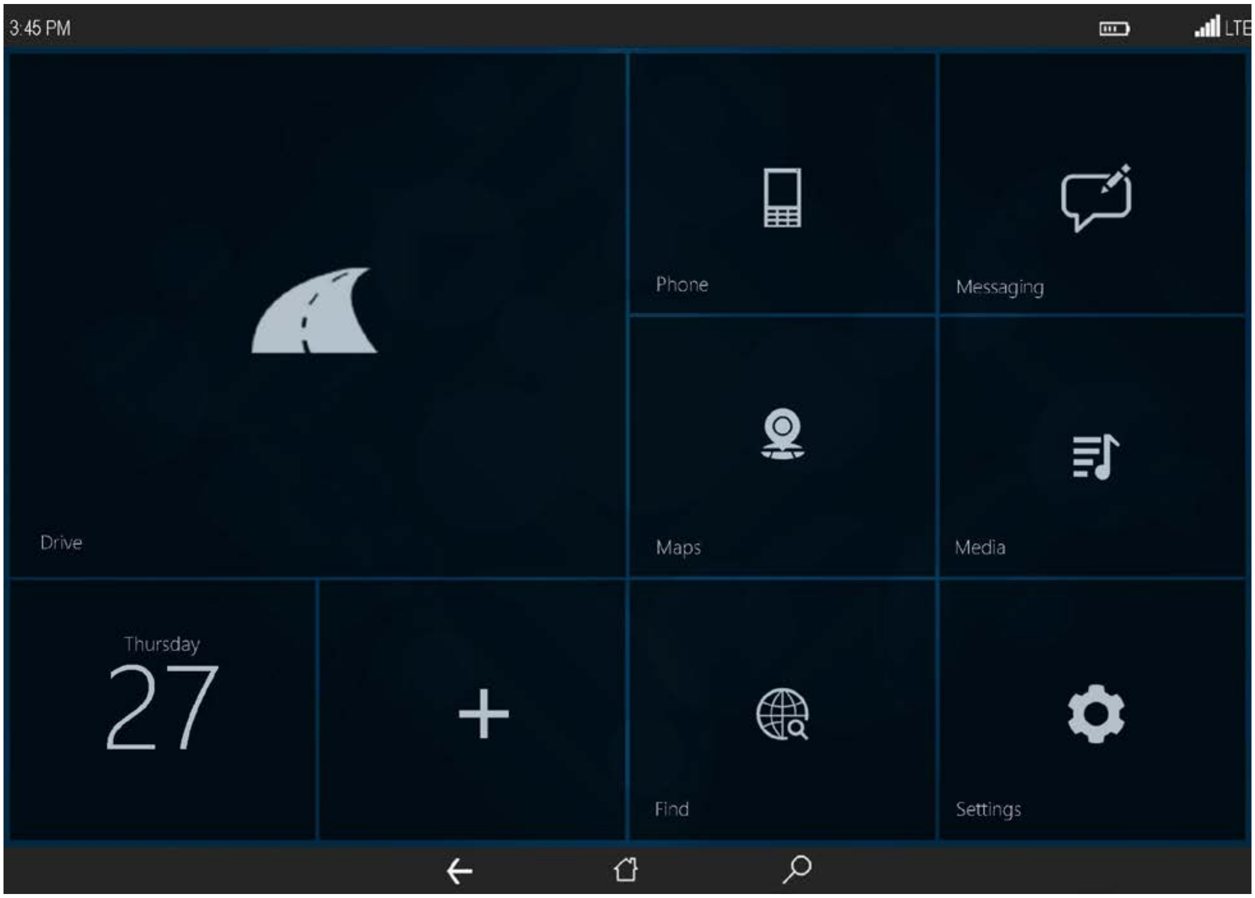

3:45 PM
LTE
15.5 miles / 36 minutes
Starbucks
1555 Northwest 52nd Street
Gainesville, Florida 32606
Go
+ Add Destination


3:45 PM
LTE
2 FOUND
Search for: Starbucks Gainesville Florida
Shawn Johnson
3665 Mayweather Highway Wilmington, Delaware
Dexter Cone
1555 Main Street Wilmington, Delaware


3:45 PM
LTE
15.5 Miles / 36 Minutes
Selected Destinations
Shawn Johnson
3665 Mayweather Highway Wilmington, Delaware
Dexter Cone
1555 Main Street Wilmington, Delaware
Add Destination



3:45 PM
LTE
Fort Lee
Ridgefield
Cliffside Park
Fairview
North Bergen
Union City
Hoboken
Bronx
SOUTH BRONX
Manhattan
EAST HARLEM
TREMONT
STEINWAY
New York
LONG ISLAND CITY
HABERMAN
Manhattan
RIDGEWOOD
RED HOOK
PARK PLACE HISTORIC DISTRICT
5:25
ETA
Starbucks
4835 53rd Street
Gainesville, FL 32606


3:45 PM
LTE
Drive
Phone
Messaging
Maps
Media
Thursday
27
Find
Settings

APPENDIX N
DEMOGRAPHIC QUESTIONNAIRE

Self-Driving Vehicle Human-Machine Interface Study

Introduction

Thank you for agreeing to participate in the study. Prior to beginning the study tasks I have a few brief personal questions that I would like to ask that will aid us in analyzing the information that we collected.

General Questions

1. How would you describe your gender?

   [ ] Male

   [ ] Female

   [ ] Other

2. How old are you?___________________________________

3. Which of the following best describes your personal income?

   [ ] under $11,500

   [ ] $11,500 to $15,000

   [ ] $15,000 to $25,000

   [ ] $25,000 to $35,000

   [ ] $35,000 to $45,000

   [ ] $45,000 to $55,000

   [ ] $55,000 to $65,000

   [ ] $65,000 to $76,500

   [ ] $76,500 or more

   [ ] Declined to provide

4. What is your current level of employment?

   [ ] Employed full time

   [ ] Employed part time

   [ ] Not currently employed

[ ] Retired

[ ] Full time student

[ ] Part time student

5. Which of the following best describes your race or ethnic group?

   [ ] Asian

   [ ] Black/African-American

   [ ] Caucasian

   [ ] Latino or Hispanic

   [ ] Native American

   [ ] Native Hawaiian or Other Pacific Islander

   [ ] Mixed Race

6. Have you ever legally driven a vehicle before?

   [ ] Yes

   [ ] No

7. What kind of transportation do you use most often?

   [ ] Passenger car

   [ ] Minivan / Van

   [ ] Pickup truck

   [ ] SUV

   [ ] Motorcycle Scooter

   [ ] Public Transportation

8. Which best describes your level of education

   [ ] Some High School

   [ ] High School Diploma / GED

   [ ] Some College

   [ ] 2 Year Degree

   [ ] 4 Year Degree

   [ ] Graduate Degree

9. Based on the time frames provided, how would you classify the length of time that you have been visually impaired?

   [ ] Some of your life

[ ] Most of your life

[ ] All of your life

[ ] I am newly visually impaired

10. Based your degree of vision loss if you had to identify yourself as either blind or low vision, which would you choose?

    [ ] Blind

    [ ] Low Vision

11. What is your diagnosed visual acuity in your better seeing eye with conventional correction (e.g. glasses or contact lenses)?

    ____

12. On a scale of 1 to 7, with 1 being strongly disagree and 7 being strongly agree. Please indicate your level of agreement with the following statement. I am familiar with the roads and landmarks in the immediate vicinity of the Florida Center for the Blind.

    Disagree [1] [2] [3] [4] [5] [6] [7] Agree

APPENDIX O
SELF-DRIVING CAR ASSESSMENT SCALE

Self-Driving Car Acceptance Scale

I will ask you a series of questions regarding self-driving vehicles. For each question please respond with a a number between 1-Strongly Disagree or 7-Strongly Agree.

1. Self-driving cars are safe.	1						7
2. I would trust a self-driving car to get me to my destination.	1						7
3. People will need to watch self-driving cars closely to be sure the computers don't make mistakes.	1						7
4. I would be willing to pay more for a self-driving car compared to what I would pay for a traditional car.	1						7
5. The benefits of a self-driving car would outweigh the amount of money it would cost.	1						7
6. The cost of a self-driving car would be the most important thing I would consider before purchasing one.	1						7
7. I do not think that computers should be driving cars.	1						7
8. It is important for a human to be able to take back control from a self-driving car.	1						7
9. There are some driving scenarios that will be too difficult for a self-driving car to handle.	1						7
10. I would enjoy driving a car.	1						7
11. I would prefer to be the driver rather than the passenger	1						7
12. I enjoy cruising or going for joy rides.	1						7
13. A self-driving car would allow me to be more productive.	1						7
14. A self-driving car would allow me to be more safe while in the car.	1						7
15. Self-driving cars will reduce traffic problems.	1						7
16. Self-driving cars will be easy to use.	1						7
17. It will be a lot of work to figure out how to use a self-driving car.	1						7
18. It would take me a long time to figure out how to use a self-driving car.	1						7
19. I like to use technology to make tasks easier for me.	1						7
20. I have bad experiences when I try to use new technology instead of doing things "the old-fashioned way".	1						7
21. There are tasks in my life that have been made easier by computers doing the work for me.	1						7
22. I would like to own a self-driving car.	1						7
23. Even if I had a self-driving car, I would still want to drive myself most of the time.	1						7
24. In a self-driving car, it will be important to me to have the option to turn off the computer and drive myself.	1						7

APPENDIX P
SYSTEM USABILITY SCALE QUESTIONNAIRE

User ID #:

System Usability Scale Questionnaire

Instructions: Read each of the following statements and this brief explanation of the scale: 1 = Strongly Disagree to 5 = Strongly Agree. For each statement mark one box that best reflects your reaction to the Apple Car Play system based on your interaction with the system *today.*

		Strongly Disagree 1	2	3	4	Strongly Agree 5
1.	I think that I would like to use this system frequently.	☐	☐	☐	☐	☐
2.	I found the system unnecessarily complex.	☐	☐	☐	☐	☐
3.	I thought the system was easy to use.	☐	☐	☐	☐	☐
4.	I think that I would need the support of a technical person to be able to use this system.	☐	☐	☐	☐	☐
5.	I found the various functions in this system were well integrated.	☐	☐	☐	☐	☐
6.	I thought there was too much inconsistency in this system.	☐	☐	☐	☐	☐
7.	I would imagine that most people would learn to use this system very quickly.	☐	☐	☐	☐	☐
8.	I found the system very cumbersome to use.	☐	☐	☐	☐	☐
9.	I felt very confident using the system.	☐	☐	☐	☐	☐
10.	I needed to learn a lot of things before I could get going with this system.	☐	☐	☐	☐	☐

APPENDIX Q
ATLAS INITIAL TUTORIAL DIALOGUE

S = SYSTEM U = USER

S: “Hello I’m ATLAS. I am here to help you with anything that you need while using this vehicle. With my help you can control most vehicle systems using just your voice. Let’s review the basics. Whenever you want me to do something just say my name, ATLAS, followed by your request. If I ask you a question and need a response I will play this sound…”
S: *beep*
S: “Please speak your response clearly. Let’s practice. Say‘ATLAS what time is it?’”
S: *beep*
U: “Atlas, what time is it?”

If success
S: “Good job. The current time is [system time].”
If failure & repeat < 3 times
S: “I’m sorry I didn’t understand you. Say ‘ATLAS’ what time is it?”
If failure & repeat = 3 times
S: “I’m sorry I still didn’t understand you. It seems like you’re having trouble. Let’s try something else. Say ‘ATLAS’ what day is it?”
If success
S: “Good job. It is [current day]”

S: “There are certain things that you can say without saying my name first. If you need help just say ‘Help’ and I will respond. If you have an emergency just say ‘Emergency’ to get my attention. If you are in an accident say ‘Accident’ and I will contact emergency services if necessary. Now let’s review vehicle control. To start a trip you can say ‘ATLAS, drive’. You can stop the vehicle at any time by saying ‘ATLAS, stop’. I will pull over as soon as it is safe to do so. When we arrive at your destination I will stop as close to the building as possible. If possible I will send walking directions to the entrance of your destination to any nearby mobile device. I can also park myself and will provide you with instructions on how to summon me when you are ready to leave. Those are the basics. I will provide additional tips and information as you begin to use the system. If you think you understand the basics, after say ‘I understand’. If you would like me to repeat the instructions, say, ‘repeat’”
S: *beep*
U: “I understand.”
S: “Ok, I will standby for further instructions. Say ‘ATLAS, drive’ at any time to set a destination or press the drive button. You can repeat the tutorial at any time by saying ‘Tutorial’.”

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BIOGRAPHICAL SKETCH

Julian's major was Human-Centered Computing. While simultaneously working as a senior software developer for Clemson University he completed his Doctor of Philosophy in the spring of 2018.