Assessing Alternate Approaches for Conveying Automated Vehicle "Intentions"

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Thesis submitted to the faculty of the Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the degree of

Master of Science
In
Biomedical Engineering

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September 27, 2019
Blacksburg, VA

Keywords: Highly automated vehicles, automated driving systems, human-machine interfaces, automated rideshare, trust, comfort, safety

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ABSTRACT

Objectives: Research suggests the general public has a lack of faith in highly automated vehicles (HAV) stems from a lack of system transparency while in motion (e.g., the user not being informed on roadway perception or anticipated responses of the car in certain situations). This problem is particularly prevalent in public transit or ridesharing applications, where HAVs are expected to debut, and when the user has minimal training on, and control over, the vehicle. To improve user trust and their perception of comfort and safety, this study aimed to develop more detailed and tailored human-machine interfaces (HMI) aimed at relying automated vehicle intended actions (i.e., "intentions") and perceptions of the driving environment to the user.

Methods: This project developed HMI systems, with a focus on visual and auditory displays, and implemented them into a HAV developed at the Virginia Tech Transportation Institute (VTTI). Volunteer participants were invited to the Smart Roads at VTTI to experience these systems in real-world driving scenarios, especially ones typically found in rideshare or public transit operations. Participant responses and opinions about the HMIs and their perceived levels of comfort, safety, trust, and situational awareness were captured via paper-based surveys administered during experimentation.

Results: There was a considerable link found between HMI modality and users' reported levels of comfort, safety, trust, and situational awareness during experimentation. In addition, there were several key behavioral factors that made users more or less likely to feel comfortable in the HAV.

Conclusions: Moving forward, it will be necessary for HAVs to provide ample feedback to users in an effort to increase system transparency and understanding. Feedback should consistently and accurately represent the driving landscape and clearly communicate vehicle states to users.

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GENERAL AUDIENCE ABSTRACT

One of the greatest barriers to the entry of highly automated vehicles (HAV) into the market is the lack of user trust in the vehicle. Research has shown that this lack of faith in the system primarily stems from a lack of system transparency while in motion (e.g., the user not being told how the car will react in a certain situation) and not having an effective way to control the vehicle in the event of a system failure. This problem is particularly prevalent in public transit or ridesharing applications, where HAVs are expected to first appear and where the user has less training and control over the vehicle. To improve user trust and perceptions of comfort and safety, this study developed human-machine interface (HMI) systems, focusing on visual and auditory displays, to better relay automated vehicle “intentions” and the perceived driving environment to the user. These HMI systems were then implemented into a HAV developed at the Virginia Tech Transportation Institute (VTTI) and tested with volunteer participants on the Smart Roads.

DEDICATION

This thesis is dedicated to all of the individuals from Medford Lakes to Blacksburg who helped me get to this point. You are loved.

ACKNOWLEDGEMENTS

Thank you to my committee, Dr. Zachary Doerzaph, Luke Neurauter, Dr. Charlie Klauer, and Dr. Miguel Perez, who offered vital guidance and advice throughout the duration of this project.

Thank you to the teams at the Virginia Tech Transportation Institute Center for Advanced Automotive Research (VTTI-CAAR), especially Eric Glenn, Jacob Walters, and Melissa Hulse, for all of your assistance and support.

Thank you to Alexandria Noble, Keegan Yates, Whitney Tatem, Maria Evgeniadis, Mindy Buchanan-King and Adam Novotny, who took the time to help edit and review this document.

The Center for Technology Development (CTD) team at VTTI developed the test HAV used in this study.

This project was funded by the Safety through Disruption (Safe-D) National University Transportation Center (UTC), a grant from the U.S. Department of Transportation – Office of the Assistant Secretary for Research and Technology, University Transportation Centers Program.

ATTRIBUTIONS

Marty Miller (Research Associate, VTTI-CAAR) assisted in the creation of the project idea and helped write the project proposal. Once the project was awarded funding, he took on a project management role and collaborated to create the experimental design. Marty was the lead designer of the visual and auditory HMIs and oversaw their implementation into the test vehicle. He also played an integral role in participant testing and data collection. Marty helped with data analysis and reviewed all written project materials.

Dr. Zachary Doerzaph (Center Director, VTTI-CAAR) and Luke Neurauter (Group Leader, VTTI-CAAR) provided subject matter expertise and contributed to the original project idea and experimental design plan. Throughout the entire study, they oversaw management of the project and offered guidance and support when needed.

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INTRODUCTION

According to the Centers for Disease Control (CDC), death due to unintended injury resulting from automotive crashes is the third leading cause of adult deaths in the United States (Xu, Murphy, Kochanek, Bastian, & Arias, 2018). The National Highway Traffic Safety Administration (NHTSA) Fatality Analysis Reporting System (FARS) shows that, in 2017, there were more than 37,000 roadway fatalities, with the majority resulting from human error (NHTSA, 2018). Scientists and engineers have been working tirelessly to implement disruptive vehicular technologies with the goal of reducing the number of injuries and deaths resulting from automotive crashes. These technologies have the potential to improve occupant safety and further reduce roadway crashes. Features such as lane keeping assist (LKA), adaptive cruise control (ACC), and automated emergency braking (AEB) have been shown to significantly reduce or mitigate vehicle crashes and subsequent injury (Sternlund, Strandroth, Rizzi, Lie, & Tingvall, 2016; Schram, Williams, & Ratingen, 2013). Based on the proven success of these lower levels of vehicle automation, higher levels of automation, including highly automated vehicles (HAVs), could have large impacts on roadway safety.

Automated Vehicles

Automated vehicles (AVs) are able to monitor their surroundings using sensors (e.g., camera, radar, ultrasonic, and LiDAR) coupled with computing processes to independently detect and react to hazards or obstacles in the roadway. There are several different levels of vehicle automation, as defined by the SAE J3016 standard, as seen in Figure 1 (SAE International, 2018).

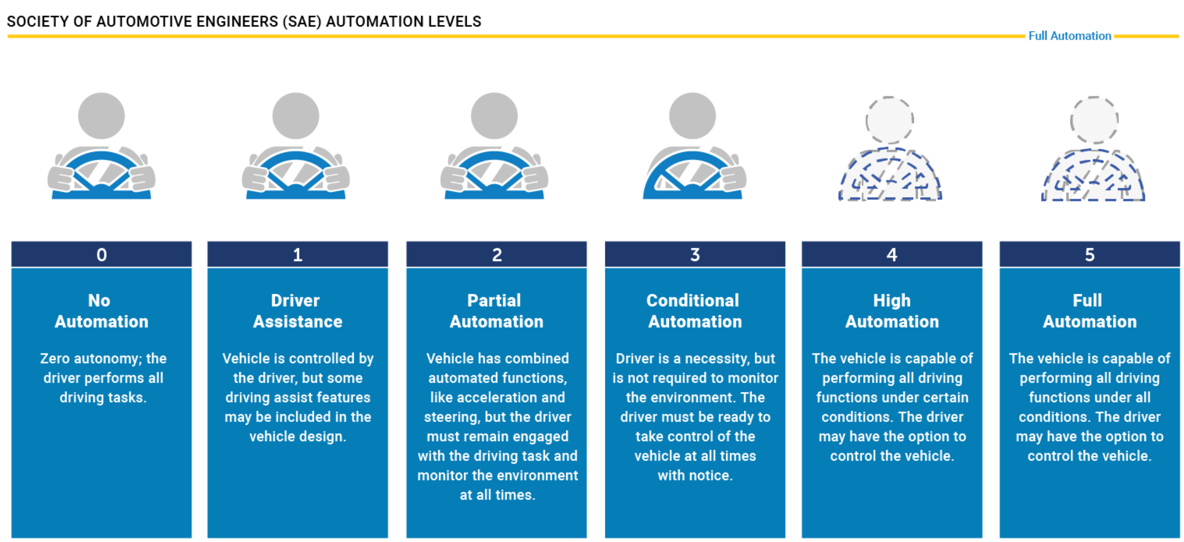

Figure 1: SAE levels of vehicle automation.

Level 0 (L0) vehicle automation encompasses a majority of vehicles currently on the roadway, where human drivers manually perform all operational tasks. The lower levels of vehicle automation, categorized as Level 1 (L1) or Level 2 (L2), provide the driver with assistance or partial automation. In vehicles with L1 capabilities, the vehicle can control itself in the longitudinal direction (e.g., ACC) or the lateral direction (e.g., LKA). Vehicles with L2 capabilities are able to control themselves in both longitudinal and lateral directions. Although L1 and L2 vehicles may reduce the driver's operational workload, users are still required remain engaged in the driving task and be ready to resume control at any time. Level 3 (L3) automation, also known as "conditional automation", requires drivers to still remain in the driver's seat and be prepared to resume control of the vehicle, however the driver is not required to be fully engaged in the driving task at all times. They are permitted to engage in secondary tasks or look away from the roadway for extended periods of time, but they must be ready to take control of the vehicle after an advanced notice. Vehicles with higher levels of automation, known as Level 4 (L4) and Level 5 (L5), are able to perform all driving tasks and react to most (e.g., L4 automation) or all (e.g., L5 automation) obstacles and roadway scenarios, allowing the user to completely disengage from the driving task. These higher levels of automation are classified as HAVs or self-driving vehicles.

Vehicle automation has the potential to benefit roadway safety, the economy, roadway efficiency, and mobility (NHTSA, 2018). In theory, since the higher levels of AVs are able to act independently of the driver, they have the potential to mitigate vehicle crashes caused by drowsy, distracted, or reckless driving, and could universally increase transportation safety (Fleetwood, 2016). As mentioned previously, since lower levels of vehicle automation have already been proven to positively impact roadway safety, it is expected that the integration of more advanced vehicles onto the roadway could not only improve occupant safety but also the safety of other road users (Litman, 2015).

Currently, the highest levels of automation available on the consumer market are L1 and L2. Large original equipment manufacturers (OEMs), such as General Motors, Volvo, Hyundai, Ford, and Toyota, have recently partnered with advanced vehicle companies with the hope of bringing higher levels of vehicle automation to market as soon as 2020 (Fields, 2017; Pratt, 2017; Samuelsson, 2016; You, 2017). However, there are still major questions surrounding HAVs relating to their legality and security, therefore by some estimates higher levels of automation are not being projected to become widely available until as late as 2050 (Intel, 2018; Yan, Xu, & Liu, 2016; Schellekens, 2015; Greenblatt, 2016). Prior to this future wide-scale deployment of HAVs to private consumers, the first wave of highly automated passenger vehicles is expected to emerge in ridesharing or mass transit applications, where their effects will be most beneficial and higher vehicle costs can be absorbed (Litman, 2015; Palmer, Dessouky, & Abdelmaguid, 2004; Brush & Niles, 2016).

HAVs and Rideshare

Shared automated vehicles (SAVs) and transit HAVs transport multiple different users to different destinations with minimal input from the riders. These vehicles could have significant impacts on mobility, the economy, and the environment due to their shared nature and their potential to increase safety and efficiency on the roadway. These vehicles have the capacity to be beneficial to individuals who are mobility-impaired and could provide last-/first-mile solutions or on-demand transportation access to remote areas, complementing current public transportation systems (Merat, Madigan, & Nordoff, 2017; Agatz, Erera, Savelsbergh, & Wang, 2011; Shladover & Bishop, 2015). In addition, these vehicles have the potential to mitigate the need for large parking areas and reduce congestion in urban areas, which would not only positively benefit the infrastructure of the area, but also the environment. A study performed by Fagnant, Kockelman, & Bansal (2015) developed a simulation which modeled a fleet of SAVs, as if they were implemented into current travel patterns, in a 12-mile to 24-mile radius around Austin, Texas. Based on this model, they found that SAVs could replace close to nine vehicles within the radius while maintaining a reasonable level of service (e.g., users only waiting one minute), thus reducing vehicle congestion and increasing individual mobility. SAVs have also been predicted to decrease overall per-mileage cost of commutes (Zakharenko, 2016).

To date, multiple small-scale public transit HAV deployments have been conducted. The City Automated Transport System (CATS) study tested user response to a week-long trial of the Navya vehicle, a fully automated, low-speed shuttle, at a university, with the goal of identifying needs for mobility and vehicle constraints. This study found that the general public's opinion regarding public transit HAVs and SAVs was high, and the absence of a human driver was not seen as problematic (Christie, Koymans, Chanard, Lasgouttes, & Kaufmann, 2016). A similar study called the CityMobil2 project also deployed an automated shuttle around a university campus. Once again, this study found that public attitudes and opinions toward the shuttle were positive, mostly due to the potential for lower vehicle costs and increased mobility; concerns raised were those related to the safety and security of riding in the vehicle, especially at night (Piao, et al., 2016). Researchers on the CityMobil2 project also predicted that public transit HAVs would have positive impacts to the global economy (i.e., increasing jobs and reducing costs of personal trips), society (i.e., increasing mobility), the environment (i.e., reducing energy consumption and emissions), and transport (i.e., increasing road capacity and occupant comfort) (Sessa, 2016; CityMobil2-Experience and Recommendations, 2017). However, these studies may have yielded positive public opinion about the two shuttles because they were deployed on or near university campuses, where the population is more likely to be accepting of new technology.

Although SAVs have the potential to significantly improve roadway congestion and individual mobility, there are potential drawbacks and limitations to this type of dynamic ridesharing. With increased mobility also comes increased total vehicle miles traveled (VMT), which could have negative impacts on roadway infrastructure and the environment. Fagnant, Kockelman, & Bansal (2015) found that SAVs could generate 8% more VMT than conventional passenger vehicles, mostly due to dynamic vehicle routing and variable user location. As mentioned above, there are also concerns about the safety and security of riding in a vehicle with strangers and without a human driver present (Amey, Attanucci, & Mishalani, 2011; Piao, et al., 2016). These concerns are especially prevalent in mobility-impaired communities, where occupants may rely on the interactions with the vehicle driver for payment, access to the vehicle, or security (Simek, et al., 2018). Drawbacks aside, SAVs designed while considering safety, security, and system transparency, afford opportunities for increased mobility, which could be invaluable for numerous under-served populations.

Trust and Acceptance of HAVs

While HAVs have the potential to dramatically improve driver safety and mobility, 56% of Americans state they would not want to ride in a driverless car if given the chance, citing distrust of the system as the biggest contributing factor (Pew Research Center, 2017). Thus, trust and acceptance of HAVs are considered by many to represent the main barriers to their future adoption and use (Chao, 2018).

Because of this user distrust, numerous survey-based studies have been performed to assess the public's opinion on HAVs and factors that could potentially influence user acceptance and trust. Zmud, Sener, & Wagner (2016) distributed an online survey to residents in Austin, Texas, which showed that people were apprehensive toward higher levels of automation in vehicles mainly due to a lack of trust in the system, the second reason being safety, and the third reason being cost. Another similar study found the willingness to use HAVs was dependent on the rate of adoption and likelihood of system failure (Bansal, Kockkelman, & Singh, 2016). Potential users of HAVs still have serious concerns surrounding software safety and security, which have negative effects on trust (Kyriakidis, Happee, & De Winter, 2015; Owens, Antin, Doerzaph, & Willis, 2015).

User behavior and psychological characteristics have also been examined to determine whether they have a significant impact on users' trust levels in AVs (Rudin-Brown & Parker, 2004). Studies have suggested that locus of control (Choi & Ji, 2015), the belief of the degree of control one has over the events in their life, individual driving style (Bellem, Thiel, Schrauf, & Krema, 2018), and sensation-seeking, one's inclination to seek out thrill and novel experiences, affected a user's base level of trust and comfort in automation. Nordhoff, Van Arem, & Happee (2016) found that populations exhibiting an internal locus of control, where individuals believe they can control event outcomes, or those with high sensation-seeking tendencies, where individuals seek adventure and thrill, would have a more difficult time trusting a fully automated driving system.

Low user acceptance in HAVs primarily stems from the lack of user trust and feelings of safety while interacting with the system. Therefore, user-centric systems that aim to increase vehicle-to-user communication could be a key component to maximizing benefits and limiting drawbacks of HAVs.

Human-Machine Interface (HMI)

A unifying theme across all studies cited above is the population's inherent distrust in highly automated driving systems. However, studies have found that providing additional information about such systems to users had positive effects on overall trust and acceptance (Rodel, Stadler, Meschtscherjakov, & Tscheligi, 2014). Research suggests that properly communicating the "intentions" of the vehicle (e.g., intention to stop, accelerate, or decelerate) and roadway perceptions (i.e., displaying the presence of hazards in the driving path) could improve situational awareness of the occupants and may be one way of enhancing perceptions of comfort, safety, and trust among users (Verberne, Ham, & Midden, 2012; Hoff & Bashir, 2015; Endsley, 1995). To this end, HMIs are thought to be a potential channel for better communication of AV system status to the user (Seppelt & Victor, 2016).

A HMI is a type of user interface that is designed to communicate system-states and critical information to a user through a variety of modalities. The HMI constantly provides feedback to the user about the system, which allows them to remain "in-the-loop" and make more effective decisions (Norman, 1990). Since the emergence of passenger vehicles, automotive HMIs have been essential for communicating vehicle information to users. These HMIs can be as simple as a speedometer indicating vehicle speed or as complex as an in-vehicle navigation system; both communicate important information about the vehicle and system-state to the driver. As vehicles become more sophisticated and driving automation becomes more prevalent, HMI systems have transitioned from communicating only vehicle-specific information to describing the real-time driving environment to users.

More human-centric and HAV-tailored HMIs could assist users in monitoring the driving landscape and to keep them "in-the-loop" of how the vehicle is reacting to external stimuli. It is reasonable to argue that keeping drivers "in-the-loop" is only important for lower levels of AVs since, in theory, users of higher levels of AVs should not have to make critical decisions and thus do not need to know the details of the vehicle's "intentions". However, multiple studies have shown that implementing well-designed, informative HMI systems increased users' situational awareness, thus facilitating trust between the vehicle and the passenger, which are fundamental aspects to perceptions of comfort and overall acceptance (Stockert, Richardson, & Lienkamp, 2015; Debernard, Chauvin, Pokam, & Langlois, 2016). Safety benefits of HAVs may only be realized if the public is willing to accept the vehicles as a viable mode of transportation. Additional information given to users via HMIs may facilitate trust and acceptance by allowing riders to rationalize decisions of the vehicle and understand why one course of action is taken over another. Further, it may provide some benefits to encourage rider intervention in an instance of potential system failure. These topics are explored within this Thesis.

Previous Studies and Current Gaps in the Knowledge

Few studies have explored the best method for conveying critical driving information to HAV users or increasing user trust via improved HMIs. Research has been done in this area but has primarily focused on lower levels of vehicle automation (L2 and L3) and alerting drivers to takeover situations (Blanco, et al., 2015; Kyriakidis, et al., 2017; Debernard, Chauvin, Pokam, & Langlois, 2016; Sentouh, Popieul, Debernard, & Boverie, 2014; SAE International, 2018). A contributing factor to the lack of previous investigations of HMIs for HAVs could be due to the limited technology currently available in AVs, since higher levels of vehicle automation do not exist in the consumer market. Currently, one of the most advanced production HMI available is the Tesla Autopilot status screen, which relays the vehicle's ACC/LKA status and its perceived surroundings to the driver (United States Patent No. US20110082620A1, 2009). This HMI has only been implemented into vehicles with L2 features and has not yet been expanded to higher levels of automation within the public domain. Pre-production advanced vehicle companies, such as Waymo, have implemented HMI systems into their fully automated rideshare vehicles. However, specifications of these systems have not been widely publicized, and, as far as can be ascertained, no studies have been conducted that examine human interactions with these systems (United States Patent No. US9950619B1, 2015).

Previous studies have been conducted which focus on the optimal design of HMI systems for AVs. However, these studies have largely examined the problem from the perspective of L2 and L3 vehicle automation and have not yet targeted the higher levels. Debernard et al. (2016) applied Cognitive Work Analysis (CWA) theories and Human-Machine Cooperation and Transparency principles to determine what information is best to display on an AV HMI and in which manner.

Based on this study, the optimal HMI system must communicate to the driver the "intentions" of the vehicle and why/when/how these actions will be performed. Similarly, Pacaux-Lemoine & Flemisch (2016) explored optimal HMI design via a meta-model implementing Human-Machine Cooperation principles. The developed model showed that HMIs should have three main layers: 1) Planning/strategic levels of navigation (e.g., where the vehicle is planning on traveling/where the vehicle currently is located), 2) Guidance to the user, and 3) User control (Pacaux-Lemoine & Flemisch, 2016). Another study confirmed the findings by Pacaux-Lemoine & Flemisch, stating that the three principles most important for HMI design are displaying the driving context, showing vehicle intention, and allowing the user to choose an alternative to the vehicle's intended action (Guo, et al., 2017).

In addition, standards and guidelines exist, such as those from the European Union, Alliance of Automotive Manufacturers, Japanese Automobile Manufacturers Association, and NHTSA, which outline how best to design an HMI device for a wide range of vehicles. Currently, most of these standards do not address higher levels of AVs, or they are tailored to a specific population of individuals, such as the blind and visually impaired or to the elderly (Young, Koppel, & Charlton, 2017; Board & Stevens, 2002; Heinrich, 2012; Alliance of Automotive Manufacturers, 2006; Naujoks, Wiedemann, Schomig, Hergeth, & Keinath, 2019; NHTSA, 2014).

Research Objective

Testing improved vehicle-user communication systems, such as HMIs, is important, specifically in scenarios unique to rideshare and public transit vehicles, where a rider may have little to no access to the primary vehicle control systems and may only be able to provide minimal input to the vehicle (i.e., setting a final destination). Additionally, studying how users perceive information about an advanced vehicle system, which could ultimately contribute to a user's increased understanding of the driving system's "intentions", is vital for understanding HAV acceptance and predicting future adoption.

In an effort to better understand methods for effectively conveying relevant driving information and developing appropriate user trust in AVs, this Thesis developed and examined a variety of HMI strategies focused on visual and auditory communication. Volunteer participants, naive to HAVs, experienced the HMI systems across realistic driving scenarios, during which researchers gauged participants' situational awareness and perceptions of comfort, trust, and safety. Users' preferences about the vehicle and HMI were surveyed to help better inform future development of these systems. All data collected aimed to answer the study's central research questions:

1. What HMI strategies increased users' perception of comfort, trust, and safety in the vehicle and their situational awareness of the driving landscape?
2. Did giving users more detailed information via HMIs improve understanding of the vehicle's future actions (i.e., "intentions") or perceptions of the roadway?
3. Were there any personality traits or behaviors that would make a user more or less likely to feel comfortable or safe in a HAV?

Researchers predicted that HMI systems that portrayed the most detailed, driving-pertinent information, such as a mixed-modal HMI, would result in the highest reported levels of trust, comfort, safety, and situational awareness in the HAV. In addition, these HMI systems were expected to more clearly communicate intended vehicle actions and perceptions of the roadway. When examining behavioral traits and characteristics, researchers expected that individuals with previous exposure to automated driving systems (e.g., ACC, LKA, AEB), higher sensation-seeking tendencies, or higher initial comfort would report higher perceived levels of trust, comfort, and safety.

Outline of Thesis

The Methods section of this Thesis outlines the procedures used to answer the central research questions presented above. The highly automated test vehicle used in the study is described, as well as the HMI systems implemented. The experimental procedure and parameters, including participant demographics and vehicle scenarios, are explained in detail. In addition, an overview of data analysis strategies is provided.

The Results and Discussion section presents data obtained through the study and displays potential trends while the Conclusions section provides an overall narrative of the study and how the results could impact the current state of knowledge surrounding this research topic. Limitations of the study are presented and discussed, followed by recommendations for future HMI systems based on the study findings.

The Appendix includes all materials used for participant recruitment, questionnaires used to collect subjective data, and statistical analyses conducted.

METHODS

To understand the effects of differing HMI modalities on users' situational awareness and feelings of comfort, trust, and safety, prototype HMI systems were tested in a real-world setting with naive volunteer participants. Performing this type of high-fidelity testing ensured the most natural reactions to the systems were captured.

Testing Environment

Experimentation was performed on the Virginia Smart Roads, a collection of controlled-access, transportation test beds located at the Virginia Tech Transportation Institute (VTTI) in Blacksburg, Virginia. The roads encompass a variety of driving environments that simulate highway and urban roads and were built to the Virginia Department of Transportation roadway standards. In this study, to create the most realistic driving environment for a highly automated rideshare vehicle, both the highway and urban (i.e., Surface Street), sections of the Smart Roads were used.

The highway section of the road was used to simulate higher speed driving, larger roadway curves, and more variable roadway areas, such as work zones. The Surface Street section of the road simulated an urban environment with multiple turns, intersection crossings, and vulnerable road user (e.g., pedestrians) presence. Both sections of the road can be seen in Figure 2.

Figure 2: Top-down view of the Surface Street (foreground) and highway (background) sections of the Smart Roads used for testing.

Test Vehicle

The vehicle used for experimentation was a 2012 Cadillac SRX, seen in Figure 3, which was converted into an HAV by the Center for Technology Development (CTD) team at VTTI. This vehicle leveraged VTTI's Automated Vehicle Research Platform, a system designed to permit rapid prototyping and testing of automated vehicle perception, control, and interface strategies.

Figure 3: Cadillac SRX test vehicle.

The vehicle was configured with a focus on the research questions of this project. Thus, for simplicity, it was programed to drive predetermined paths, without the aid of a driver, by following differential GPS (DGPS) waypoints and came to preprogrammed stops for set amounts of time. All vehicle dynamics were controlled by a central processing unit (CPU). The CPU controlled the servo motor housed in the steering wheel (e.g., allowing the vehicle to turn), depressed the linear actuators in the brakes (e.g., allowing the vehicle to decelerate and come to a stop), and adjusted an electronic throttle (e.g., allowing for acceleration and speed adjustments). Although this vehicle represented a higher level of automation than what was seen on the consumer market at the time of testing, it is important to note that it did not have all of the capabilities that would be expected of a production vehicle with L4 or L5 automation. For example, the test vehicle did not use perception sensors, such as radar or LiDAR, to identify hazards or obstacles in its path and would not stop or perform maneuvers to avoid an unexpected obstacle, if present. However, using the "Wizard of Oz" technique, researchers preprogrammed the HMI to display all important information for each choreographed scenario such that participants' experiences were consistent with those expected from a vehicle with L4 or L5 features (Steinfeld, Jenkins, & Scassellati, 2009; Green & Wei-Haas, 1985; Salber & Coutaz, 1993). Indeed, this ruse resulted in participants who believed they were riding in a HAV with no driver in the front seat and that all perception, decision, and response systems fully functional.

During experimentation, to further simulate a rideshare scenario and lack of user access to vehicle controls, two volunteer participants sat in the rear seats of the vehicle (e.g., behind the driver's and front passenger's seats), with nobody sitting in the driver's seat. Video screens, seen in Figure 4, were installed onto the back of the front seat headrests that displayed visual information and produced auditory alerts to represent the different HMI conditions. The in-vehicle computer was fed raw vehicle data, which were then transferred to the headrest-mounted screens via a mini-HDMI cord to display the appropriate visual and auditory cues to users. Participants only had one display in their direct view, and each screen portrayed identical vehicle and environmental information.

Figure 4: Video screens installed for HMI conditions.

The test vehicle was equipped with a data acquisition system (DAS) developed at VTTI, displayed in Figure 5. The DAS recorded vehicle metrics such as vehicle dynamics and location, as well as audio and video of the testing sessions. The system was housed in the trunk of the vehicle, out of participants' sights.

Figure 5: Data acquisition (top-left silver box) and automation system (remaining added components) installed into the trunk of the test vehicle.

Cameras capturing test session video and audio were positioned on the top of the headrest-mounted video screens and underneath the rearview mirror, to obtain footage of the participants' faces and forward roadway, as shown in Figure 6. Another camera was installed behind participants' shoulders, facing toward the front of the vehicle, to confirm the visual information displayed via the headrest-mounted screens.

Figure 6: Camera positions for capturing participant face-views (1 & 2), the roadway (3), and screen-view video (4).

Since the test vehicle was still a prototype and had not undergone a functional safety validation, building multiple safety backups, triggered in the event of a system malfunction, was crucial. Two manual stop buttons were installed into the vehicle, as seen in Figure 7: one in front of the center console (1) and one on the back of the armrest console (2). The front stop button, accessible by the passenger seat experimenter, was designed to immediately and completely shut down all vehicle automation but apply no braking. If the front button was pressed, the passenger seat safety driver would need to bring the vehicle to a stop with the safety brake ("driver's ed brake") hidden in the footwell of the passenger seat. When depressed, the rear button would not shut down the automated system but instead would bring the vehicle to a controlled, gradual stop. The purpose of this stop button, which will be discussed in further detail later, was to provide the study participants a mechanism for stopping the vehicle in the event of an emergency or system failure.

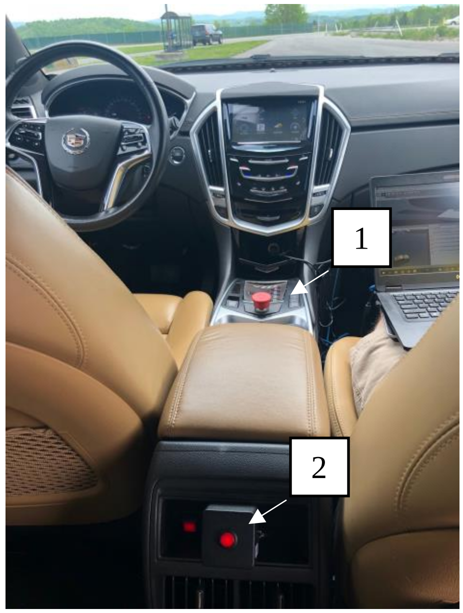

Figure 7: Stop button locations in the test vehicle.

HMI Conditions

The HMI systems were created using Unity, a software system originally created for video gaming platforms, which allows users to create two- and three-dimensional interactive virtual environments. All vehicle scenarios were first translated into a virtual simulation through Unity using data captured from preliminary drives of the test routes. Using these simulations, the visual and audio HMI cues presented to the user during each scenario were implemented. This technique, also known as "Wizard of Oz" experimentation, makes the riders of the vehicle believe that it is operating completely autonomously, where in reality, a majority of the information presented has been preprogrammed by researchers. The information presented via the HMI systems was preprogrammed to appear either at a set point in time, by using test session length, location along the driving path, by using DGPS coordinates of the vehicle, or at a certain vehicle speed, by leveraging vehicle data collected by the DAS. Each participant only experienced one of the following HMI conditions (e.g., between-subject) during a testing session.

No HMI

For the "no HMI" condition, participants rode in the vehicle without any of the HMI systems active. The goal of this condition was to better understand and quantify users' base levels of comfort, trust, and safety in the highly automated test vehicle. Due to trends emerging within the early phase of the data collection, two conditions were ultimately run: "with knowledge" and "without knowledge". For the "with knowledge" condition, researchers revealed more information about the vehicle and testing environment by telling participants that the vehicle would not precisely follow the lane lines and that the steering wheel made noise while active. Researchers also emphasized the fact that the testing environment was a controlled-access research test track. For the "without knowledge" condition, researchers omitted this information.

Researchers realized that, as a result of providing extra information, the reported metrics of participants who experienced the "with knowledge" condition were relatively high. Researchers concluded that these elevated metrics could result in a lack of result sensitivity when other HMI conditions were later introduced to participants. Participants who experienced the "without knowledge" condition reported much more realistic metric levels, thus the condition provided researchers with a more effective foundation on which to base other HMI comparisons and was considered the "true" control of the experiment. The research team also felt that removing the implementation-specific information was more representative of a rider's experience in a deployed system and would produce more generalizable results. The more minimal on-boarding process used for the "without knowledge" condition was also duplicated for the rest of the HMI conditions.

Visual-Only

The visual HMI displayed driving-relevant information on the headrest-mounted screens, such as the predicted driving path (Figure 8), pedestrian crossings, and work zone areas. The visual condition made use of geofenced areas in Unity to trigger key events, such as a pedestrian crossing the road or to display a lead vehicle. Such display content was carefully choreographed with the actual motion of objects on the roadway such that occupants' experiences were consistent with an actual HAV.

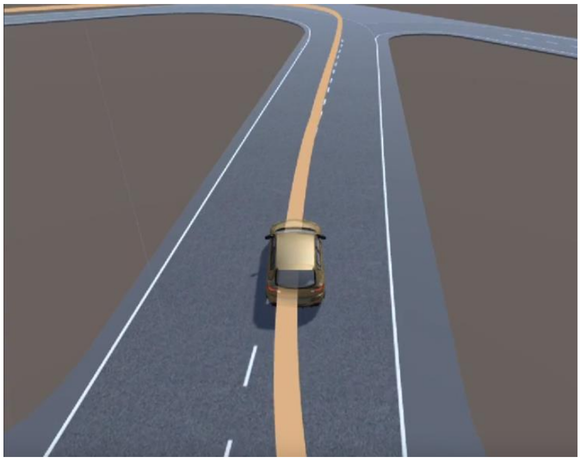

Figure 8: Vehicle path shown on the visual HMI.

Additionally, the visual HMI condition relied heavily on the creation of an accurate 3D simulations of the Surface Street and highway sections of the Smart Roads. Permanent road fixtures, such as shipping containers, traffic lights, and buildings surrounding the Surface Street were preprogrammed into the simulation. Temporary road fixtures were preprogrammed into specific scenarios, such as the traffic cones that created a lane shift during the "work zone" scenario. These types of roadway obstacles and fixtures are typically not seen in other mapping programs (e.g., Google Maps) or in other HMI systems currently available on the market (e.g., Tesla Autopilot screen).

Audio-Only

The auditory HMI condition used a series of tones, developed in-house by VTTI researchers, played through the speakers of the headrest-mounted screens that indicated when the vehicle began a route, stopped, accelerated, decelerated, detected a hazard in the driving path, or completed a route. Sounds were created in Audacity, a digital audio recording and editing software, by generating sine waves at varying frequencies. The waves' durations and tones were then altered and effects were added to attain the researchers' desired notification and alert sounds. Geofenced areas of the simulated road were created in Unity, seen in Figure 9, which indicated where key events (e.g., pedestrian crossing) would occur. When the vehicle entered or exited these "fences," it cued a specific tone to play.

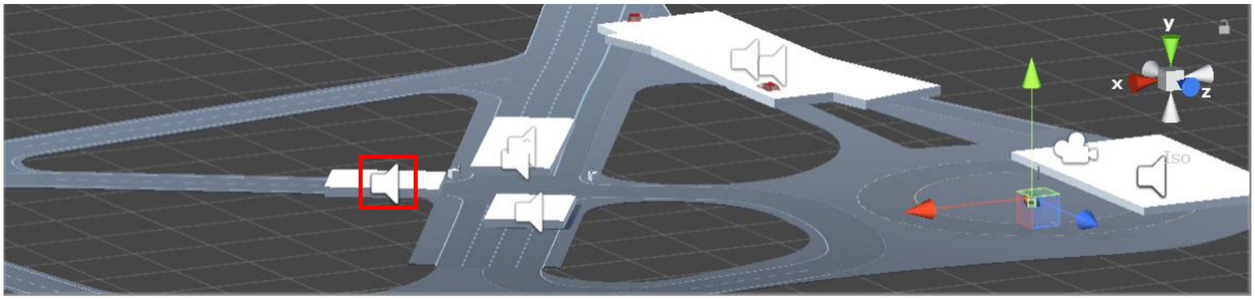

Figure 9: Unity geofenced areas which designated when an auditory cue would be played, as indicated by the "speaker" symbol (boxed in red).

Minimal work has been done which examines how to communicate HAV information to users in an auditory mode, therefore, creating the tones proved to be a particular challenge. Ultimately, the tones were inspired by the sounds manual vehicles typically emit (e.g., engine noises from acceleration or deceleration), alerts or notifications traditionally used in lower levels of advanced vehicles (e.g., hazard alerts), and autonomous concept vehicles, specifically the Volvo 360c (Volvo Cars, 2018).

Mixed-Modal

The mixed-modal HMI condition was a combination of the visual and audio HMI systems, as seen in Figure 10. Driving information was conveyed by images displayed on the screen and tones played through the screen's speakers.

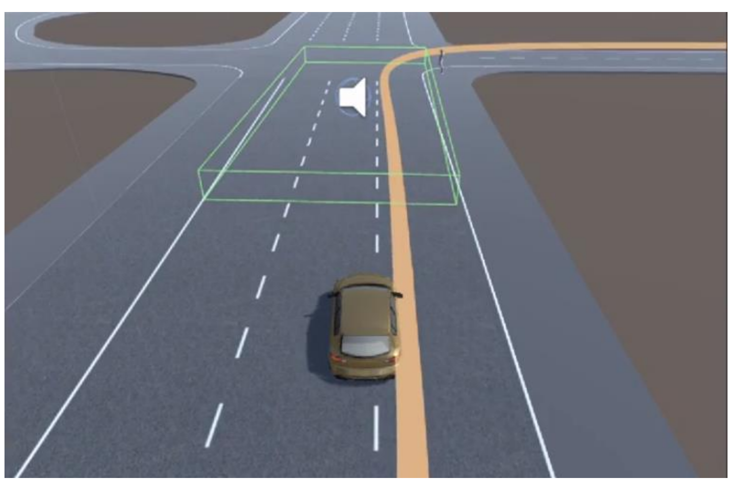

Figure 10: Geofence to indicate audio and visual cues of pedestrian crossing. Participants could not see the geofenced areas on their HMI version.

Study Participants
For this study, the goal was for 32 participants aged 25-40 to test the different HMI conditions, as seen in Table 1. The age range selected for this study represents the population most likely to use rideshare (Krueger, Rashidi, & Rose, 2016; Shahee, Chan, & Gaynor, 2016; Smith, 2016). In addition, using a single age range helped simplify data analysis and reduce time required for testing on the Smart Roads.

Table 1: Planned Experimental Participant Matrix

Study Participants, n=32							
No HMI (n=8)		Audio-Only (n=8)		Visual-Only (n=8)		Mixed-Modal (n=8)	
Male	Female	Male	Female	Male	Female	Male	Female
4	4	4	4	4	4	4	4

However, due to practical budget and time constraints and the unanticipated addition of a second "no HMI" condition, 37 participants ranging in age from 25-38 ultimately participated in the study, as seen in Table 2.

Table 2: Actual Experimental Participant Matrix

Study Participants, n=37									
No HMI "With Knowledge" (n=7)		No HMI "Without Knowledge" (n=8)		Audio-Only (n=8)		Visual-Only (n=8)		Mixed-Modal (n=6)	
Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
4	3	4	4	4	4	4	4	3	3

Since participants would be interacting with a vehicle in a highly-realistic setting and were asked to evaluate HMI systems, the study required that they have no history of brain damage, respiratory disorders, seizures, dizziness, vertigo, no current mobility restrictions, and normal or corrected to normal hearing and vision. In addition, participants were required to not be prone to motion sickness or have difficulty sitting in the rear seats of a vehicle. To help reduce bias among the participant pool, they also must not have heard or be familiar with research involving self-driving vehicles or work for any automotive company or supplier that is involved in the design, engineering, or development of automotive-related technologies.

Experimental Scenarios
All scenarios (i.e., vehicle maneuvers) performed during the testing session were inspired by real-world driving events and maneuvers typically seen in ridesharing environments. Each scenario diagram below has a legend, indicating vehicle paths and maneuvers. The start and end points of the test vehicle routes were consistent between each scenario. Across all scenarios, the vehicle speed varied from 15 mph to 35 mph. Most autonomous shuttles and HAVs currently operating

on roadways travel at low speeds, typically 7 mph to 25 mph (Krisher, 2018; University of Michigan, 2018). The higher, more varied speeds used in this study greatly increased the fidelity of the test vehicle and the users' experiences.

For the first and last trial, participants experienced the same scenarios. For the other trials, scenarios were counterbalanced across all participants and HMI conditions through a reverse counterbalancing approach, an example shown in Table 3 (Allen, 2017). Researchers created two random scenario orders and then reversed them, creating two additional orders. Each HMI condition used these same four scenario orders which can be seen in the full experimental matrix, found in Appendix A.

Table 3: Example Scenario Matrix for "No HMI" Condition

HMI Condition	**Participant #**	**Scenario Order**					
		Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6
No HMI "Without Knowledge"	P08	Baseline	Ped Xing	Following Lead Vehicle	Passenger Pick Up	Left Turns	Surprise
	P09						
	P10	Baseline	Left Turns	Passenger Pick Up	Following Lead Vehicle	Ped Xing	Surprise
	P11						
	P12	Baseline	Passenger Pick Up	Ped Xing	Left Turns	Following Lead Vehicle	Surprise
	P13						
	P14	Baseline	Following Lead Vehicle	Left Turns	Ped Xing	Passenger Pick Up	Surprise
	P15						

Participants only experienced one HMI condition (e.g., between-subjects) but all scenarios (e.g., within-subjects) across the six session trials. HMI conditions were decided to be tested between-subject rather than within-subject due to budgetary and time restrictions. By limiting participants' exposure to only one HMI condition, it allowed them to be sufficiently exposed to the system across a variety of different vehicle maneuvers and roadway scenarios.

Sessions always began with the Baseline scenario and ended with the "surprise event" scenario. The Baseline scenario allowed participants to become familiar with the vehicle and what would be expected of them during the testing session. The goal of the surprise event was to better understand how quickly participants could become acclimated to the vehicle systems and if they were aware enough of their surroundings to recognize a system malfunction and take corrective action.

Heavy Vehicle Remote Evasive Maneuvering Object (HV-REMO)

To simulate pedestrian crossings, an inflatable human-shaped target was used, as displayed in Figure 11. This "pedestrian" was maneuvered using a remotely operated base, called the HV-

REMO, controlled by an on-road experimenter. Soft targets are attached to the remotely operated based with Velcro, and the mechanism can be run-over or impacted with a vehicle with minimal to no damage being imparted to the impacted vehicle or the HV-REMO device. Using a fake pedestrian also decreased safety risks and allowed for the execution of the surprise scenario.

Figure 11: HV-REMO base on the Smart Road with a pedestrian cardboard cut-out attached (left). Soft target attachment used for this project (right).

Baseline

The aim of the Baseline scenario was to allow participants the chance to experience the vehicle automation and testing environment prior to introducing more complex scenarios. Participants travelled in a loop around the Surface Street and highway section of the Smart Roads while the HMI system was inactive, shown in Figure 12. No events (e.g., pedestrian crossings, confederate vehicle interactions, stopping) occurred during this time. Test vehicle speed did not exceed 35 mph during the scenario.

Figure 12: Baseline scenario vehicle path.

Pedestrian Crossing (Detected and Undetected)

In this test, the vehicle began on the Surface Street and looped around toward the straightaway portion of the road. For the detected Pedestrian Crossing scenario, the vehicle came to a full stop for 10 seconds at the intersection while the HV-REMO pedestrian crossed the street. During this crossing, the HMI system indicated a pedestrian was present. The vehicle path can be seen in Figure 13.

The undetected pedestrian crossing followed the same overall path as the detected pedestrian crossing but with one exception: when the vehicle reached the intersection, it did not come to a complete stop, and the HMI did not indicate the pedestrian was present in the crosswalk. Instead, the vehicle continued the route while the pedestrian was still in the crosswalk, thereby striking the HV-REMO target unless the occupants took emergency action and pressed the stop button. This was considered the "surprise event" and occurred only at the end of each testing session as the last trial. The HMI systems did not indicate a hazard was present during this scenario (e.g., the visual display did not show a pedestrian and the audio system did not emit a tone) to simulate a noticeable vehicle "malfunction".

To further reduce risk to the test vehicle and participants, the striking speed was kept intentionally low, at approximately 10 mph.

Figure 13: Pedestrian crossing (detected and undetected) scenario diagram.

Following Lead Vehicle/Work Zone Lane Shift

The test vehicle began the route and came to a stop behind a lead vehicle, driven by the confederate driver. After a ten-second stop by the test vehicle, both vehicles turned right, toward the highway section, with the test vehicle following the lead vehicle. Both vehicles entered the highway section via the exit-ramp. Once on the highway, the lead vehicle continued toward the entrance gate and the test vehicle traveled around Turn 1. For the remainder of the route, the test vehicle did not follow a lead vehicle. After Turn 1, the test vehicle speed increased to 35 mph, simulaitng a more “highway-like” speed.

After the long straightaway on the highway section of the road, the test vehicle approached the traffic light intersection, decelerated to 25 mph, and turned left onto the highway/Surface Street connector. On the connector, a work zone lane shift was set up using traffic cones, shown in Figure 14. Once the test vehicle reached this point, it decelerated to 15 mph and merged to the opposite lane. After the end of the lane shift, the test vehicle transitioned back to the original traveling lane.

The test vehicle then continued the rest of the route until reaching the main intersection of the Surface Street section, where it came to a stop for 10 seconds. To further increase the visual complexity of the driving landscape and to show that the pedestrian was not deemed a hazard, since it was not located directly in the driving path, the vehicle began to turn right at the same time the HV-REMO pedestrian crossed the street. The scenario diagram is shown in Figure 15.

Figure 14: Lane shift location for work zone.

Figure 15: Following Lead Vehicle/Work Zone scenario diagram.

Left Turns

To further simulate a more complex, urban setting, the test vehicle began Left Turn scenario by first following the outermost loop on the Surface Street, then traveling in a smaller loop at the bottom of the straightaway, where it then approached the intersection and came to a stop for 10 seconds. As the test vehicle turned left to complete the loop, the HV-REMO pedestrian simultaneously crossed the road, as seen in Figure 16. For the visual HMI, the display showed that the pedestrian was present. For the auditory HMI, since the pedestrian was not within the intended path of the vehicle and not considered a hazard, no alerts were triggered.

Figure 16: Left Turns test vehicle path. The double arrows indicate the vehicle passed over that section of the route twice.

Passenger Pick Up

This scenario was designed to simulate a passenger pick up similar to what may occur during a carpool rideshare trip. The test vehicle first traveled toward the center of the Surface Street, where it stopped for 45 seconds. During the stop, a researcher approached the vehicle, opened the driver's door (e.g., as if getting inside the vehicle), closed the door, and then retreated to a safe distance from the vehicle.

After the researcher was a safe distance away and 45 seconds had elapsed, the test vehicle continued the route, traveling down the straightaway, toward the intersection. At the crosswalk, the vehicle stopped for 10 seconds while the HV-REMO pedestrian crossed. After, the test vehicle continued straight, around the bottom of the Surface Street. After completing the loop, the test vehicle approached the intersection and stopped again for 10 seconds. After the stop, similar to the Left Turns scenario, as the test vehicle began to move and complete the rest of the route, the HV-

REMO pedestrian simultaneously crossed the road. The vehicle path described above can been seen in Figure 17.

Figure 17: Passenger Pick Up test vehicle path. The double arrows indicate the vehicle passed over that section of the route twice.

Experimental Procedure

During experimental sessions volunteer participants sat in the rear seats of the test HAV and experienced vehicle scenarios on the Smart Roads. In the following section, researchers' roles during experimentation and the procedure of test sessions are outlined in detail.

Researchers Involved

Moderator

The moderator was the lead researcher for each testing session. In this role, the moderator was responsible for all interactions with participants, including onboarding, distributing surveys, and fielding any participant questions. In addition, the moderator was in charge of starting/concluding each vehicle scenario and communicating with the Smart Roads control room via a two-way, handheld radio. The moderator did not sit in the test vehicle during any scenarios to make participants feel as if nobody was in control of the vehicle and there were no safety backups, further enhancing the ruse of a fully automated vehicle.

Confederate Driver

The confederate driver was responsible for driving the confederate vehicle and controlling the HV-REMO according to scenario specifications. It was also the confederate driver's responsibility to set up the test vehicle according to the provided guide (Appendix B) and perform vehicle checks prior to each testing session.

Safety Driver

Since the test vehicle used in the study was a prototype, researchers in this role acted as a redundant safety backup in case of a system malfunction. For this position, a VTTI researcher sat in the front passenger seat of the test vehicle and acted as a participant. The safety driver went through all onboarding tests, completed all surveys, and experienced all vehicle scenarios.

In the event of an automation failure or vehicle malfunction, the safety driver could disable automation using the stop button located in the center console then bring the vehicle to a stop with the safety brake or through manual steering control (e.g., reaching steering wheel from passenger seat). Before experimentation began, safety drivers were trained by researchers on potential failures which could occur and how to react in emergency situations. In addition, safety drivers were seasoned VTTI researchers who had also undergone additional institutional safety training. Because of the safety drivers' extensive safety trainings and prior vehicle-research experiences, identifying test vehicle malfunctions and conducting the appropriate steps for intervention was at their discretion. If intervention was necessary, after stopping the vehicle, the safety driver 1) continued to act as a participant and called the moderator on the two-way radio or 2) revealed themselves as a VTTI researcher to the participants by reading a prewritten script (Appendix C), as required by the Institutional Review Board (IRB).

Testing Procedure

Volunteer participants were identified by the Recruitment Office at VTTI through a database of eligible participants, social media, and newsletter ads (Appendix D). Potential participants were instructed to contact VTTI directly with any questions about the project and for additional information. After expressing interest, their verbal consent to participate in the study was obtained over the phone and an eligibility screening (Appendix E) was conducted. Those who were interested and eligible were scheduled to come to VTTI to participate in a testing session lasting approximately one and a half hours.

Upon the arrival of all scheduled participants (two at one time) and the safety driver posing as a participant, the group was directed by the moderator to a subject prep room, which are IRB-approved rooms located at VTTI and used by researchers for filling out onboarding paperwork with participants and performing pre-session evaluations. First, W-9 tax forms (Appendix F), which were required by the Virginia Tech Controller's Office to process payment, were administered to participants, and valid forms of identification were checked by the moderator. Next, each participant was directed, one at a time, to a separate room to fill out additional paperwork, such as the Informed Consent Form (ICF, Appendix G) and to complete hearing and vision assessments (Appendix H). Finally, participants were asked to complete a brief pre-test questionnaire, which included scaled-down sensation-seeking and locus of control questionnaires (Appendix I), adapted from Zuckerman's Sensation Seeking Scale (1978) and Rotter's Locus of Control Scale (1966). This pre-session questionnaire was further used to assess participants' familiarity with AVs and to pinpoint any behaviors that could impact their inclinations to accept new technologies. Throughout the entire onboarding process, the moderator assisted participants with the completion of these forms as needed (e.g., answering questions, clarifying study expectations).

Once all participants completed the W-9, ICF, hearing and vision assessments, and pre-test questionnaire, an overview of the schedule and testing protocol was provided by the moderator. This overview emphasized the purpose of the research study, the environment where the testing sessions would take place, and what was expected of them as participants.

The participants were then led to a Chevy Tahoe vehicle for transportation to the Surface Street section of the Smart Roads. Parked on the Surface Street was the Cadillac SRX research vehicle, set up by the confederate driver and ready for automation engagement. The moderator directed participants to their seating locations, first directing the safety driver to the front passenger seat, thereby giving participants less time to notice the safety brake in the footwell of the passenger seat, then directing the other participants to their seats in the second row, behind the driver's and front passenger's seats. To further reduce bias, seating locations of each participant (left side, behind the steering-wheel vs. right side, behind the safety driver) were counterbalanced based on gender, as participants were able to view the roadway differently on one side of the vehicle compared to the other. Once all passengers were seated and buckled, the moderator explained how to operate the stop buttons and two-way radio, available for direct communication with the moderator. The moderator also reiterated what would occur during testing, what was expected of the participants, and safety procedures. Participants were also advised before each trial to limit discussion during the testing session, to mitigate risk of biasing individual's subjective opinions.

After setting up at the initial staging area and fielding any remaining questions, the moderator engaged vehicle automation and the first test scenario was initiated. Across all participants, the first trial scenario was the baseline route. The test vehicle traveled the scenario path with no HMI systems engaged to allow participants to become more comfortable with the vehicle, vehicle maneuvers, and to gauge their base levels of comfort, trust, safety, and situational awareness while riding in the vehicle.

Following each scenario, the moderator approached the vehicle and administered a paper-based, post-trial questionnaire (Appendix J) individually to each participant for them to evaluate the HMI system, or lack thereof, and their experiences during the maneuver. To reduce response bias due to external influences, the questionnaires were distributed to participants on separate clipboards and discussion was discouraged. After the questionnaires were completed, the moderator inputted a numerical code, specific to each scenario, into the vehicle's computer system to stage the next scenario. After the final session trial (the "surprise" event), the moderator read a short debrief (Appendix K) to participants explaining that the scenario was preprogramed to include a system malfunction and distributed a final questionnaire.

Once the testing session was complete, participants were asked to exit the test vehicle to be transported back to the main VTTI building in the Chevy Tahoe, where they were thanked for their time and provided with $60 in compensation through a prepaid ClinCard (MasterCard).

Vehicle Malfunctions

Although the test vehicle was more advanced than anything used not only at VTTI but also in other studies conducted in this subject area, due to the prototype nature of the test vehicle, numerous vehicle malfunctions and failures were experienced throughout the duration of the study. At times, the vehicle steering and speed did not function appropriately, causing the safety driver to intervene. For example, there were instances where the steering completely failed or the vehicle exhibited erratic speed surges. In the event that the safety driver needed to intervene and stop the research vehicle, they could either 1) continue to act as a participant or 2) if they could not continue the ruse, read aloud a debrief (Appendix L) to explain their role and why they stopped the vehicle.

If the vehicle was brought to a stop, but the safety driver continued to act as a participant, the moderator was called via the two-way radio and participants were transported in the confederate vehicle to the Automation Hub, a VTTI building with direct access to the Surface Streets. At the Automation Hub, participants sat in a conference room with the moderator and safety driver while the confederate driver communicated with the CTD team to resolve the vehicle issues. If the test vehicle computer was able to be re-booted, the test vehicle regained full function, and the malfunction experienced by participants did not adversely affect them physically or mentally, the session continued with the next scenario. No data was collected from the scenario where the malfunction occurred.

If the safety driver stopped the vehicle and revealed their true role, the vehicle malfunction was not able to be resolved, or a participant did not want to continue riding in the test vehicle, the session was ended by the moderator and participants were paid a prorated amount based on their participation time. If the malfunction was experienced later in the testing session (e.g., after Trial 4), data collected before error occurred was considered for analysis. However, if the malfunction was experienced earlier in the testing session, data obtained was not used, and the testing session was required to be repeated with new participants.

Data Analysis Methods

Qualitative, subjective data were collected during test sessions to determine relationships between independent variables (Table 4) and dependent variables (Table 5). A majority of data were collected through the surveys distributed pre-test and post-trial.

Table 4: Independent Variables

Independent Variable	Levels
HMI Condition (No HMI, Audio-Only, Visual-Only, Mixed-Modal)	No HMI, Audio-Only, Visual-Only, Mixed-Modal
Trial Number	1, 2, 3, 4, 5, 6
Scenario Type	Baseline, Pedestrian Crossing, Surprise, Following Lead Vehicle/Work Zone, Left Turns, Passenger Pick Up
Previous Exposure to AV (Yes, No)	Yes (Y), No (N)
Initial Comfort Level (High, Mid, Low)	High, Mid, Low
Age	Ages 25-38
Gender	Male (M), Female (F)
Sensation-Seeking	High, Mid, Low
Locus of Control	Internal, Mixed, External

Table 5: Dependent Variables

Dependent Variables	Levels
Comfort	Survey scores of 1-7
Trust	Survey scores of 1-7
Safety	Survey scores of 1-7
Situational Awareness	Survey scores of 1-7
Desire to Press the Stop Button	Survey scores of 1-7
Desire for Additional Information	Survey scores of 1-7
Clarity of Vehicle Intentions	Survey scores of 1-7
Clarity of Vehicle Perceptions	Survey scores of 1-7
Additional Information Desired	Open-Ended Feedback
Feedback about the HMI System	Open-Ended Feedback

Researchers expected that participants who experienced the more-detailed, information-rich HMI systems, such as the mixed-modal and visual-only systems, would report higher levels of comfort, trust, safety, situational awareness, and vehicle communication clarity. In addition, based off of previous literature, researchers predicted that individuals who exhibited higher initial comfort, higher sensation-seeking tendencies, external locus of control, and who had previous exposure to AV systems would also report higher metrics.

As trial number increased (e.g., as the test session progressed over time), researchers expected participants' metrics to increase as they became more acclimated to the test vehicle, automated systems, and testing environment. However, when participants experienced a more complex scenario, such as the Following Lead Vehicle/Work Zone scenario, compared to a simpler scenario, such as the Pedestrian Crossing scenario, it was expected that participants' levels of comfort, trust, and safety would decrease.

Self-Reported Metrics

Data collected about participants' behavioral characteristics and perceptions of the HMI systems were obtained through pre-session and post-trial surveys. The pre-session surveys were distributed in the building during the onboarding process, prior to entering the Smart Roads. The post-trial surveys were distributed in the test vehicle, following each experimental scenario. Surveys contained statements asking participants to rate their levels of agreement on a seven-point Likert scale with anchor words, seen in Figure 18.

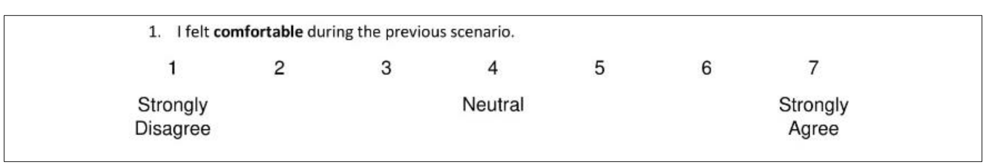

Figure 18: Sample Likert-scale question posed to participants during the post-trial questionnaire.

"Strong disagreement" were scores of 1, "disagreement" were scores from 2-3, "neutral" were scores of 4, "agreement" were scores from 5-6, and "strong agreement" were scores of 7. Each survey also had one to two open-ended questions to capture additional qualitative, open-ended feedback and individual opinions about the test vehicle, automated systems, and HMIs.

Statistical Analysis

Data visualization and statistical analysis were performed using code written in Python (Appendix M), leveraging the features of several built-in libraries. Since the surprise event represented a different vehicle state than what was presented in the other trials, unless otherwise shown, data from these trials were not included in analyses. Data were assumed to have a normal distribution.

First, figures were generated from the datasets to better visualize trends in the data. A 95% confidence interval was used to calculate the error bars for each figure. Afterward, main effects were examined by performing analysis of variance (ANOVA) calculations with an alpha value of 0.05 using an ordinary least squares (OLS) approach, also known as a linear regression. In addition, interaction analyses were performed using the same method. From the OLS regressions, statistical metrics such as the sum of squares, degrees of freedom, and residuals were determined. Most importantly, from these models the p-value was obtained, which indicated whether there were statistically significant differences between the groups. If the p-value was less than 0.05, statistical significance was present between groups, and Tukey Honest Significant Difference (HSD) post-hoc tests, with alpha values of 0.05, were performed. The Tukey HSD tests determined which variants between groups were causing the significance.

However, since the OLS models assumed all observations were independent, which could lead to multiple comparison issues, a R-based linear mixed-effect model (Appendix N) was also implemented for further statistical analysis (Bell, Fairbrother, & Jones, 2019). This type of model allowed researchers to examine a combination of both between-subject and within-subject factors, both of which were present in this experiment. The model also accounted for correlation in individual participant's responses to survey questions (Laird & Ware, 1982) by assigning a random effect value to each Participant ID. In addition, it considered the effects of multiple independent variables on a single dependent variable and compensated for groups with unequal sample sizes (Bates & Pinheiro, 1998). Since mixed-effects models consider multiple variable interactions and participant response correlations, more interactions and variability can be accounted for and conclusions drawn from statistical outputs are more robust and defendable.

Using the lme4 package available in R, linear mixed-effects models (e.g., lmer) were created by considering the combined effect that HMI condition, trial number, and scenario type had on comfort, safety, trust, and situational awareness. In addition, random effects were added for each specific Participant ID in the dataset. Although more independent variables could have been included in the model to account for more interactions, to reserve statistical power for post-hoc tests, researchers limited model factors. If significance was determined from the linear mixed-effect model, similar to the main effects and interaction analyses, Tukey HSD tests were applied to identify the specific factors which contributed to the statistical significance.

All raw statistical analysis tables can be found in Appendix O.

Participant-Specific Analysis
To further account for individual response correlation and to determine if any trends were present in the data, individual participants' reported levels of comfort, trust, safety, and situational awareness were examined across the first 5 trials of the testing session, considering the scores obtained after the Baseline scenario as an individual factor. Only the data of participants who experienced a complete testing session (e.g., all 5 trials) were considered. Data collected after the surprise event was not considered in this analysis.

Individual participant scores for each metric (e.g., comfort, trust, safety, and situational awareness) were organized according to trial number. The differences between each trial-specific score were then calculated: first examining the differences between Trial 2 and Trial 1, then Trial 3 compared to Trial 2, etc. These values were then summed to find a net difference score which indicated whether or not reported metrics increased (e.g., a positive net score), decreased (e.g., a negative net score), or remained the same (e.g., a net score equal to zero) for that specific participant across the testing session. An example of the method outlined above can be seen in Table 6 below.

Table 6: Participant-Specific Analysis Example

PID	**T1**	**T2**	**T3**	**T4**	**T5**	**T2 vs. T1**	**T3 vs. T2**	**T4 vs. T3**	**T5 vs. T4**	**Sum**	**Trend**
P01	6	6	6	6	6	0	0	0	0	0	None
P02	5	6	6	6	6	1	0	0	0	1	Increased
P03	7	7	7	7	7	0	0	0	0	0	None
P04	5	4	5	3	4	-1	1	-2	1	-1	Decreased

These trends were then categorized by HMI condition to determine if a particular condition showed higher trend prevalence compared than another HMI type. By performing this analysis, it allowed researchers to gain a better understanding of the HMI conditions' effects on participants' reported metrics, while accounting and controlling for individual response correlations. Raw data from analysis can be found in Appendix P.

Open-Ended Feedback
Participants' responses to the open-ended questions administered during the post-trial questionnaires were examined using a content analysis. Such examination was undertaken to better understand whether consistent themes could be seen across participant feedback. These patterns had the ability to highlight consistent experiences and themes across participants. To determine these patterns, a deductive qualitative analysis paired with inter-rater reliability was employed.

A deductive qualitative analysis used the study's research questions to guide how the data were organized and categorized (Armat, Assarroudi, Rad, Sharifi, & Heydari, 2018; National Science Foundation, 1997). In this case, the central research questions and themed data categories were focused on understanding which HMI modality was best for communicating vehicle-critical information and increasing comfort, safety, trust, and situational awareness among users. To further refine these broad, higher-level groupings, a combination of descriptive coding (i.e., summarizing central themes seen in the data) and pattern coding (i.e., finding patterns of specific mentions in the data) were used (Saldana, 2018). Themes were created by researchers in brainstorming sessions. In this study, “primary themes” referred to the broader themes seen throughout participant responses, and “secondary themes” were the specific mentions within those larger categories. Inter-rater reliability is the method of two or more people categorizing data within a specific subset and the degree to which their responses agree (Lange, 2011). Based on this level of agreement, a Cohen’s kappa value (κ), or a numerical value of agreement between two raters not due to chance, was calculated (McHugh, 2012; Fleiss & Cohen, 1969).

Two researchers individually matched participant qualitative feedback with the predetermined themes. Once the individual researcher’s responses were recorded, a single researcher compared them for agreement. The “no HMI” and “HMI” post-trial surveys had different open-ended questions, therefore, the responses were analyzed separately.

The “no HMI” open-ended question asked participants what kind of information, if any, would have improved their experience during that specific scenario. Based on the comments received, responses were coded into two primary categories: 1) Participant wanted additional information and 2) Participant mentioned undesirable vehicle dynamics. These primary categories were then further reduced into secondary categories, as seen in Table 7.

Table 7: “No HMI” Primary and Secondary Thematic Categories

Wanted More Information	**Mentioned Undesirable Vehicle Dynamics**
Turn signals	Vehicle did not follow lane lines
Music	Steering wheel noise
Navigation/maps	Speeds/turns/braking
Hazard detection	Location of vehicle stops

The “HMI” open-ended question asked participants for any feedback they had about the HMI system. Since this question was more about opinions of the HMI system, the responses were more variable, and more primary categories were created to encompass all comments, as seen in Table 8. Additional secondary categories were also developed according to the responses that emerged.

Table 8: “HMI” Primary and Secondary Thematic Categories.

The HMI Was Not Accurate	**Mentioned Undesirable Vehicle Dynamics**	**Wanted More Information from the HMI**	**HMI and Comfort**
Vehicle position was not correct	Vehicle did not follow lane lines	Turn signals	HMI increased comfort
External stimuli (e.g., other passenger or vehicle) position was not correct	Speeds/turning/braking	Navigation/maps	HMI decreased comfort
Timing/vehicle dynamics were not correct	Location of vehicle stops	Hazard detection	HMI had no effect on comfort

Researchers used Microsoft Excel to organize and code the qualitative data. Each theme was given its own column, and each participant response was placed in a row. Then, researchers determined whether the qualitative theme applied to the comment. If a theme was applicable, researchers marked it as "1", and if a theme was not applicable or the row was blank, a "0" was used, as seen in the example below (Table 9).

Table 9: Primary Thematic Coding Example

HMI Condition	Scenario	Additional Information Wanted	Want More Info	Undesirable Vehicle Dynamics
Visual-Only	6	"Turn signals"	1	0

After each researcher was finished assigning their individual scores, the two sets were compared and Cohen's kappa values were calculated. Variables were first assigned for all possible different scoring combinations, as seen in Table 10.

Table 10: Variable Assignment for Different Scoring Combinations

		Researcher B	
		1	**0**
Researcher A	**1**	a = 11	c = 10
	0	b = 01	d = 00

Next, the individual probability of researchers' total agreement [*P(A)*] was calculated based on the assignment of "1" [*P(1)*] or "0" [*P(0)*]:

$$P(A) = \frac{a+d}{a+b+c+d} \tag{1.1}$$

$$P(1) = \frac{a+b}{a+b+c+d} * \frac{a+c}{a+b+c+d} \tag{1.2}$$

$$P(0) = \frac{c+d}{a+b+c+d} * \frac{b+d}{a+b+c+d} \tag{1.3}$$

Based on *P(1)* and *P(0)* values, *P(E)*, or the probability of agreement between researchers due to chance, was calculated:

$$P(E) = P(1) + P(0) \tag{1.4}$$

Finally, using *P(A)* and *P(E)*, the Cohen's kappa value was calculated:

$$k = \frac{P(A) - P(E)}{1 - P(E)} \tag{1.5}$$

Resulting kappa values indicated researchers' level of agreement, not due to chance, as defined in Table 11 (Viera & Garrett, 2005).

Table 11: Cohen's Kappa Value Ranges and Agreement Levels

Kappa Value Range	Agreement Level
0	No agreement
0.01-0.20	Slight agreement
0.21-0.40	Fair agreement
0.41-0.60	Moderate agreement
0.61-0.80	Substantial agreement
0.81-0.99	Near perfect agreement
1	Perfect agreement

All coded qualitative raw data can be found in Appendix Q; Cohen's Kappa calculations can be found in Appendix R.

Surprise Event Analysis

Instead of using the post-trial survey data to analyze the surprise event, researchers decided to examine video and audio of participants pre- and post- strike to obtain more realistic, objective measures of participant behavior during these times. Not only would it allow evaluation of participant reactions, but these recordings could also exhibit "bystander effects", where a person did not intervene in a critical situation due to the presence of other people (Fischer, et al., 2011). In the context of this study, a participant may have reached for the stop button or said something which indicated awareness of the system malfunction but hesitated to perform any sort of evasive action, due to other individuals also riding in the vehicle.

Video and audio recordings captured by the in-vehicle cameras were consulted in Hawkeye, a VTTI software package allowing researchers to view all data collected by the DAS during experimentation. Footage from 20 seconds prior to and 20 seconds after the test vehicle impacted the balloon pedestrian was viewed by researchers for adequate participant behavior analysis. Based on participant reactions seen pre- and post- strike, similar to the open-ended feedback analysis, different categories were created which encompassed these behaviors (Table 12) and the events seen in the footage were assigned a category. Some participants exhibited multiple reactions, assigned to multiple categories, during this timeframe.

Table 12: Pre- and Post- Strike Participant Reaction Categories

Participant Reaction
No reaction
Movement towards stop button
Verbal comment
Change in facial expression
Other

In some test sessions, certain cameras did not work or failed halfway through the testing session. Therefore, the surprise event analysis only used footage where participants' face-view was available during the time of the strike. Raw data for the surprise event can be found in Appendix S.

RESULTS AND DISCUSSION

Summary data obtained through the experiment, aiming to answer the study's research questions, can be found in the graphs below. Values seen above each bar represent the group averages, and values displayed at the bottom of each bar (i.e., n=) represent the sample size for each group. This sample size does not represent the number of participants who answered the question but rather the number of repeated measures of participant responses for that question. The surprise event represented a different condition than what was experienced by participants during the other session scenarios and trials, therefore data been removed from reporting, unless otherwise stated.

"No HMI" Conditions

As described in the Methods, the preliminary results of the "with knowledge" condition indicated that levels of comfort, trust, safety, and situational awareness were much higher than originally anticipated. The research team was concerned that such elevated measures in this condition would limit the response opportunity for the treatment conditions. The concern led to a detailed review of the experimental protocol and creation of a second "no HMI" condition, which collected data under a slightly different protocol, the results of which can be seen in Figure 19.

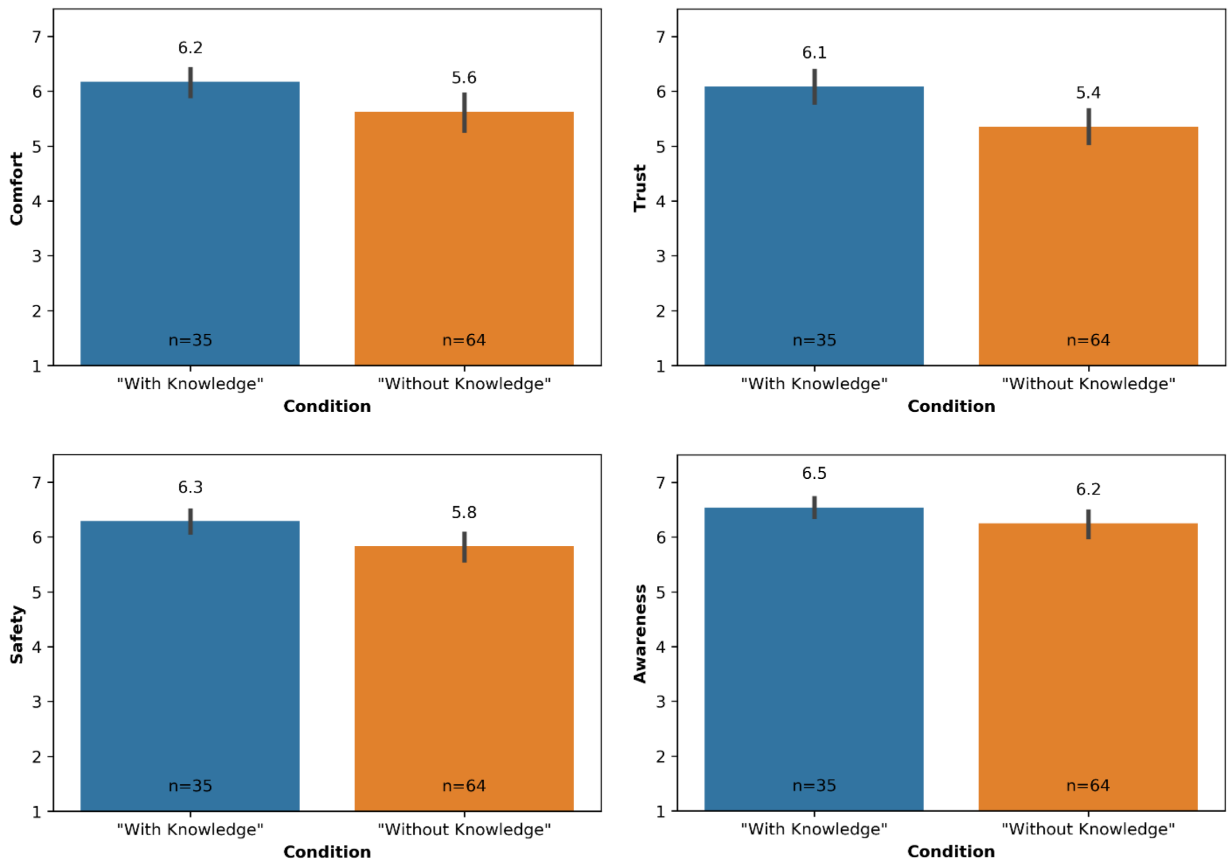

Figure 19: "No HMI" conditions compared to self-reported levels of comfort (top-left), trust (top-right), safety (bottom-left), and situational awareness (bottom-right)

During the "with knowledge" condition, researchers revealed more information about the vehicle limitations and testing environment safety controls. Likely because of these extra forewarnings, participants reported significantly higher, perhaps artificially elevated, levels of perceived comfort (p=0.03), trust (p=0.003), and safety (p=0.02). Situational awareness was not affected by the differences in conditions.

It is interesting to consider the implications that a few, relatively minor, changes in the information provided to participants exhibited a significant effect on the metrics. While not a primary investigation of this study, the results indicate that appropriate training on HAV may have substantive impacts on the rider's impression, even when systems are imperfect.

A Likert scale question about whether additional information would improve levels of comfort, trust, safety, and situational awareness was also presented. From this question, participants' desire for information when none was supplied could be measured. Summary data from the Likert scale question can be seen in Figure 20.

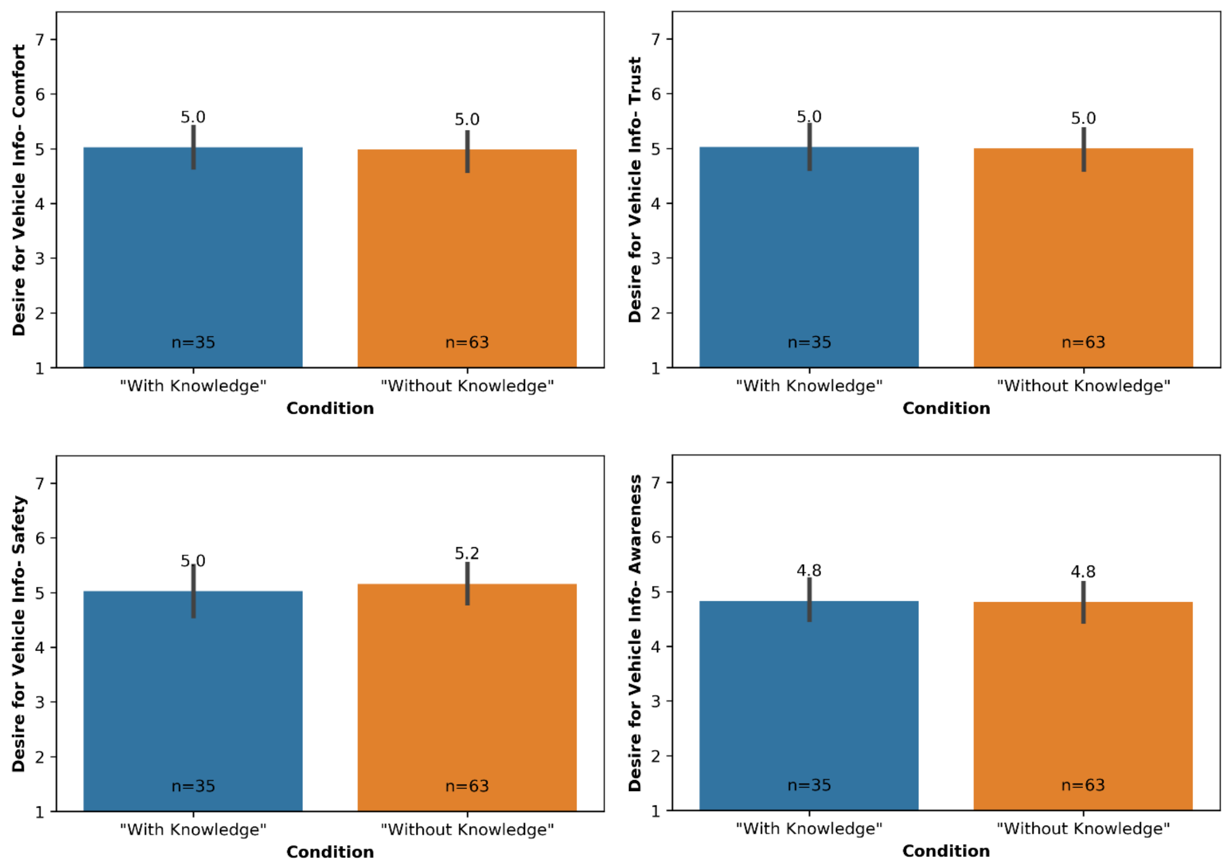

Figure 20: Desire for more information and how it would affect participants' comfort (top-left), trust (top-right), safety (bottom-left), and situational awareness (bottom-right) compared to the two different "no HMI" conditions.

Researchers expected participants to want more information about the vehicle's "intentions" during these conditions, particularly in the "without knowledge" condition, as no additional information was provided. However, when participants were asked whether more information would improve their levels of comfort, trust, safety, and situational awareness, a majority indicated neutral-slight agreement. Even though significant differences were seen between the two "no

HMI" conditions in reference to comfort, safety, and trust (Figure 19), participant responses between them appear equal (Figure 20).

Considering that participants had no previous experience with HAVs, they may not have understood what types of information could have been presented during the maneuver, resulting in low desire for more information. Another likely explanation for the neutral desire for additional information was the participants' levels of comfort, trust, safety, and situational awareness during these "no HMI" conditions. These reported metrics were already relatively high to begin with, therefore providing participants with additional vehicle information may have only caused marginal improvement. This effect is prominent in the "with knowledge" condition, which resulted in the decision to consider the "without knowledge" condition as the "true" control condition. Thus, the "with knowledge" condition has been omitted from the subsequent data reporting and analysis, unless otherwise specified. In subsequent graphs, "No HMI" indicates the "without knowledge" control condition.

HMI Condition and Perceived Comfort, Safety, Trust, and Situational Awareness

To answer one of the primary research questions of the study, HMI conditions were compared to participants' reported levels of comfort, trust, safety, and situational awareness during experimental sessions, shown in Figure 21.

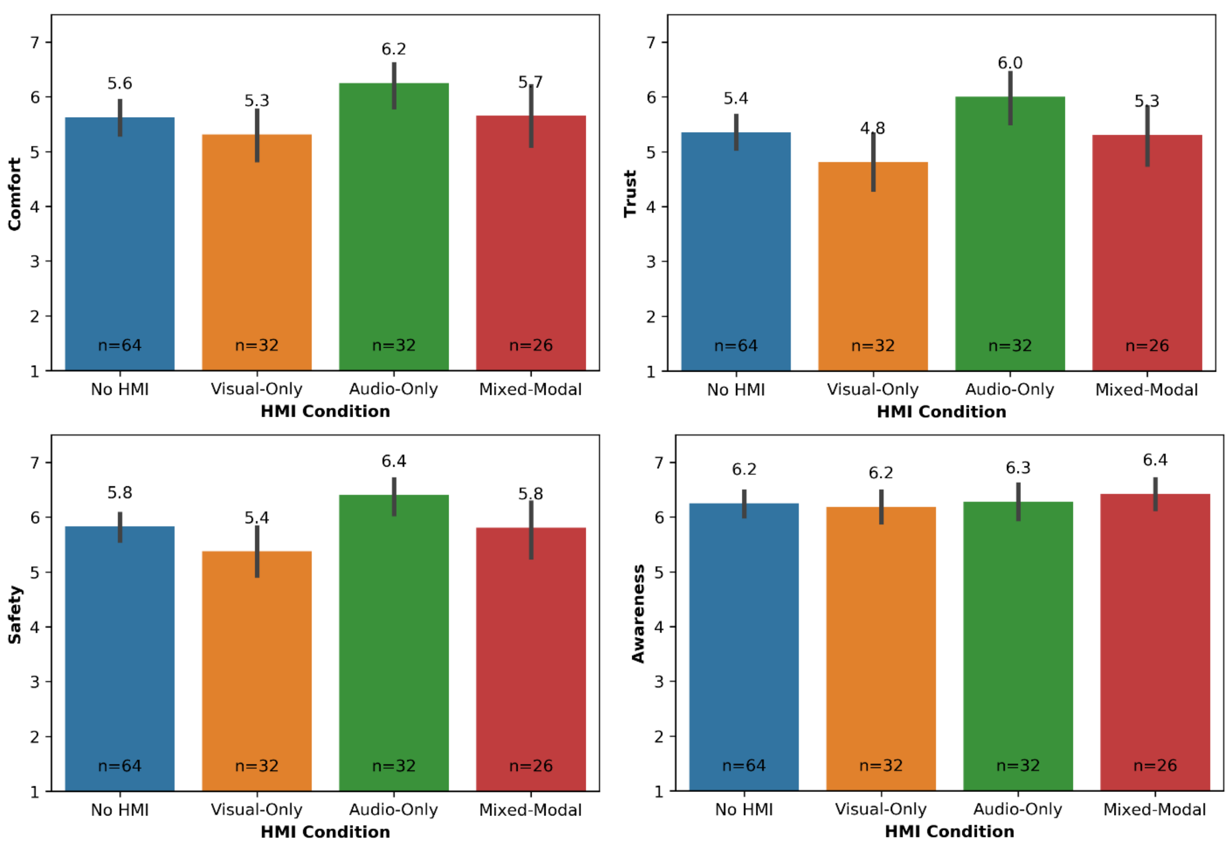

Figure 21: HMI condition compared to self-reported levels of comfort (top-left), trust (top-right), safety (bottom-left), and situational awareness (bottom-right).

After examining both the summary data and statistical analysis outputs, researchers determined that participants who experienced the auditory HMI condition reported significantly higher levels of comfort ($p=0.004$), trust ($p=0.002$), and safety ($p=0.0005$) than those who experienced the visual-only condition. Unexpectedly, participants who experienced the visual-only HMI condition reported the lowest levels of the metrics, even when compared to the "no HMI" condition. Researchers initially hypothesized that the auditory HMI would produce the lowest levels of perceived comfort, trust, and safety, and would be the least effective at communicating vehicle "intentions", since it provided users with the least detailed vehicle information. As additional, more detailed information was supplied to the user through the visual and mixed-modal HMIs, these metrics were expected to increase.

Perceived situational awareness was not significantly affected by any HMI condition, however, the reader should interpret this finding with caution. Prior to the session, situational awareness was not defined for participants and no strategies for how to quantify it were implemented into the experimental design. Therefore, participants may have had different perspectives of what situational awareness represented when asked about it during post-surveys.

The scenarios used for this experiment were variable and modeled on real-world driving situations. Since there was variability from scenario to scenario (e.g., different vehicle maneuvers, additional vehicles on the roadway, or additional research personnel present), whether these differences affected participants' impressions was of interest. Reported levels of comfort, trust, safety, and situational awareness can be seen in Figure 22. In subsequent sections, certain scenario names have been simplified. "Ped Xing" represents the Pedestrian Crossing scenario, "Work Zone" represents the Following a Lead Vehicle/Work Zone scenario, "Turns" represents the Left Turns scenario, and "Pick Up" represents the Passenger Pick Up scenario.

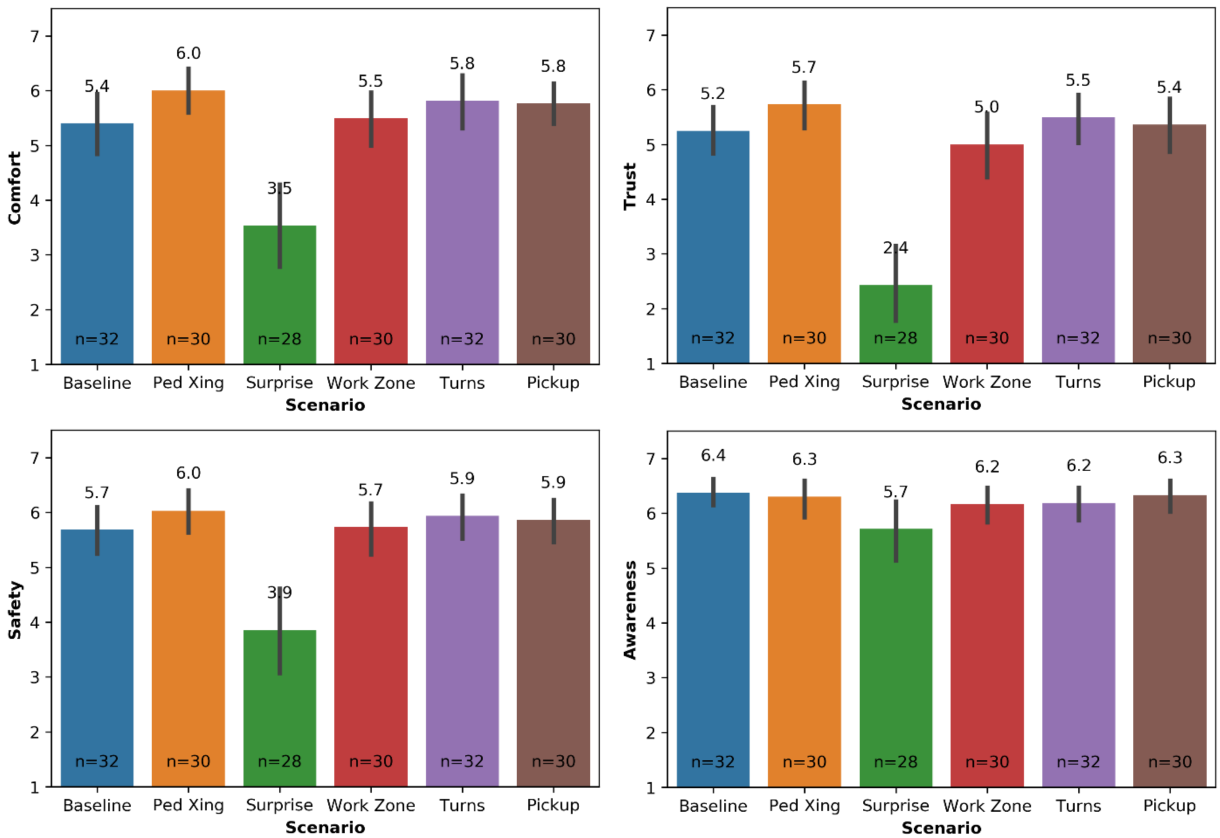

Figure 22: Scenario type compared to participants' reported levels of comfort (top-left), trust (top-right), safety (bottom-left), and situational awareness (bottom-right).

Only the surprise event (e.g., undetected Pedestrian Crossing scenario) had a significant effect on these metrics ($p_{comfort}$=6.42e-09, p_{safety}=1.96e-08, p_{trust}=1.15e-15). A slight decline in perceived comfort, trust, and safety was seen during the Baseline, Following a Lead Vehicle/Work Zone, and Passenger Pick Up scenarios. This slight decline may imply that factors such as the presence of obstacles or familiarity with the vehicle, could have altered participants' feelings of comfort, safety, and trust. The Baseline scenario was always the first scenario participants experienced, so participants may have been acclimating to the vehicle and testing environment. In addition, no HMI systems were active during this scenario, so no vehicle information was being communicated to the passengers. For Following Lead Vehicle/Work Zone and Passenger Pick Up scenarios, participants may have been a bit more uneasy because there were additional vehicles and obstacles present on the road. These additional environmental factors increased the variability and complexity of the driving landscape and may have subsequently increased riders' perceptions of risk to personnel or other vehicles.

To determine whether participants would become acclimated to the vehicle dynamics and maneuvers over the duration of the session, trial number was examined. Hypothetically, researchers believed that due to vehicle acclimation there would be a steady increase in perceived levels of comfort, trust, safety, and situational awareness across Trials #1-5 (i.e., as the session progressed), with a sharp decline in Trial #6 due to the surprise event. Summary data comparing trial to participant reported metrics can be seen in Figure 23.

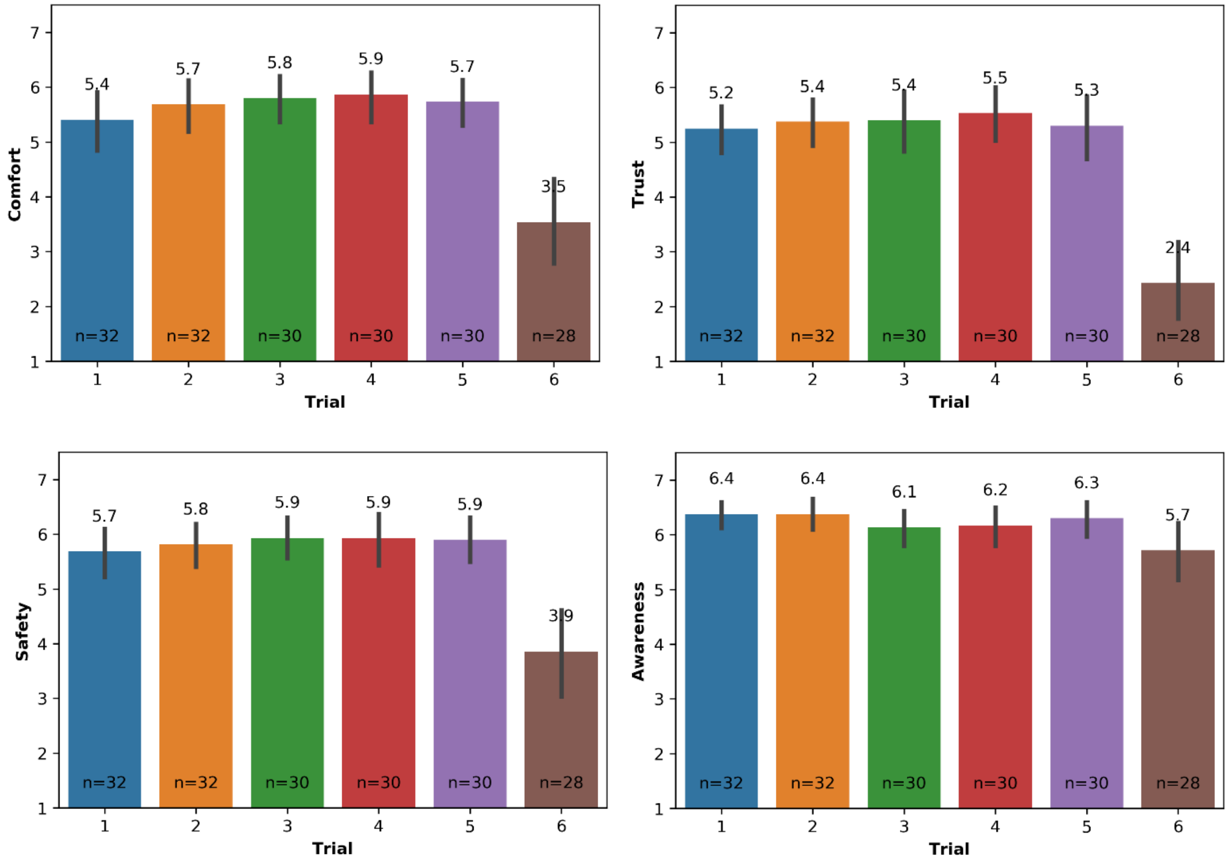

Figure 23: Comfort (top-left), trust (top-right), safety (bottom-left), and situational awareness (bottom-right) levels compared to trial number.

As expected, there was a slight trend, though not statistically significant, of comfort, safety, and trust increasing as the session progressed. Only Trial #6 (i.e. the surprise event) created a significant decrease in perceived comfort (p=1.28e-08), trust (p=6.31e-15), and safety (p=2.59e-08). As people become more familiar with a piece of technology, they can become acclimated to it. This acclimation can either be positive, as users become more comfortable or trusting in the technology, leading to wider acceptance, or it can be a negative, as users become over-reliant on the technology and misuse it (Parasuraman & Riley, 1997; Cunningham & Regan, 2015; Sauer, Chavaillaz, & Wastell, 2016).

To determine levels of over-reliance, participants were supplied with a stop button that they were instructed to press if they felt uncomfortable or if the vehicle seemed as if it was malfunctioning. Their desire to press the stop button when experiencing different vehicle scenarios, session trials, or HMI conditions, derived from post-trial questionnaires, is shown in Figure 24. Not only was the stop button a metric of comfort and safety, as participants would presumably only feel the need to press it if they felt at risk, but it was also a metric of situational awareness, as hopefully they would notice the vehicle and HMI malfunctioning during the surprise event and press it.

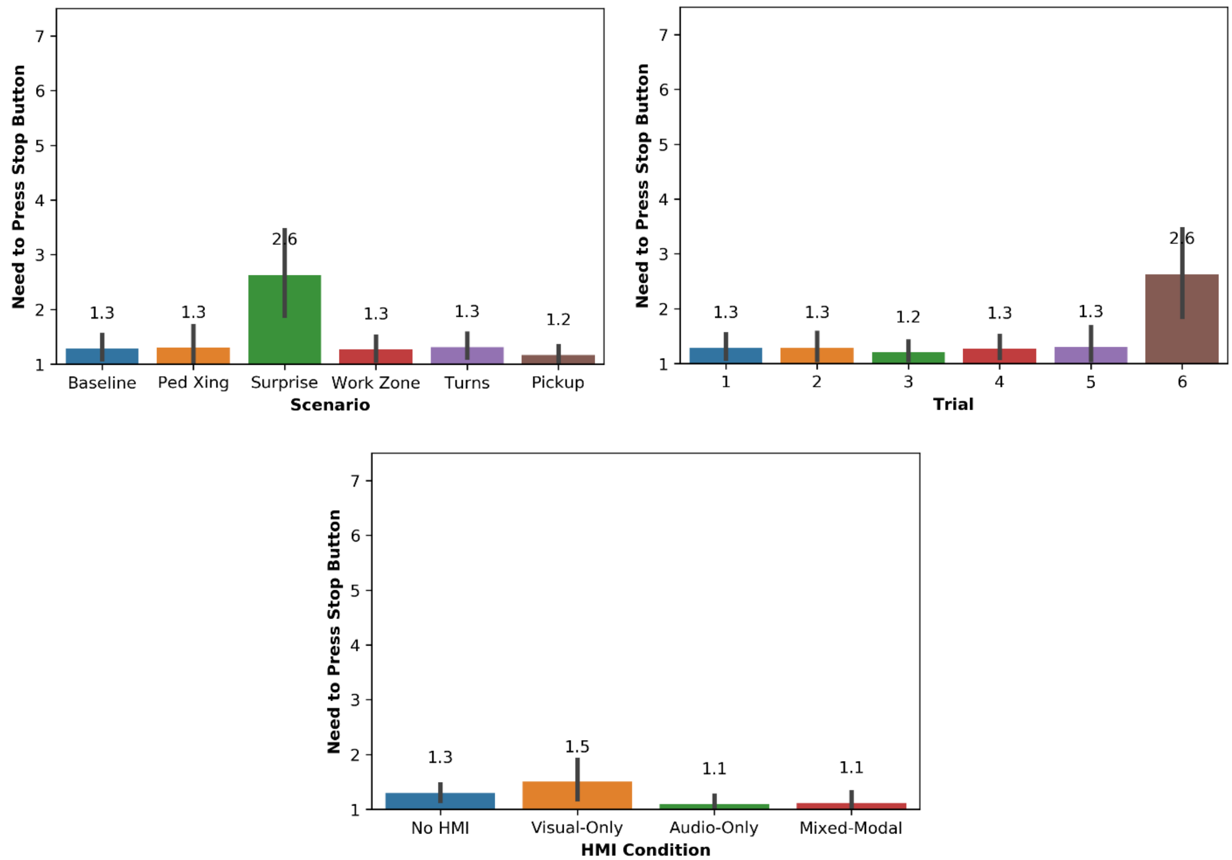

Figure 24: Participants' desire to press the stop button compared to the scenario type (top-left), trial number (top-right), and HMI condition (bottom).

Although participants reported an elevated desire to press the stop button while they experienced the surprise event (p=6.60e-07), Trial #6 (p=7.29e-07), and the visual HMI condition (p=0.05), across all sessions, only one participant out of the thirty-nine pressed the stop button during the surprise event to indicate the vehicle was not behaving appropriately. Even though the participants were only in the vehicle for a relatively short time, it was enough for them to seemingly become comfortable with the test vehicle and not recognize a system malfunction, even with sufficient time to press the stop button before impact. This lack of action could indicate an absence of situational awareness or an over-reliance of the system (Abe, Itor, & Tanaka, 2002; Noble, Dingus, & Doerzaph, 2016). Another explanation for the lack of stop button depressions could be that although the balloon pedestrian in the roadway was in danger, the participants themselves were not. The participants may have thought the stop button was only supposed to be used in an actual emergency, instead of a simulated one.

With new technology, vehicle malfunctions and miscommunications will be inevitable. The roadway is a highly variable place both due to other drivers and environmental conditions, such as weather. For example, a large proportion of vehicle sensors cannot operate in adverse weather conditions such as rain or snow. Also with new technology, as seen in countless surveys about user trust and automation, these levels of user trust and comfort are delicate and can be easily reduced by both false negatives (e.g., a system does not detect a hazard) and false positives (e.g., a system detects a hazard that is not present), especially in familiar, daily driving scenarios where users are expecting vehicles to perform perfectly (Dzindolet, Peterson, Pomranky, Pierce, & Beck, 2003; Johnson, Sanchez, Fisk, & Rogers, 2004; Madhavan, Wiegmann, & Lacson, 2006). When looking at the surprise event where a false negative was introduced, participants' levels of comfort, trust, and safety were significantly degraded and their desire to press the stop button was elevated. Both of these findings may support concerns that a single undesirable experience within a HAV can rapidly erode user impressions of the technology. In addition, the results support the claims that HAVs should not rely on any human intervention during critical system failures.

HMI and System Transparency

Previous studies have suggested that information presented in combined modalities are able to leverage multiple different sensory channels to improve user processing and understanding (Mousavi, Low, & Sweller, 1995; Leahy & Sweller, 2011) therefore reducing reaction time, if intervention is needed (Blanco, et al., 2016). Participants were asked to rate the vehicle's effectiveness at communicating its "intentions" (i.e., where it was planning traveling, when it would start/stop) and its perceptions of the roadway (i.e., hazard detection), as seen in Figure 25. This question was important as it determined whether the HMIs aided in increasing vehicle system transparency, and if they did, which system was most effective.

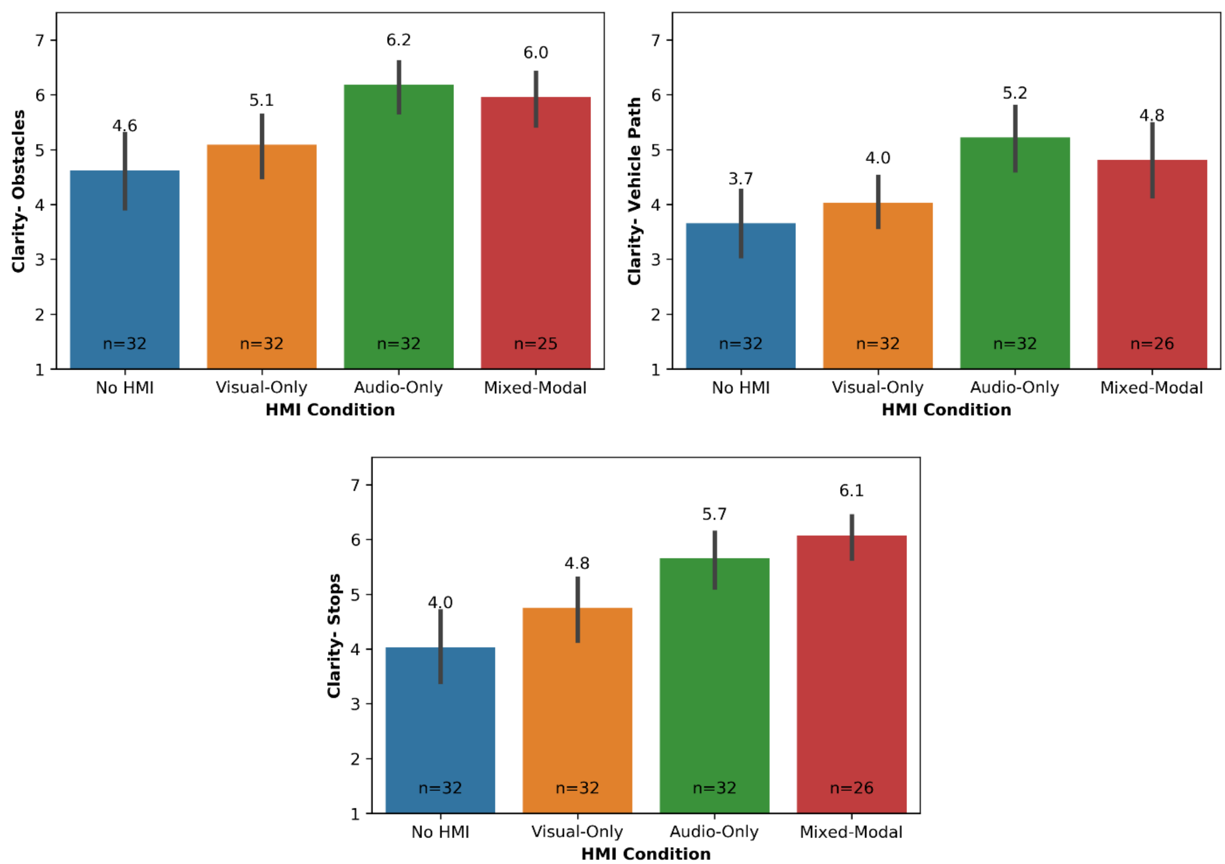

Figure 25: HMI condition compared to how clear it was at communicating the presence of obstacles in the roadway (top-left), the planned vehicle path (top-right), and intention to stop (bottom).

The mixed-modal and audio-only HMI conditions had the most success in communicating vehicle "intentions" to the user. When communicating information about obstacles in the roadway and the vehicle travel path, the audio-only HMI was significantly more effective than the "no HMI" ($p_{obstacles}$=2.30e-06, p_{path}=0.0001) and visual HMI ($p_{obstacles}$=0.04, p_{path}=0.04) conditions. The audio only HMI was also significantly better at communicating the vehicle's intention to stop compared to the "no HMI" condition (p=5.02e-05). This is an interesting finding as the audio HMI was not expected to be the most effective at communicating "intentions", especially for vehicle path, where there was no showcasing of the future vehicle trajectory. This may indicate that occupants find little value in understanding the exact intended path of the vehicle but rather base their impressions on higher-level information such as an intent to simply start moving.

The mixed-modal HMI condition was more effective at communicating the presence of obstacles and planned vehicle path compared to the "no HMI" condition ($p_{obstacles}$=2.30e-06, p_{path}=0.0001). It was also most effective at communicating the vehicle's intention to stop compared to both the "no HMI" (p=6.30e-07) and visual-only (p=0.0009) HMI conditions.

Since the mixed-modal HMI had the ability to leverage multiple different sensory channels, it was theorized to be the most effective at communicating vehicle-information. These findings can be seen in the study, where the mixed-modal condition was most effective at communicating the vehicle's intention to stop. This version of the HMI system encompassed both auditory cues, that communicated the vehicle's intentions to stop, and visual stimuli, that communicated the actual stopping location. This combination of modalities gave participants additional details about the driving landscape and thus may have increased their understanding about the driving system.

Unexpectedly, the auditory HMI proved to be the best at communicating vehicle path, even though no specific tones were used to represent this information. The only tones that indicated vehicle movement were the acceleration and deceleration tones, which did not communicate specific information about vehicle maneuvers, such as turning. Most likely users' overall higher preference for the auditory HMI condition artificially elevated their responses to whether the HMI clearly communicated obstacle detection, intention to stop, and planned vehicle path.

Although the "no HMI" condition received the lowest scores across all conditions, participants still rated it as "neutral" for communicating the presence of obstacles, intention to stop, and vehicle path. This HMI provided no vehicle information and participants were expected to provide ratings at the low-end of the scale. A possible explanation for the neutral ratings relate to the cues already built into a vehicle, such as the wheel turning or the engine revving. These unavoidable feedback devices could have unintentionally communicated vehicle path, via the turning of the wheel, or acceleration/deceleration, making them somewhat comparable to the other conditions. Such stimulus may be diminished in HAVs, which remove the steering wheel and/or leverage quieter drivetrains, such as electrification.

However, even when information is presented in two different modalities, if one uses visual cues typically those cues will be dominant over the others (Posner, Nissen, & Klein, 1976; Spence, 2009). Participants who experienced the visual-only HMI reported the lowest metrics of comfort, trust, safety, and situational awareness. To get a better idea of how the information presented through the different HMI modalities affected participants' reported metrics, participants were asked to rate their level of agreement with whether the information provided by the HMI increased their feelings of comfort, safety, trust, and situational awareness during the previous trial, as seen in Figure 26. This question also allowed researchers to better understand the effectiveness of the HMI systems.

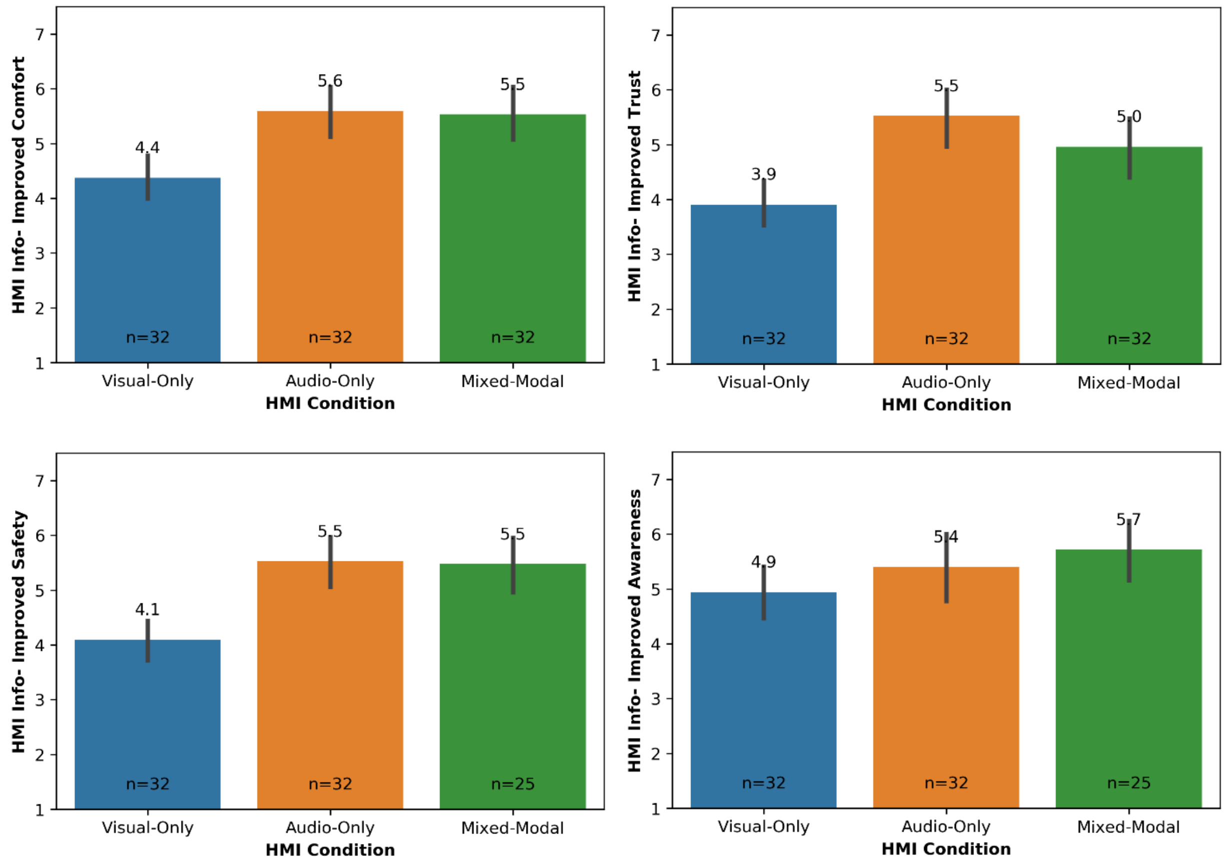

Figure 26: Participants' level of agreement with whether the information provided by the HMI system increased their feelings of comfort (top-left), trust (top-right), safety (bottom-left), and situational awareness (bottom-right).

Overall, the results show that the information displayed through both the audio-only and mixed-modal increased comfort (p_3=0.0003, p_4=0.0005), trust (p_3=1.30e-05, p_4=0.003), and safety (p_3=1.27e-05, p_4=5.19e-05) levels among participants. Marginally, the audio-only condition had the overall highest levels of comfort, trust, and safety across all HMI conditions. Information provided by the HMI conditions did not significantly improve situational awareness across groups, but participants who experienced the mixed-modal condition reported the highest levels of situational awareness. The mixed-modal HMI provided participants with both auditory and visual information, therefore increasing the degree of detail of which the driving landscape was presented, possibly causing them to feel more aware of their surroundings.

The visual HMI system may have specifically highlighted the vehicle's shortcomings, such as not perfectly adhering to lane lines. In the qualitative feedback, a majority of participants who experienced the visual or mixed-modal HMI condition mentioned noticing the vehicle not following the lane lines or staying centered in the lane. Since participants were able to see both the physical roadway and the visual display at the same time, it was easier for them to simultaneously compare the two and identify discrepancies between them, potentially contributing to the lower levels of perceived comfort, trust, and safety. These lower metrics may indicate that rider impressions of system performance decrease with the provision of detailed visual information regarding the HAV perception system. Given that small differences between the HAV perception and the actual environment are likely even in production systems, this finding may indicate that HMI developers should exercise caution when deciding how much detail to present to the driver, particularly if the perceived information is not safety relevant (e.g., at long ranges when sensing errors are more likely). In addition, the visual-only HMI may have made participants keep their gaze on the screen and off of the roadway, which could have caused uneasiness, especially if they noticed that the vehicle was not perfectly following lane lines or exhibiting undesirable speed and braking profiles.

On the other hand, the auditory HMI system still supplied the user with information about the vehicle, system state, and "intentions", but did not draw specific attention and focus to the vehicle's shortcomings. From the auditory cues, participants were able to understand when the vehicle detected an obstacle or when it was about to brake, but their attention was not drawn to its misalignment on the roadway. In addition, users may prefer the audio cues compared to the visual information because they are simple enough to quickly comprehend and do not require users to look away from the roadway to fully understand them. Users are able to confirm the cause of the audio cues instantaneously without dividing their visual attention, whereas with the visual HMI they are required to look away from the road or screen to do so. If users are already uncomfortable with the test vehicle to begin with, they may want to monitor its performance, which cannot be accomplished if they are required to look at a screen.

The auditory cues that were presented to participants may have been simpler and easier to understand compared to the information shown on the screens during the visual or mixed-modal HMI conditions. Auditory cues in general lead to faster comprehension and reaction times (Shelton & Kumar, 2010; Jain, Ransal, Kumar, & Singh, 2015). The audio cues that participants experienced during the sessions were not just simpler, but they were also able to better communicate classification to users. For example, the auditory tones used for obstacle detection communicated not only the presence of an obstacle in the roadway but also its classification as a potential hazard, whereas the visual HMI as configured could only communicate the presence of an obstacle. These audio cues may have had more semantic meaning compared to the visual information presented, therefore increasing participant comfort and trust in the vehicle and overall system transparency.

Factors Influencing Users' Acceptance of HAV

Understanding if behavioral factors could have an effect on user acceptance of HAVs is important, as this could help inform future adoption strategies. As mentioned above, literature has suggested that individuals with higher sensation-seeking scores may be more willing to accept automated driving systems, and demonstrate higher levels of perceived comfort, trust, safety, and situational awareness when exposed to technology (Rudin-Brown & Parker, 2004). Sensation-seeking scores were calculated based on a nineteen-question survey distributed as part of the pre-session questionnaire. Scores from 1-7 were rated as those with "low" sensation-seeking tendencies (i.e., those who do not take as many risks or get involved in dangerous behaviors), scores from 8-11 were rated as "mid" (i.e., individuals who exhibit neutral sensation-seeking tendencies), and scores from 12-19 were rated as "high" (i.e., those who are more likely to demonstrate riskier behaviors). The "high", "mid", and "low" ranges were created by researchers based off of minimum and maximum scores participants could achieve from the survey. Sensation-seeking levels compared to reported metrics can be seen in Figure 27.

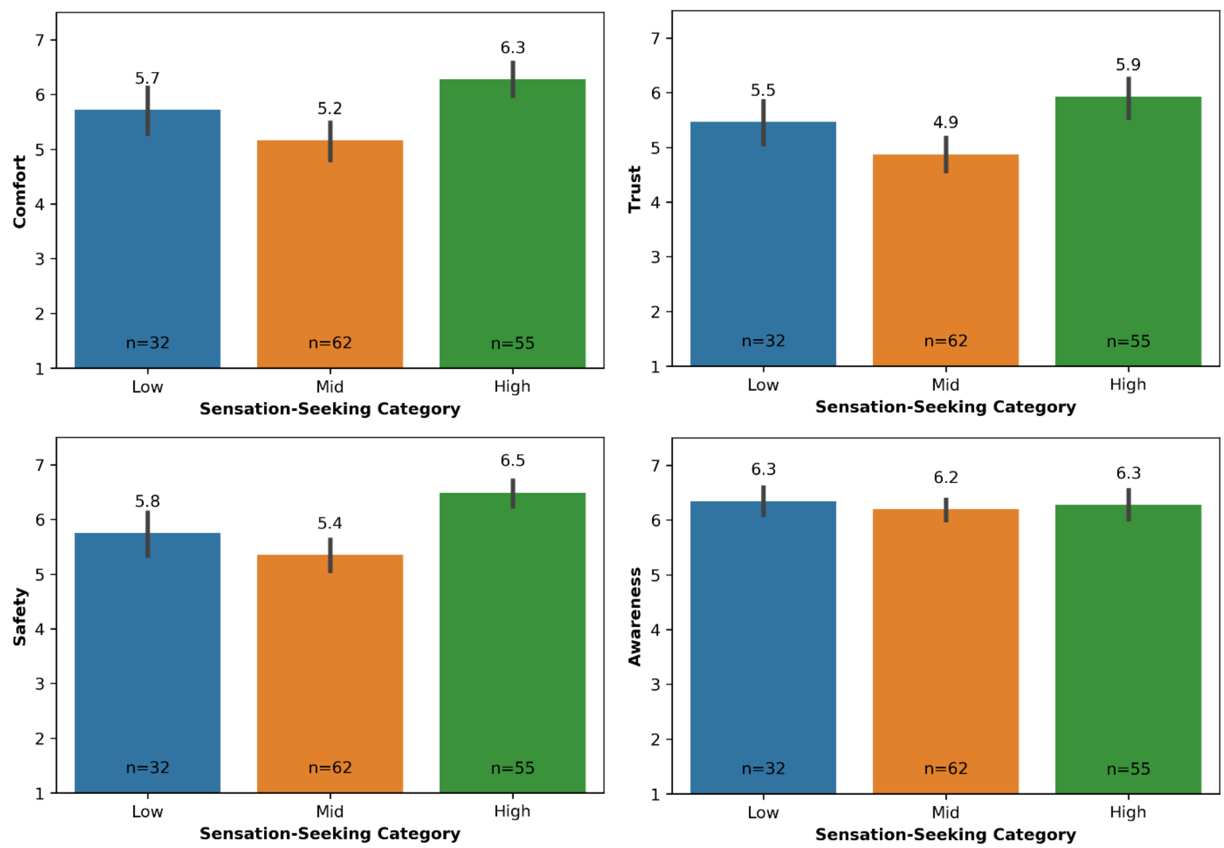

Figure 27: Sensation-seeking category compared to participants' reported levels of comfort (top-left), trust (top-right), safety (bottom-left), and situational awareness (bottom-right).

Higher sensation-seekers reported significantly higher levels of comfort compared to mid-level sensation-seekers (p=8.84e-06), and higher levels of safety compared to both mid-level (p=6.82e-08) and lower sensation-seekers (p=0.0013). The higher scoring sensation-seekers only exhibited marginally higher levels of trust compared to the other two groups. Situational awareness was not affected by sensation-seeking levels.

Based on reported metrics, the higher sensation-seekers, those who are more prone to taking risks and experiencing thrill, seemed more at ease in the test vehicle compared to the other populations, which aligns with researchers' original hypothesis and previous studies that examined sensation-seeking and willingness to accept new technology. Since the high sensation-seeking population was initially more prone to being at ease in the test vehicle, they reported higher metrics of comfort, trust, and safety.

For a majority of participants, this study was the first time they had been a part of vehicle research on the Smart Roads. With that, and the fact that the vehicle was framed as a prototype, the experimental sessions were a novel experience. Since this experience was unfamiliar, participants with lower sensation-seeking scores may have had more hesitation about the vehicle and therefore reported lower levels of perceived comfort, trust, and safety than the higher sensation-seekers. However, the "low" sensation-seekers still reported relatively high metrics. These individuals may have been more apprehensive toward the vehicle to begin with, but it may have caused them to pay closer attention to the vehicle and HMI systems. This heightened awareness of the vehicle may have allowed them to more closely monitor the test vehicle's appropriate response to external stimuli, therefore increasing their comfort and trust when it behaved appropriately.

When considering only "high" sensation-seekers compared to "low", experimental levels of comfort, trust, and safety align with the theories outlined in literature. However, "mid" level sensation-seekers reported the lowest metrics overall. These are the individuals who still want to seek out new experiences but may still be apprehensive toward the novel experience or have limits as to how much risk they are willing to take (Munsey, 2006). Although in current literature there are not many explanations as to why this trend could occur, this "bathtub" curve could be the result of the "mid" sensation-seeking population having some combination of qualities both from the "high" and "low" sensation-seeker personalities. Although additional objective analysis of the data is required for further investigation, these individuals may be comfortable enough to accept riding in the vehicle, but not comfortable enough to accept the vehicle's performance limitations, and thus remain distrusting and apprehensive.

Literature has also suggested that individuals with an internal locus of control (i.e. those who believe events are based on their own actions, not external factors) would have a more difficult time accepting a HAV (Nordhoff, Van Arem, & Happee, 2016). Locus of control scores were obtained via a thirteen-question survey during the pre-session questionnaire. Participants with "internal" locus of control scored from 1-5, those with "mixed" locus of control (i.e., individuals who believe events that occur are due to a combination of external factors and their own actions) were scorers from 6-8, and those with "external" locus of control (i.e., individuals who believe events that occur are due to external factors) were scorers from 9-13. Similar to sensation-seeking score ranges, the locus of control ranges were determined by researchers based off of minimum and maximum potential scoring. Locus of control scores compared to metric levels are shown in Figure 28.

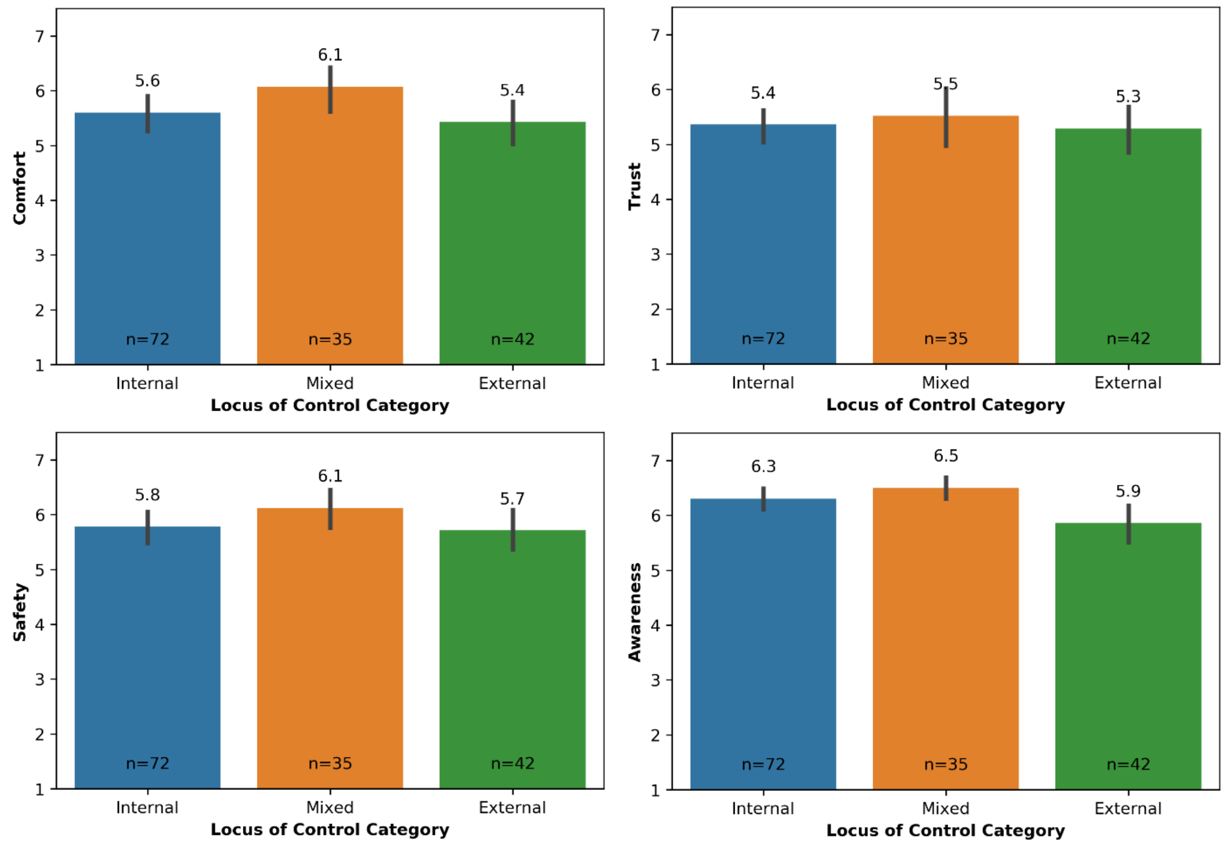

Figure 28: Locus of control and reported levels of comfort (top-left), trust (top-right), safety (bottom-left), and situational awareness (bottom-right).

External locus of control individuals reported significantly lower levels of situational awareness compared to both internal (p=0.02) and mixed (p=0.002) locus of control scorers. Previous research has also shown that external locus of control individuals are more likely to take on a passive role while experiencing automation (Stanton & Young, 2005). Since the vehicle used in the study was presented as "self-driving" and participants had no control over the decisions it made, those who identified as having an external locus of control may have not felt the need to pay as much attention to the vehicle and roadway. They resigned themselves to the fact that they would not be able to change whatever events occurred during the test session, so having a high level of situational awareness would be unnecessary.

Levels of comfort, safety, and trust were not significantly affected by locus of control affiliation, which directly opposes findings from previous studies. Since previous studies have been largely theoretical and survey-based, whereas in this study an actual vehicle was used in a real-world setting, it is possible that, in reality, locus of control theories may not play as much of a role on user comfort, safety, and trust for HAVs as previously reported.

In the same pre-session questionnaire, participants were also asked if they had any previous exposure to AVs. Researchers expected that if participants had previous exposure to these types of advanced technologies, they may be more comfortable while riding in the test vehicle during experimental sessions due to this familiarity. Metric levels compared to previous exposure can be seen in Figure 29.

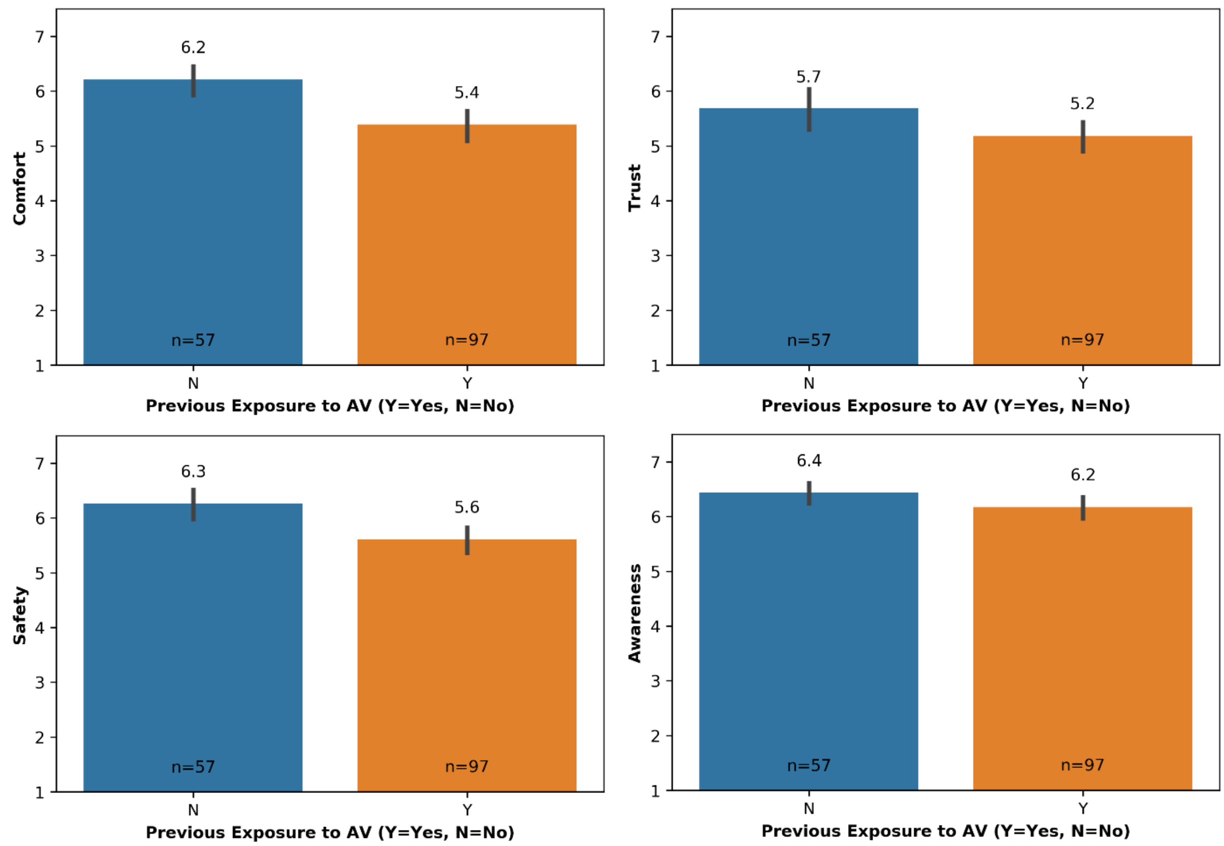

Figure 29: Previous exposure to AVs or AV technology compared to comfort (top-left), trust (top-right), safety (bottom-left), and situational awareness (bottom-right).

Individuals who had previous exposure to AV technologies, such as ACC, LKA, and AEB, reported significantly lower levels of comfort (p=0.0002), safety (p=0.0007), and trust (p=0.03) during test sessions. No significant difference was seen in situational awareness.

Conversely, literature states that those individuals with previous experience or exposure to a technology should have higher levels of comfort and trust than for those individuals where the technology is unfamiliar. According to the Technology Acceptance Model (TAM) and the Unified Theory of Acceptance and Use of Technology (UTAUT), prior experience with a technology has favorable effects on its acceptance and trust by a user (Venkatesh, Morris, Davis, & Davis, 2003; Venkatesh & Davis, 2000; Davis, 1989).

Participants in the study who indicated prior experience with AV systems, may have had a better understanding of what commercially-available systems actually look like and how they perform. Because commercially-available systems address a more constrained problem and have been heavily tested and validated, they perform more consistently than the prototype systems participants experienced during testing sessions. Participants who had previous exposure to AV may have had certain expectations of these types of systems and may have been more critical or surprised by the prototype system, therefore leading to a reduction in perceived comfort, safety, and trust (Abraham, Seppelt, Mehler, & Reimer, 2017).

Additionally, participants were asked about their baseline levels of comfort regarding HAVs. If participants were more comfortable with the HAV to begin with, it was expected that they may be more comfortable during the test sessions. Experimental metric levels compared to initial comfort level are shown in Figure 30. "Low" initial comfort levels were scores from 1-2, "mid" comfort levels were scores from 3-5, and "high" initial comfort levels were scores from 6-7. Researchers determined levels based on minimum and maximum potential scores.

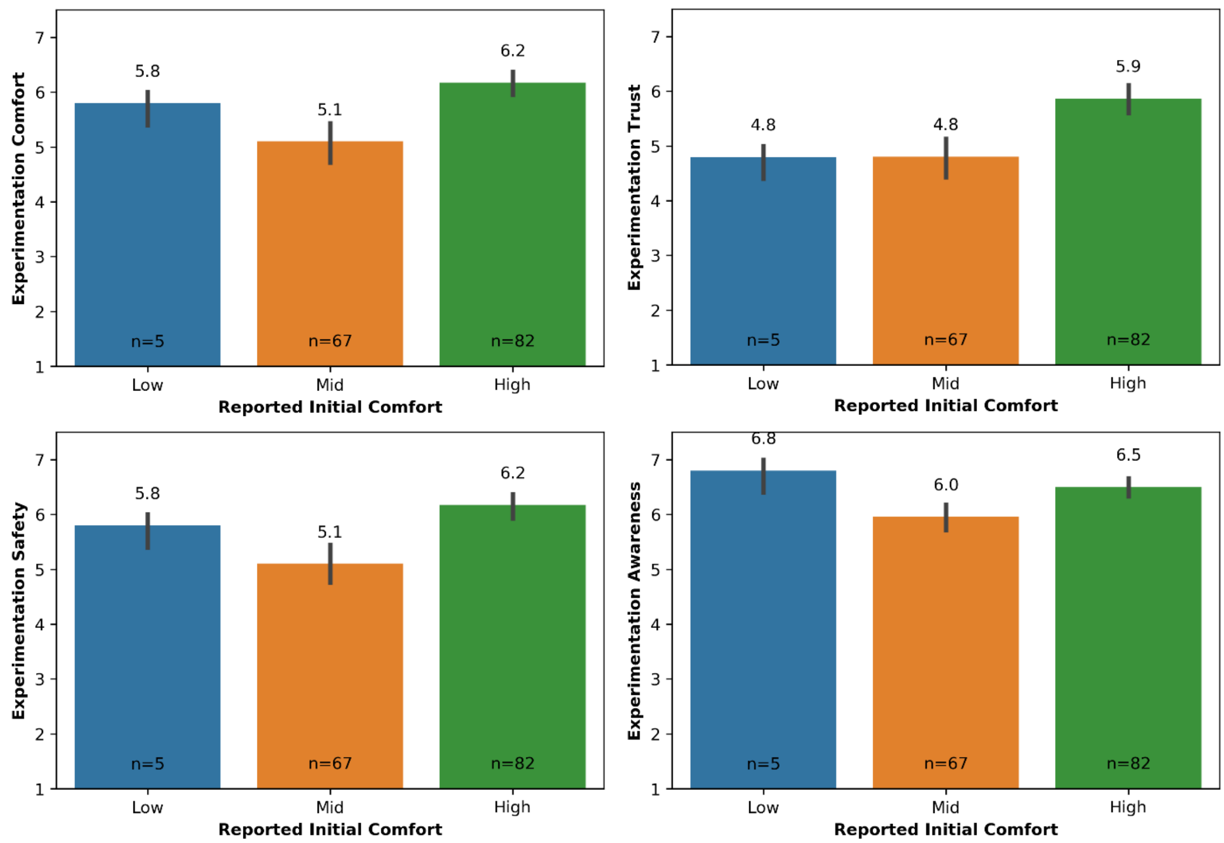

Figure 30: Initial comfort levels reported during the pre-session questionnaire compared to metrics of comfort (top-left), trust (top-right), safety (bottom-left), and situational awareness (bottom-right) reported during experimental sessions.

Participants who selected "mid" comfort reported significantly lower reported levels of comfort (p=7.27e-07), trust (p=2.55e-06), safety (p=7.30e-07), and situational awareness (p=0.0001) during testing compared to those who reported high initial levels of comfort. Similar to participants who had previous exposure to AV technologies, those who are already comfortable with a certain technology should also maintain those levels while experiencing it in a different environment, even in a different iteration or implementation.

When considering only the "low" and "high" initial comfort levels, results presented confirm these acceptance theories. However, when participants selected "mid" for initial comfort, similar to the bathtub curve seen in the sensation-seeking results, they reported lower metric levels. There is not much current literature to support these trends, but where the initial comfort metrics differ from the sensation-seeking data is in the situational awareness category. In the sensation-seeking graphs, there were no noticeable differences across groups. However, in the initial comfort graphs above, it can be seen that those who reported “mid” initial comfort levels also reported lower levels of situational awareness across test sessions. Participants may have been trusting enough in the vehicle to not pay as much as attention during sessions, however, this lack of attention may have decreased their feelings of comfort, trust, and safety.

Age and Gender vs. Comfort, Safety, Trust, and Situational Awareness

No statistically significant differences in reported levels of comfort, safety, trust, or situational awareness were found when considering age or gender.

Linear Mixed-Effect Model

When examining metrics of perceived comfort, trust, safety, and situational awareness across HMI conditions, scenarios, and trials, the linear mixed-effect models indicated scenario type as being a significant factor. Specifically, reported metrics of comfort and trust were significantly reduced in the Following Lead Vehicle/Work Zone scenario compared to the Pedestrian Crossing scenario ($p_{comfort}$=0.04, p_{trust}=0.01). It is important to note that Trials #1/#6 and the surprise event data were not included in these analyses, since they represented a different experimental condition.

As mentioned above, the Following Lead Vehicle/Work Zone scenario was the most complex of all scenarios participants experienced. This scenario required the test vehicle to follow another vehicle and change lanes to avoid a set of cones in a simulated work zone. The addition of more external variables such as the confederate vehicle and obstacles in the roadway, introduced more opportunity for the test vehicle to malfunction, with potentially more severe consequences if an error were to occur. This additional risk could have contributed to lower perceived comfort and trust. The detected Pedestrian Crossing scenario was one the simplest scenarios, with only one loop traveled on the Surface Street and only one pedestrian crossing occurring. There was less external complexity and less opportunity for test vehicle failures, resulting in higher levels of comfort and trust in the vehicle. The results of the linear mixed-effects model confirm significance in the trends seen in the summary data.

The mixed-models created in R not only accounted for the random effects that participants had on the experiment, but it also considered between-subject (i.e., HMI condition) and within-subject (i.e., Trial and Scenario) factors. The OLS models assumed all participant responses were independent and could not account for multiple variable interactions. The heightened complexity of the mixed-models produced different, but more robust, conclusions than the OLS models, however, the results from the simpler model should not be discredited, as they still exhibit important and interesting trends in the data. The OLS model results paired with the trends seen in the summary data and qualitative feedback still make strong cases for some factors, such as the effect that HMI condition has on participant perceptions of comfort, safety, and trust. In addition, the sample size of the experiment did not allow for all independent factors to be considered in the mixed-model. These simpler OLS models are necessary for analyzing all data collected and understanding its influence on participant responses.

Participant-Specific Responses

The goal of analyzing reported metrics specific to individual participants allowed researchers to calculate an overall trend across responses while accounting for personal baseline levels. In addition, it allowed researchers to gain a better understanding of whether certain response trends were more prevalent in one HMI condition over another. Trend summaries of reported comfort, trust, safety, and situational awareness metrics, specific to HMI condition, can be seen in Tables Table 13, Table 14, Table 15, and Table 16 below. The highest values for each trend type are highlighted.

Table 13: Participant-Specific Results, Comfort

	No HMI	Visual-Only	Audio-Only	Mixed-Modal
No Trend	5	4	2	2
Decreased	2	1	1	3
Increased	1	4	5	1

Table 14: Participant-Specific Results, Safety

	No HMI	Visual-Only	Audio-Only	Mixed-Modal
No Trend	5	3	3	2
Decreased	1	3	1	2
Increased	2	2	4	2

Table 15: Participant-Specific Results, Trust

	No HMI	Visual-Only	Audio-Only	Mixed-Modal
No Trend	3	3	2	1
Decreased	2	4	1	2
Increased	3	1	5	3

Table 16: Participant-Specific Results, Situational Awareness

	No HMI	Visual-Only	Audio-Only	Mixed-Modal
No Trend	5	2	3	2
Decreased	1	3	3	2
Increased	2	3	2	2

The audio-only HMI, regardless of initial baseline reporting, seemed to have the most positive effect on metrics of comfort, trust, and safety of participants, whereas the visual-only HMI seemed to have negative effects. These findings help to confirm the trends seen in the summary data presented above and further validates the effectiveness of the audio HMI, especially when compared to the visual HMI.

Content Analysis

When examining the feedback derived from the open-ended survey questions and applying inter-rater reliability methods, researchers obtained moderate-perfect agreement (k_{min}=0.48, k_{max}=1) on all dataset comparisons, categorizing with both the primary and secondary themes. It is important to note that these questions were asked in an open-ended manner, so comments made may have contained multiple categorical themes, thus the reason why the secondary categorical values may not always add up to the total amount of comments received for that condition. Researchers' categorical classifications and corresponding Cohen's kappa values can be seen in Appendix R.

No HMI

For the "no HMI" condition, 34 comments were received from participants about the vehicle and vehicle systems, where 20 comments mentioned participants' desire for additional vehicle information and 16 mentioned the vehicle exhibiting undesirable dynamics. The secondary category response breakdowns can be seen in Figure 31.

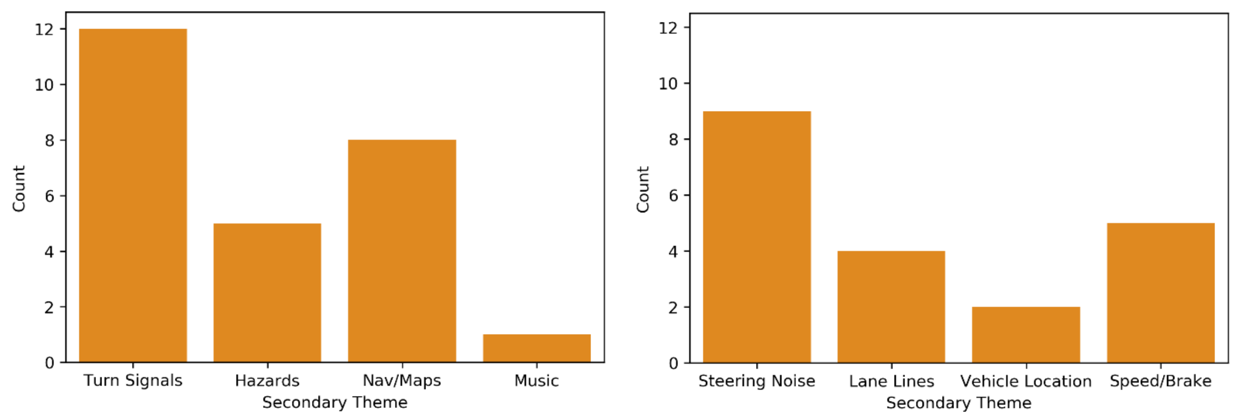

Figure 31: Comments received by participants were separated into secondary categories of additional information desired (left) and undesirable vehicle dynamics (right).

Twelve out of twenty comments received from participants that referenced the desire for additional vehicle information mentioned wanting "turn signals", "automated signaling", or that "signaling direction would be nice". In addition, hazard detection and gaining a better understanding of where the vehicle was located in the driving environment, or implementing better roadway maps and navigation systems, seemed to be desirable as multiple participants mentioned wanting "road/hazard detection", "visuals on what the car is sensing and where", "being able to see in front of the vehicle", and "being able to see the road".

In comments where participants mentioned undesirable vehicle dynamics, more than half mentioned the noise emitted by the steering wheel due to the rotating servo motor. Some participants even labeled the noise as "distracting", "annoying", and indicated the desire for the sound to "not be included in future designs". The test vehicle's inability to precisely follow roadway markings and rough braking and speed changes were also a concern. Participants recognized that “the car knew it was driving on lane lines” and that it “felt like the car drove over road lines”. In addition, some mentioned that the vehicle’s “braking was not smooth” and that they desired “less ‘stabby’ braking” and “jerking of the car/brakes”.

When no vehicle information was presented, participants’ desire for hazard detection, navigation, and maps confirmed researchers’ design choices made for the visual-only, audio-only, and mixed-modal HMIs. This feedback can also help inform future HMI designs, with more focus being placed on these specific factors. In addition, comments made by participants about including turn signals and undesirable vehicle dynamics can help emphasize which vehicle-specific factors to focus on for designing more user-friendly HAVs.

HMI

Participants provided 45 comments about the vehicle and HMI systems when experiencing the audio, visual, and mixed-modal HMI conditions. In the dataset, 13 comments mentioned the participants’ desire for the HMIs to communicate more information, 19 mentioned undesirable vehicle dynamics, and 15 mentioned the HMI being inaccurate. Three comments were also received which said that the HMI systems increased participants’ comfort, however due to its low frequency, it was not considered as a primary theme. Based on the three major themes seen in the data, the comments were further broken down into secondary categories, as seen in Figure 32.

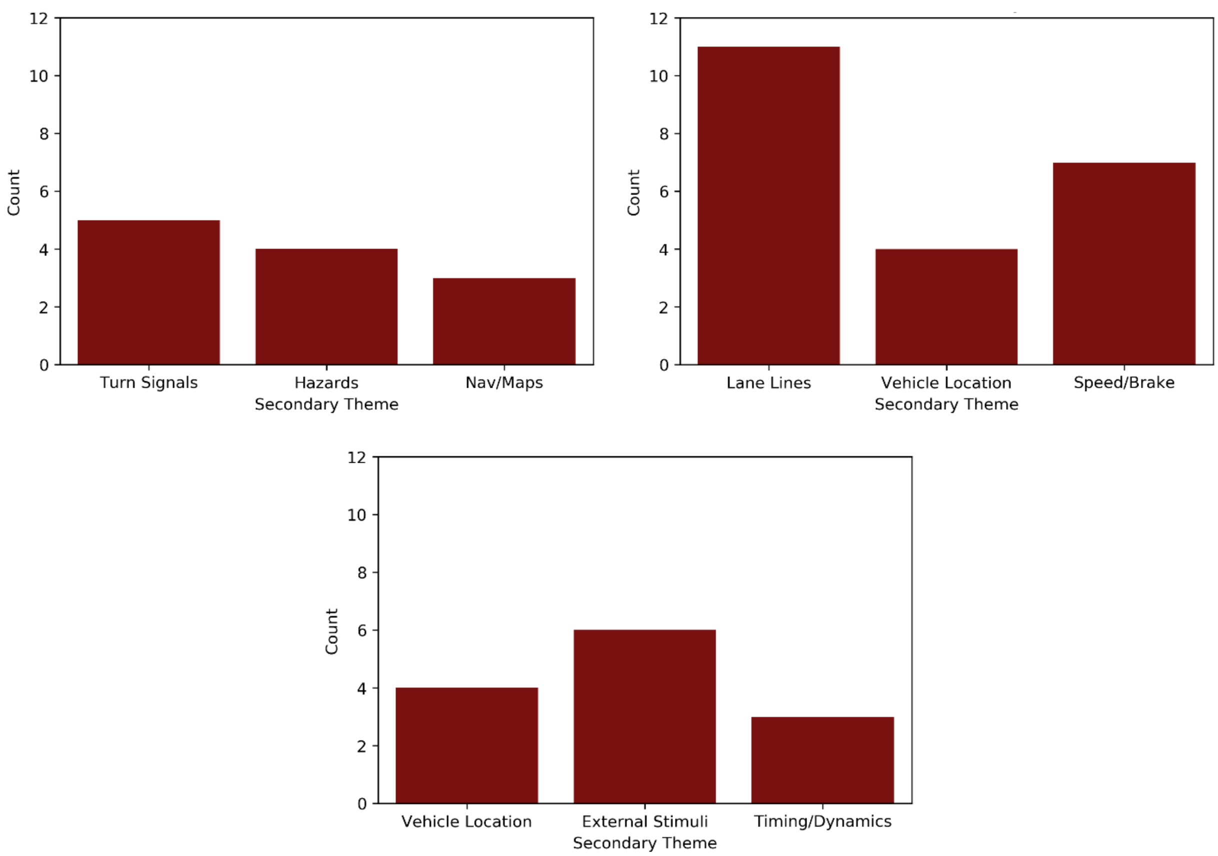

Figure 32: Comments received by participants were separated into secondary categories of additional information desired (top-left), undesirable vehicle dynamics (top-right), and inaccurate HMI (bottom).

Similar to the no HMI qualitative feedback, the comments received by participants during the HMI conditions confirm the HMI design decisions made by researchers. However, these comments also show that still many improvements can be made in these areas, especially in the case of HMIs which show information visually. These comments also confirm the need for improved HAV vehicle dynamics and the need for turns to be communicated to passengers via in-vehicle turn signaling. These qualitative findings may also provide additional evidence for participants' reported levels of comfort, trust, and safety during sessions. For example, if the vehicle was braking or turning roughly, it may have caused a decrease in participant metrics, regardless of which HMI they experienced.

Additional Information Wanted

When participants expressed the desire for more information communicated to them through the HMI, 5 comments were received from participants who experienced the visual-only HMI condition, 4 were made by those who experienced the mixed-modal condition, and 4 were made by those who experienced the audio condition.

Similar to the "no HMI" condition, most comments made by participants who experienced the audio-only HMI condition and expressed the desire for additional information, mentioned wanting indicators for "detecting routes/turns" and "turn signaling", as the "route was still unclear at times and it was difficult to determine which way we would turn". In addition, a participant mentioned wanting additional communication between the vehicle and user by pointing out that they thought "a human should be prompted before proceeding in the wrong lane to go around an obstacle".

Comments made by participants who experienced the visual-only HMI condition mentioned wanting improved hazard detection, as one participant was "nervous every time new items like cones were present" and another noticed that "the vehicle failed to show an animal that had wandered onto the track". Once again, participants who experienced the visual condition also mentioned the desire to "use blinkers", or improve turn signaling.

Participants who experienced the mixed-modal condition primarily mentioned the desire for improved turn signaling by indicating that "signal lights would help" and that "not using signal lights keeps me from knowing what the next move is and makes me feel less comfortable".

Undesirable Vehicle Dynamics

From the comments received mentioning undesirable vehicle dynamics, 8 were made by participants who experienced the visual HMI condition, 10 were made by participants who experienced the mixed-modal HMI condition, and no comments were made by participants who experienced the audio HMI condition.

During both the visual and mixed-modal HMI conditions, a majority of comments focused on the vehicle's ability to follow the roadway lane lines. Participants commented on the fact that the test vehicle "struggled to stay in its lane" and that it was "disconcerting that the vehicle doesn't follow lane lines". It also seemed as if the vehicle's "turns [were] being overcorrected", that it was "taking curves or switching lanes too roughly", or "starting too suddenly", and that it exhibited "inconsistent acceleration and braking intervals", which made participants less comfortable, with one participant saying that their "safety and trust was significantly reduced" when the vehicle went wide during a turn.

Inaccurate HMI

When analyzing comments mentioning the HMI inaccuracy, 8 were received from participants who experienced the visual HMI, 6 when participants experienced the mixed-modal condition, and only 1 comment was made by participants who experienced the audio-only condition.

During the visual condition, most participants noticed that the HMI did not accurately display the vehicle position, notably the "delay between the HMI and car position" and the misrepresentation of the vehicle's "orientation within multiple lane lines" and the "location of the approaching 'passenger'". In addition, participants had feedback about the HMI accuracy with some stating plainly that the "screen doesn't seem accurate" and one mentioning that the "rideshare HMI person was not accurate at all" which was "actually a bit alarming".

Participants who experienced that the mixed-modal condition also mentioned the HMI not seeming accurate with one commenting that the "timing appears more scripted than the system reacting to actual stimulus", another mentioning that "the HMI does not always show the same thing as what is going on outside", and an additional participant saying that "the other car and human movements seemed unnatural". As the scenarios were preprogrammed and perfect timing by researchers was required to ensure that the HMI matched the environment, it is possible that this synchronization did not occur for every scenario, which would have been much easier to identify through visual feedback.

Surprise Event

To gain a better understanding of participant behavior during the surprise event and determine if there were any unintended bystander effects during this time, test session video and audio of participants before and after the surprise event was examined by researchers. In total, face-view footage of 17 participants, across all HMI conditions, was available for review. Out of the 17 total participants, face-view footage was recorded of 5 participants who experienced the "no HMI" condition, 6 participants who experienced the visual-only condition, 3 participants who experienced the audio-only condition, and 3 participants who experienced the mixed-modal condition.

Pre-Strike

Footage 20 seconds prior to the event was evaluated to understand participant behavior leading up to the preprogrammed vehicle malfunction, as seen in Table 17.

Table 17: Pre-Strike Participant Reactions

HMI Type	n	No Reaction	Stop Button	Verbal Comment	Facial Expression	Other
No HMI	5	3	0	0	2	0
Visual-Only	6	5	0	1	1	0
Audio-Only	3	0	1	1	1	0
Mixed-Modal	3	1	0	0	1	2

Out of all 37 participants, only 1 pressed the stop button, and face-view footage of the participant was available for this event. This individual seemed to understand that the stop button was provided for the possibility of a vehicle malfunction as they remarked “I hit the button to try and save him” (e.g., the balloon pedestrian). Researchers also did not see any instances in the available video where a participant reached for the stop button but did not press it, presenting a lack of evidence of any noticeable bystander effects.

Other participants showed expressions of confusion or nervousness leading up to the strike. Some began to laugh uncomfortably when they noticed the malfunction and seemed to understand the situation they were in. Some that experienced the visual-based systems checked back and forth from the screen to the driving landscape to visually confirm the lack of pedestrian detection. Although it seemed that these participants had an idea that something was wrong, they still did not press the button or make a move to do so. Based on comments made to researchers after the test session concluded, it seemed that some participants viewed the stop button as a mechanism to stop the testing session if an incident occurred inside the vehicle or to participants themselves, such as a medical emergency, rather than a mechanism to be used for external adverse situations. No additional training about the stop button function, besides what would happen if it was pressed, was provided to participants before the test session began. This lack of training and differing opinions about the button’s functionality could have contributed to the lack of button presses.

From the pre-strike video, researchers also saw that a large number of participants who experienced the visual or mixed-modal HMIs did not react in any way during the time leading up to the surprise event. These participants, excluding those who experienced the “no HMI” condition, experienced conditions which used the visual screen as a mode of communicating vehicle roadway perceptions. Upon closer inspection of the face-view video, it was found that participants stared directly at the screen for most of the time leading up to the strike, and they did not recognize the vehicle malfunctioned until after the event occurred. This lack of reaction could suggest an over-reliance on the HMI system, as participants focused heavily on the screens and expected them to perform in the same manner as they did in previous trials. Additionally, the lack of reaction could suggest that the screens were distracting and lowered situational awareness of the user, as they did not acknowledge the target in the driving path prior to the strike. Other participants who exhibited no reaction to the event, seemed to be fixated on front windshield or the side window. These types of behaviors could suggest low levels of situational awareness, even though reported measures were relatively high across all conditions and vehicle scenarios.

Post-Strike

Footage 20 seconds after the event was also examined to assess participants’ reactions to the vehicle strike, the results of which can be seen in Table 18 below.

Table 18: Post-Strike Participant Reactions

HMI Type	n	No Reaction	Stop Button	Verbal Comment	Facial Expression	Other
No HMI	5	0	0	1	5	0
Visual-Only	6	0	0	2	5	1
Audio-Only	3	0	0	2	2	0
Mixed-Modal	3	0	0	0	3	0

From the post-strike data, it can be seen that all participants examined through the event footage exhibited some sort of reaction to the event that occurred. Changes in facial expression, such as looks of discomfort, confusion, or shock, and verbalized comments or remarks about their confusion were the most prevalent reaction types. Although the HMI and vehicle systems did not indicate a malfunction occurred, after the event, all participants recognized the vehicle did not react to the obstacle in the appropriate manner.

CONCLUSIONS AND RECOMMENDATIONS

This Thesis outlined a high-fidelity, environmentally realistic study with the goal of obtaining users' natural reactions to new HMI systems designed for a fully automated vehicle. Based on the data obtained, the study found that:

1. Auditory and mixed-modal HMI systems increased users' feelings of comfort, safety, and trust during the experimental sessions relative to other HMI conditions.
2. Information provided by the HMI systems did not do much to improve situational awareness, but the information provided by the auditory and mixed-modal HMI systems clearly communicated the vehicle's "intentions" while increasing feelings of comfort, trust, and safety.
3. Certain factors such as sensation-seeking, locus of control, previous exposure to AV, and initial comfort level affected feelings of comfort, trust, safety, and situational awareness reported during testing.

Based on the results of this study, it can be seen that users of the HAV greatly benefited from increased HAV system transparency. Additional vehicle information increased overall levels of comfort, trust, safety, and situational awareness. Although the audio-only and mixed-modal systems performed the best relative to the other HMI systems, for the most part, reported metrics were high across all conditions.

However, if this type of technology were to be implemented into future HAVs, the information portrayed should be a good representation of the external environment, and the HAV and HMI should appear to interface seamlessly. As seen in the results presented, participants could easily identify when the path planning of the HMI and test vehicle did not match up, and it subsequently decreased their trust and comfort in the vehicle. Or, if this type of technology were to be implemented, it may be better to display higher-order information, rather than allocating resources and computing power to communicate non-essential details. Showing minute details of the driving environment, although important for system transparency, may negatively impact transparency and trust if these details are represented with inconsistent accuracy.

In addition, as commonly mentioned by participants in the open-ended feedback, normal feedback devices, such as turn signals, should still be present in the vehicle. It appears, that in a vehicle which still has driving controls, albeit with no driver present, these types of displays must be present even in situations in which they are difficult to observe from non-driving positions. It appears these types of familiar vehicle HMIs still communicate desirable information to a user, perhaps contributing to their perception of trust. Such findings can be helpful to OEMs, as they direct the design of not just future HMI systems, but future AVs.

Although results show that information presented via audio alerts demonstrated higher reported levels of comfort, safety, and trust during experimentation, dual modality HMIs (e.g., both visual and audio information) may be best for catering to a wider population of individuals, especially for communities with hearing or vision deficiencies, where HAVs can have positive impacts on increased mobility. Such considerations for special populations were not directly considered as part of this research.

Limitations

This study had several key limitations which may affect the generalizability of these findings. First, this study did not encompass all driving scenarios or maneuvers. The roadway is a highly variable place, and a selection of scenarios were chosen that represented normal driving. However, different scenario types or vehicle maneuvers could impact participant feedback and reactions. Also, external variables, such as weather, were controlled so sessions could be as consistent as possible across participants, but not everything was able to be controlled in a real-world testing environment, such as on the Smart Roads. For example, wildlife ran into the roadway or gusts of wind knocked over the balloon pedestrian as it was crossing in front of the vehicle, causing some inconsistencies between participant experiences.

In addition, participant biases were controlled by the moderator by discouraging them from sharing their opinions or discussing the study with the other vehicle occupants before every test session trial. However, since there was not a researcher in the vehicle besides the safety driver, who had to maintain the illusion of being a participant, researchers cannot eliminate all communication. Furthermore, participants may have not tried to directly converse with others, but facial expressions, involuntary sounds (e.g., sighs, laughing), or body language, outside of researchers' control, could have influenced other participants' opinions.

Researchers described the vehicle and testing-site prior to starting sessions. Participants were told that the vehicle was a prototype HAV developed at VTTI and that the testing-site was a controlled-access test track. Also, participants were required to read the ICF form that outlined the study in great detail and explained potential risks. Participants were well aware that the study would not be putting them in any dangerous situations, as seen in some of the qualitative feedback with one participant mentioning that even though the test vehicle did not follow lane lines, they "believed since I was aware it is a closed course I did not worry about wrecking". We now know this information may have affected the experimental results, especially given that researchers' statements before the session had a statistically significant effect on participant feedback, demonstrated best when looking at the data of the two different "no HMI" conditions.

Although the test vehicle used in this study was highly advanced and more sophisticated than what is typically seen in current vehicle research, it was still a prototype. The steering wheel of the vehicle used a servo motor to control it, which caused a noise whenever it turned that was well-beyond that which would be expected in a production vehicle. Since the vehicle was following DGPS coordinates and not the actual roadway, it did not perfectly follow the lane lines present on the road or stay centered in the lanes. Additionally, since the vehicle was not intended for production and nobody was in the driver's seat, it did not use any turn signals during turning maneuvers. Interestingly, this combination of factors was noticed by participants, as indicated in the qualitative feedback, with one participant mentioning "turns being overcorrected makes me trust the vehicle less", but that "the visual in general improves trust". Based on this type of feedback, it could be suggested that the vehicle itself could have caused lower reported levels of comfort, trust, and safety, not the HMI systems.

Finally, each session was only around an hour and a half, with participants experiencing the test vehicle for only about forty minutes of that time. Maneuvers experienced on the road were also relatively brief, lasting between 2-5 minutes. This duration of exposure may not be enough for users impressions to fully stabilize a system as complex as a HAV.

Future Work

This study lends itself as a starting point for numerous pathways of future work. The HMI technology itself can be improved by collecting actual environmental data, through sensors like LiDAR, to more accurately represent the driving landscape and give users information in real time, which is more realistic for a dynamic environment such as a road. In addition, different types of displays such as full windshield displays or augmented reality displays, where graphics are overlaid onto a real-time image of the roadway, can be explored. While the project was still under development, efforts were made to implement more sophisticated obstacle detection and hazard classification into the visual HMI condition. However due to time and budgetary constraints, this method was abandoned.

For experimentation, more complex vehicle scenarios and maneuvers, with multiple vehicles and pedestrian crossings, can be implemented. Having a fully validated automated vehicle, one that will stop in the event of an obstacle in its path and behaves at the same level as current vehicles on the roadway, will make these types of scenarios more feasible and safer. In addition, obtaining participant biometric data during sessions, such as heart rate, sweat production, or eye glance, via cameras or wearable devices, could offer an unbiased metric of comfort and stress, compared to the post-trial surveys. More importantly, these biometric sensors could also offer researchers a better understanding of perceived vs. actual situational awareness. One-on-one interviews instead of paper-based surveys could also be helpful in gaining better insight into participants' responses, could provide more qualitative feedback, and could eliminate participant biases due to other people being present in the vehicle.

Longitudinal studies could also give researchers a better understanding of how feelings comfort, trust, and safety in HAVs change over time, which could lead to better understanding HAV acceptance and adoption. In addition, longer exposure times may also allow researchers to present participants with all HMI conditions (e.g., within-subjects study) instead of only one condition. This within-subjects approach could afford a more equal comparison across HMI conditions. These longitudinal studies could also target specific populations, such as the elderly, blind and visually impaired individuals, or individuals who are deaf and hard of hearing, where these types of vehicles could have the most beneficial impact.

Although limitations were present during this study and numerous pathways of future work have been identified, this study represents the first of its kind in examining HAV HMI systems in a high-fidelity environment. No other studies have yet been conducted which place volunteer participants in a physical test vehicle, capable of driving multiple routes with varying speeds, with nobody sitting in the driver's seat or remotely controlling the vehicle. Results obtained through this real-world, representative testing are the most aligned so far to behaviors likely to be seen on-road. Data and subsequent recommendations derived from this study could both prompt critical future research in these focus areas and aid in the design and development of HMI systems for the next generation of roadway vehicles.

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APPENDIX

Appendix A. Experimental Matrix

HMI Condition	Participant #	Gender	Seating Location	Scenario Order					
				Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6
No HMI "With Knowledge"	P01	M	R	Baseline	Ped X-ing	Following Lead Vehicle	Passenger Pick Up	Left Turns	Surprise
	P02	M	R						
	P03	F	L	Baseline	Left Turns	Passenger Pick Up	Following Lead Vehicle	Ped X-ing	Surprise
	P04	M	L						
	P05	F	R	Baseline	Passenger Pick Up	Ped X-ing	Left Turns	Following Lead Vehicle	Surprise
	P06	M	L						
	P07	F	R	Baseline	Following Lead Vehicle	Left Turns	Ped X-ing	Passenger Pick Up	Surprise
No HMI "Without Knowledge"	P08	M	R	Baseline	Ped X-ing	Following Lead Vehicle	Passenger Pick Up	Left Turns	Surprise
	P09	F	L						
	P10	M	R	Baseline	Left Turns	Passenger Pick Up	Following Lead Vehicle	Ped X-ing	Surprise
	P11	F	L						
	P12	M	L	Baseline	Passenger Pick Up	Ped X-ing	Left Turns	Following Lead Vehicle	Surprise
	P13	F	R						
	P14	M	L	Baseline	Following Lead Vehicle	Left Turns	Ped X-ing	Passenger Pick Up	Surprise
	P15	F	R						
Visual-Only	P16	M	R	Baseline	Ped X-ing	Following Lead Vehicle	Passenger Pick Up	Left Turns	Surprise
	P17	F	L						
	P18	M	R	Baseline	Left Turns	Passenger Pick Up	Following Lead Vehicle	Ped X-ing	Surprise
	P19	F	L						
	P20	M	L	Baseline	Passenger Pick Up	Ped X-ing	Left Turns	Following Lead Vehicle	Surprise
	P21	F	R						
	P22	M	L	Baseline	Following Lead Vehicle	Left Turns	Ped X-ing	Passenger Pick Up	Surprise
	P23	F	R						
Visual-Only	P24	M	R	Baseline	Ped X-ing	Following Lead Vehicle	Passenger Pick Up	Left Turns	Surprise
	P25	F	L						
	P26	M	R	Baseline	Left Turns	Passenger Pick Up	Following Lead Vehicle	Ped X-ing	Surprise
	P27	F	L						

	P28	M	L	Baseline	Passenger Pick Up	Ped X-ing	Left Turns	Following Lead Vehicle	Surprise
	P29	F	R						
	P30	M	L	Baseline	Following Lead Vehicle	Left Turns	Ped X-ing	Passenger Pick Up	Surprise
	P31	F	R						
Mixed-Modal	P32	M	R	Baseline	Ped X-ing	Following Lead Vehicle	Passenger Pick Up	Left Turns	Surprise
	P33	F	L						
	P34	M	R	Baseline	Left Turns	Passenger Pick Up	Following Lead Vehicle	Ped X-ing	Surprise
	P35	F	L						
	P36	M	L	Baseline	Passenger Pick Up	Ped X-ing	Left Turns	Following Lead Vehicle	Surprise
	P37	F	R						

Appendix B. Vehicle Set Up Guide

Items needed:

Vehicle #32 Keys
Automation key (should stay in glove box)
Collector Hard Drive
Experimenter Laptop
Radio

Follow the protocol below to successfully setup the research vehicle:

1. Pop the hood and activate both power cutoff switches. Close the hood to the first closure point (no need to close it all the way).
2. Insert the HD into the right DAS in the cargo area of vehicle #32 (Gold SRX). Make sure to activate the power cutoff to the right of the cargo area.
3. Start the vehicle, this will require putting your foot on the brake and hitting the Start-Stop button THREE (3) times.
4. Make sure the mushroom button in the center console is not depressed (pull up to make sure).
5. Open the glove box and insert the automation key into the left-most key slot and turn. Make sure you hear the DAS systems start up.
6. Log in to the experimenter laptop using the credentials on the post-it note
7. Open the SOLEYE program (use the AV VIZ profile) and connect to the DAS. Once a successful connection has been made, continue.
8. Check the error node to ensure it does not say “error” or “missing”. If so, reboot the system (steps 6-7).
9. Drive to the SSE and enter.
10. Radio control room and ask for the intersection light be turned on (green light for the entire time).
11. Perform both calibration laps with the vehicle (one on the outside loop of the SSE, and another out onto the SR and then back onto the SSE via the intersection connector). Please be mindful about road hazards and debris during these laps and, if necessary, clear anything from the road.
12. Return the vehicle to the scenario starting spot.
13. Engage vehicle automation by pressing forward on the right steering column nub once (may take a few tries before it works). When engaged, the light strip on the dash will be green.
14. Perform a test scenario by inputting 3 (THREE) into the SetTestNumber field within SOLEYE. Press “SetTest” then “StartTest” and the vehicle should shift gears and start moving within 15 seconds.
15. **Once the test scenario is over, place the vehicle into park (if it is not already) and press “StopTest”**.
16. Disable automated mode by pressing forward the right steering column nub once. The light bar on the dash should not be lit up.
17. Place SRX key without the fob (just the electronic part) on the front passenger’s seat.
18. Place the laptop on the front driver’s seat and buckle the seatbelt.
19. Wait for the moderator to enter the road with the confederate vehicle.

Appendix C. Researcher Script

AV Viz: Meet and Greet Protocol

1. **Participant Arrival**
   a. Wait for the participants:
      i. Some participants come in early, please be in the lobby of B1 at least 10 minutes before scheduled time
      ii. Check the phone(s) for messages before going to B1 lobby
      iii. Be flexible: as participants arrive, take them into subject prep room, greet, and administer informed consent (one at a time, or in groups)
      iv. If all participants have not shown up after 10-15 minutes
         1. Check the front desk phone &/or Christine's phone (1-1532) for messages
         2. Call remaining participants

2. **Greet Participant**
   a. Note time of arrival
   b. Once all participants arrive, guide to B2 subject prep rooms
   c. Introduction:
   [Introduce Yourself] *Thank you for coming out today. We're going to start off by going through the informed consent form which gives you an overview of what you'll be doing throughout this experiment, what we're studying, the potential risks involved, your responsibilities as a participant, your compensation, and so forth. I would also like to point out, as stated in this form, that you are free to withdraw from the study at any point without any penalty whatsoever.*

   There are two copies of the forms, one for my records and one for yours, and your signature is required on both at the end of the document if you would like to participate in the study, on both copies.

   d. Informed Consent:
   [Ask participant to sign both copies.]
   [As experimenter, sign and date both copies of the IC. Give participant their copy.]
   Should a participant choose not to continue, proceed to Step 5.

   e. W-9:
   Next, I'm going to have you fill out a W-9. This form is required by Virginia Tech policy to process payment for your participation today.

3. **Vision Test and Hearing Tests Pre-Drive Questionnaire:**

   Now we will be administering hearing and vision tests. In order to do that, I will put each of you in a separate room. While I administer the vision tests to one of you, the other will go into a separate room and complete the hearing test.

   a. Vison Test:
   [Read vision test protocol- Attachment 10b, **second page**]

   [Guide participant back to subject prep room and get next participant]

   b. Hearing Test:
   [Read hearing test protocol- Attachment 10a, **second page**]
   [Guide participant back to subject prep room]

4. **Pre-Drive Questionnaire**

   a. Administer Pre-Drive Questionnaire:
   Next, I will have you fill out the Pre-Drive Questionnaire.

5. **Pay participant the minimum, $30, if they are not continuing with the study.**
   a. Refer to Clincard protocol in On-Road Protocol□Post-Test

6. **Overview of the Study and Day's Schedule:**
[Once all participants are back in subject prep room]

Next we will briefly go over the study that you all will be participating in today and the day's schedule.

   a. Study Overview:

   *As explained in the Informed Consent Form, this research study is investigating how the displaying of driving information to users of highly automated vehicles (HAVs) impacts their levels of comfort and trust. HAVs, often called autonomous vehicles, drive themselves and do not allow users much control over the vehicle besides choosing the driving destination. This research project will examine different ways of displaying what the car 'sees' and how it makes decisions that could affect users' trust in the vehicle. You will be asked to sit in a highly automated test vehicle which will perform a variety of maneuvers with speeds up to 35 mph on a closed test-track here at VTTI. [**omit if baseline:** During this time, you will experience one of several different display systems (auditory, visual, or augmented reality), which will showcase how the vehicle sees the world, and then assess it through questionnaires.]*

   During the test sessions, we ask that no verbal feedback, such as talking, be made, in order not to influence other participants' opinions about the vehicle or vehicle system. We also ask that you not discuss the study until after we have completed all on-road testing and questionnaires.

   Do you have any questions about the study you will be participating in today?

   b. Schedule:

Next, we will be transporting you down to the Smart Road in one of our research vehicles with trained experimenters who are employees from VTTI. Once we get to the testing site, we will exit the vehicle and get into the test vehicle. Once you are seated in the test vehicle, you will get the opportunity to look around and familiarize yourself with your surroundings. We will make sure you are set up and comfortable in the test vehicle prior to beginning the experiment. During testing, there will always be a researcher present on the road.

You will then experience 6 different vehicle maneuvers of varying length and type. After each scenario, you will be asked to fill out a questionnaire about your experience. After the 6th scenario, a researcher will direct you to exit the test vehicle and get into the other vehicle to return to the main building.

In order to minimize how often we need to leave the road, this is a good opportunity to use the facilities before we head down.

Do you have any questions about our schedule today?

[escort any participants to the restrooms, as necessary, and once all have returned and you have confirmed the team is ready to head to the road, escort participants outside to the B1 lobby and to the confederate vehicle]

7. **Guide participants to confederate vehicle**

8. **On-Road Test**
   a. Refer to On-Road Protocol

9. **Post-Drive Questionnaire, Payment**
   a. Refer to Conclusion Protocol

10. **Thank participants and guide them to leave the building**

AV Viz: On-Road Protocol

1. **Orient Participants to Testing Environment**
   a. Once vehicle has stopped:

   As you can see, we have arrived at the testing location on the Virginia Smart Road. This test location is closed to outside traffic, but you should be aware that there is an additional experimenter in the testing area who will be assisting with our tests today, including driving another vehicle that will be involved in our tasks.

   i. Test vehicle description

   The test vehicle [point at the vehicle] is a self-driving car developed here at VTTI. The vehicle is designed to drive on the Smart Roads without anyone in the driver's seat. Because it is driving itself, there is a motor within the steering wheel that will make a loud creaking/grinding noise while the vehicle is in motion. This sound is perfectly normal and indicates that the vehicle is functioning properly. In addition, because the road we are using today is reconfigurable (e.g. the lane lines can be shifted/changed), the vehicle may not perfectly follow the lane lines. However, this is normal and to be expected.

   Do you have any questions regarding the testing environment or test vehicle?

   [Answer any questions.]

   Alright if you're ready we will exit this vehicle and I will instruct each of you where to sit in the test vehicle.

   [Lead safety driver to the front passenger seat. Lead to the SRX backseat. Ensure participants do not have time/ability to examine front passenger seat, where the emergency brake is located. Vehicle key will be placed on front passenger seat for researcher to use.]

2. **Orient Participants to Study Procedure/Expectations**
   a. Once participants are seated:

   Now that you are seated, please buckle your seat belts. [Wait until seatbelts are buckled].

   i. Study procedure

   Next, I'm going to briefly walk you through what will be going on today and what we are asking of each of you.

   As I mentioned previously, you will be riding in this completely autonomous ("self-driving") vehicle, with no one sitting in the driver's seat. You will experience six different vehicle maneuvers. During these maneuvers, soft targets or other vehicles may be present. [**omit if baseline condition**: *The goal of this study is to evaluate a human-machine-interaction (HMI) system. The system you will experience today is a(n) ____________ (auditory, 2D top-down, augmented reality) system. During the scenarios, please pay attention to the system as it will relay information about the driving landscape and the vehicle's "intentions".*] *I will tell you when each scenario will begin and when each scenario has ended. After each scenario, I will ask you to complete a questionnaire, where you will discuss your experiences. The front seat participant will be receiving a separate questionnaire, since they will experience a different condition than the back-seat participants.*

   ii. Verbal feedback/handheld radio instructions

   During the test sessions, we ask that no verbal feedback, such as talking, be made, in order not to interfere with the opinions other participants. If you should need to get the attention of a researcher (e.g. want to ask a question, alert experimenter, etc.) please use this handheld radio communicate with me. To work the radio, press and hold this button until you hear the tone, then talk into the front part of the radio.

   iii. Emergency cutoff instructions

   If at any point during the test you do not feel safe or wish to end the testing scenario for any reason, please press and release this "stop" button [demonstrate how to push button]. *The front seat participant will also have a "stop" button, but this one will be located in the center console* [point to button]. *These buttons will gradually bring the test vehicle to a slow and controlled stop and will disable all autonomous features. If you do press the button, please radio the researcher.*

   We also ask that you not discuss the study, [**omit if baseline condition**: *particularly opinions about the HMI systems or test vehicle*] *until after we have completed all on-road testing and questionnaires.*

   At this time, I would also ask that you please turn off or silence your cell phones.

Do you have any questions? If you're ready, we will begin.

3. **Testing**
   a. Refer to ORE protocol for expectations and safety procedures
   b. IF THE RESEARCHER POSING AS A PARTICIPANT MUST USE THE EMERGENCY STOP AT ANY TIME, READ **PARTICIPANT DEBRIEF IN EVENT OF RESEARCHER INTERVENTION** SCRIPT
   c. In the event that an error occurs and we need to recalibrate the vehicle (e.g. Velodyne Timeout), we will take participants to the Hub for a "break" while the vehicle is recalibrated
   d. Scenarios:
      i. Scenarios #2, 4, 5, 6 will be randomized/counterbalanced. See counterbalance matrix.
      ii. **Scenario #1 will always be the first scenario participants experience**
      iii. **Scenario #3 will always be last scenario participants experience**

i. Scenario #1- Baseline (**always the first scenario**)

a. Moderator:

[Before scenario begins]

Before we start our testing session, we would like to give you the chance to get more familiar with the test vehicle. We will have you sit in the vehicle while it completes a full lap on the road. Again, please limit discussion about your ride as to not influence anyone's opinion.

I will now start your ride. About 15 seconds after I push this button, the vehicle will begin to move.

[Input test number, press "Set Test". Press "Stop Test". Press "Start Test". Step back 20ft. from vehicle. Test will begin 15 seconds after pressing "Start".]

[After test ends and vehicle comes to a complete stop, approach the vehicle. Press "Stop Test".]

Now I will ask you to complete a survey about what you just experienced. Please raise your hand when you complete the survey, and I will come and collect it.

[Distribute survey. Collect when finished]

Does anyone have any questions about what you just experienced?

[Answer questions, if any]

b. Confederate Driver: sits parked, away from driving path, sets up cones for lane shift after vehicle passes through area

c. In-Vehicle Researcher: poses as participant, keep foot on e-brake until moderator leaves/approaches the vehicle

ii. Scenario #2- Detected pedestrian crossing

a. Moderator:

[Before scenario begins]

Now we will begin our next test, again, about 15 seconds after I push this button, the vehicle will begin to move. [**omit if baseline condition:** *Please remember to pay attention to the HMI system and what information it is portraying.*]

For this scenario, you will travel throughout the intersection area of the road.

[Input test number, press "Set Test". Press "Stop Test". Press "Start Test". Step back 20ft. from vehicle. Test will begin 15 seconds after pressing "Start".]

[After test ends and vehicle comes to a complete stop, approach the vehicle. Press "Stop Test".]

Now I will ask you to complete a survey about what you just experienced. Please raise your hand when you complete the survey, and I will come and collect it.

[Distribute survey. Collect when finished]

b. Confederate Driver: park vehicle in appropriate space, move HV-REMO completely across the road when the test vehicle comes to a stop. Once the test vehicle makes the right turn, move HV-REMO back to other side of the road

c. In-Vehicle Researcher: pose as participant, complete post-trial survey, keep foot on e-brake until moderator leaves/approaches the vehicle

iii. Scenario #4- Following lead vehicle/work zone

a. Moderator:

[Before scenario begins]

Now we will begin our next test, again, about 15 seconds after I push this button, the vehicle will begin to move. [**omit if baseline condition:** *Please remember to pay attention to the HMI system and what information it is portraying.*]

For this scenario, you will travel both on the urban and highway sections of the road and will experience a work zone lane shift.

[Input test number, press "Set Test". Press "Stop Test". Press "Start Test". Step back 20ft. from vehicle. Test will begin 15 seconds after pressing "Start".]

[After test ends and vehicle comes to a complete stop, approach the vehicle. Press "Stop Test". Refer to Post-Test protocol below]

Now I will ask you to complete a survey about what you just experienced. Please raise your hand when you complete the survey, and I will come and collect it.

[Distribute survey. Collect when finished]

b. Confederate Driver: Move confederate vehicle into starting position, in the straightaway after the stop sign on SSE. Once test vehicle comes to a stop, wait 10 seconds and accelerate to 30mph. If test vehicle gets too close/too far (less/more than 3s following distance), speed up/down to maintain appropriate gap. Follow scenario path- continue towards SR gate. Once test vehicle gets to work zone section, follow its path, clean up cones (if needed) and head back to SSE.

c. In-Vehicle Researcher: pose as participant, complete post-trial survey, keep foot on e-brake until moderator leaves/approaches the vehicle

a. Moderator:

[Before scenario begins]

Now we will begin our next test, again, about 15 seconds after I push this button, the vehicle will begin to move. [**omit if baseline condition:** *Please remember to pay attention to the HMI system and what information it is portraying.*]

For this scenario, you will travel around the intersection portion of the road.

[Input test number, press "Set Test". Press "Stop Test". Press "Start Test". Step back 20ft. from vehicle. Test will begin 15 seconds after pressing "Start".]

[After test ends and vehicle comes to a complete stop, approach the vehicle. Press "Stop Test". Refer to Post-Test protocol below]

Now I will ask you to complete a survey about what you just experienced. Please raise your hand when you complete the survey, and I will come and collect it.

[Distribute survey. Collect when finished]

b. Confederate Driver: park test vehicle where indicated on scenario diagram. Get out of vehicle and stand 20ft. away, in the grassy area, control HV-REMO according to scenario description

c. In-Vehicle Researcher: pose as participant, complete post-trial survey, keep foot on e-brake until moderator leaves/approaches the vehicle

[Before scenario begins]

Now we will begin our next test, again, about 15 seconds after I push this button, the vehicle will begin to move. [**omit if baseline condition:** *Please remember to pay attention to the HMI system and what information it is portraying.*]

For this scenario, we will be simulating a ride-share pickup scenario. I will approach the vehicle when it comes to a stop, open and close the door, as if getting into the vehicle, then I will walk away.

[Input test number, press "Set Test". Press "Stop Test". Press "Start Test". Step back 20ft. from vehicle. Test will begin 15 seconds after pressing "Start".]

[Walk over to where test vehicle will stop. When the test vehicle comes to a full stop, walk up to the vehicle, open the driver door, shut the driver door, and sit back down.]

[After test ends and vehicle comes to a complete stop, approach the vehicle. Press "Stop Test".]

Now I will ask you to complete a survey about what you just experienced. Please raise your hand when you complete the survey, and I will come and collect it.

[Distribute survey. Collect when finished]

b. Confederate Driver: park vehicle out of scenario path
c. In-Vehicle Researcher: pose as participant, complete post-trial survey, keep foot on e-brake until moderator leaves/approaches the vehicle, unlock the vehicle discreetly with the key fob when moderator approaches

Now we will begin our next test, again, about 15 seconds after I push this button, the vehicle will begin to move. [**omit if baseline condition:** *Please remember to pay attention to the HMI system and what information it is portraying.*]

For this scenario, you will travel throughout the intersection area of the road.

[Input test number, press "Set Test". Press "Stop Test". Press "Start Test". Step back 20ft. from vehicle. Test will begin 15 seconds after pressing "Start".]

[After test ends and vehicle comes to a complete stop, approach the vehicle. Press "Stop Test". Refer to Post-Test protocol below]

b. Confederate Driver: park vehicle in in safe area, position HV-REMO on the 4th space on the crosswalk
c. In-Vehicle Researcher: pose as participant, complete post-trial survey, keep foot on e-brake until moderator leaves/approaches the vehicle

vii. **Post-Test**

a. After the final scenario (unexpected event), once the vehicle comes to a stop:

[Read Unexpected Event Debrief]

This concludes our testing session. Next, we will have you fill a questionnaire about what you just experienced. After you finish, we will transport you back to the main building where you will receive your compensation.

[Administer Unexpected Event Questionnaire]

b. After all questionnaires are completed:

Thank you so much for your feedback. We really appreciate it. We will now exit the test vehicle and get into the confederate vehicle to travel back to the main building.

[Drive participants back to the main VTTI lobby].

Appendix D. Participant Recruitment Ads

Wanted for Research Study

The Virginia Tech Transportation Institute (VTTI) is seeking individuals, for a transportation study, who are 25 to 40 years of age. Participants will ride as a passenger in an automated, driverless research vehicle on a closed to the public test track at the VTTI facility.

-Total participation time: one visit, lasting about 2 hours
-This project provides compensation of $60 for full participation
-Your data will be kept strictly confidential

If you are interested in learning more,
please contact us at: 540-231-XXXX or email, drivers@vtti.vt.edu.
Reference "the AV Viz study" in your message.

All inquiries welcome!

VIRGINIA TECH
TRANSPORTATION INSTITUTE
www.vtti.vt.edu

Virginia Smart Roads

Participants needed for a transportation research study

From: Virginia Tech Transportation Institute

The Virginia Tech Transportation Institute (VTTI) is seeking individuals between 25 and 40 years of age to participate in a research study during daytime hours. Participants will ride as a passenger in an automated, driverless research vehicle on a closed to the public test track at the VTTI facility.

Total participation time consists of one visit lasting approximately 2 hours. The project provides compensation of $60 for full participation.

To learn more, contact XXX-XXX-XXXX or **drivers@vtti.vt.edu** and reference "the AV Viz study" in the message.

Appendix E. Participant Eligibility Screening Questions

1. What is your current age? _______________ YOB_________

Are you willing to show identification at the time of participation in order to verify your age?

YES ____ NO ______

Criterion: Must be 25 - 40 years of age to participate. Must be willing to show an ID at the time of participation in order to verify their age. A driver's license or some other photo ID is acceptable.

2. Are you a U.S. Citizen? YES ____ NO ______

If No, are you a permanent resident with a valid green card to work anywhere in the U.S.?

YES ____ NO ______

To clarify, Are you a Visa holder or do you have a *Valid Green Card with permanent resident status*? Visa ____ Green Card ____

If you have a Visa you will not be eligible to participate. Those with a Permanent Resident Green Card are eligible.

Notes:____
_

Criterion: Must be a U.S. citizen or permanent resident (green card holder able to work anywhere in the U.S. with NO restrictions such as limit on number of hours he or she can work each week or place he or she is allowed to work, for example, he or she can't be limited to only working at 1 company or VT only). ***Visa holders are not applicable.***

3. If selected to participate in this study, you will be asked to provide your SSN number. Will you complete a W-9 for payment purposes as required by Virginia Tech at the time of participation? *(for payment documentation and tax recording purposes Virginia Tech will require them to complete a W-9)*
YES ___ NO ____

<u>Please note:</u> VA Tech would never require your SS # or any personal banking information during a phone call. If scheduled to participate in any type of study, VT would send instructions whether you need to bring personal information for an appointment, in order to complete required paperwork at a study location.

Must be willing to provide SSN number for payment purposes.

4. Are you available to come in for one 2-hour session, during standard business hours (M-F, 8-5)?
YES _____ NO _____

Comments, if any & Availability: ____

Preference for those available for a daytime session during standard business hours (M-F, 8 am to 5 pm). Note availability: some weekend appointments may occur.

5. You will be asked to ride inside of an autonomous, self-driving test vehicle, with up to 2 other participants for around 2 hours. Would this present a problem for you? YES _____ NO _____

Criterion: Sitting with other participants, in an autonomous vehicle, for the session duration must not present a problem.

6. Have you ever experienced motion sickness while in a moving vehicle? YES _____ NO _____

Are you okay with riding in the back seat and looking at a display (such as a computer screen), then to the road and back, without getting motion sickness? YES _____ NO _____

Notes: ____

Criterion: Cannot easily suffer from motion sickness while in a moving vehicle. If they have had motion sickness while trying to read while riding in the front seat, it is acceptable; but not if they have difficulty riding in the back seat under any circumstance. Cannot have difficulty riding in a back seat, looking at a display and back up to the road several times.

7. Are you familiar with any experiments involving an autonomous, self-driving vehicle (vehicles with or without a driver, which behave as self-driving vehicles)? YES_______
NO________

If YES, please describe the research, and how you became familiar with it.

____

Criterion: Must not have heard of or be familiar with research involving a self-driving or automated vehicle.

We need to ask a few questions about your medical history…

Do you have a history of any of the following medical conditions? If yes, please explain.

8. Do you have any mobility limitations which may cause you to require assistance getting in and out of a motor vehicle or walking to and from the building and out to the research location? YES _____ NO _____

Criterion: Must not require assistance to walk out to a vehicle or getting in and out of a motor vehicle – no mobility limitations. No leg braces, ankle/foot in a boot, etc. Must not require a wheel chair or mobility scooter.

9. Any Head Injury, Stroke, or illness or disease affecting the Brain? YES _____ NO _____

If yes, please explain:____

Cannot have a history of brain damage from stroke, tumor, head injury, recent concussion, or disease or infection of the brain.

10. Current respiratory disorder/disease or any condition which requires oxygen? YES _____ NO _____
Notes:____

Cannot have current respiratory disorder/disease or disorder/disease requiring oxygen.

11. Any epileptic seizures or lapses of consciousness within the past twelve months?

YES _____ NO _____ Notes:____

Cannot have had epileptic seizures or lapses of consciousness within the last 12 months.

12. Current problems with the inner ear, dizziness, vertigo, or balance problems? YES ____ NO _____

Cannot have current problems with inner ear, dizziness, vertigo, or balance problems.

13. Are you currently taking any medicines or substances that may cause drowsiness or impair your ability to view and comprehend a visual display? YES _____ NO _____

Cannot currently be taking any substances that may interfere with awareness (cause drowsiness or impair visual or cognitive abilities)

14. For research purposes, do you identify as Male, Female, [pause] or other? (Circle one)

If answer "Other", ask, "what are your personal pronouns"? ____________

Criterion: The total number of participants will be gender balanced if possible.

15. (*Females only*) Are you currently pregnant? (*if "yes," politely inform the participant:* while being pregnant does not disqualify you from participating in this study, you are encouraged to talk to your physician about your participation to make sure that you both feel it is safe. If you like, **we can send you a copy of the consent form to discuss with your physician**. *Answer any questions*)

YES _____ NO _____

Can still participate, but encourage them to speak with their doctor first

16. Do you have normal, or corrected to normal, vision in ***BOTH*** eyes? YES _____ NO _____

Criterion: Must have normal or corrected to normal vision in both eyes.

17. You will be asked to participate without sunglasses. Will this present a problem should you be eligible to participate? YES _____ NO _____

Do you wear eyeglasses that tint or darken in the sunlight while sitting inside a vehicle?

YES _______ NO _______

Criterion: Must be able to participate without sunglasses or w/o lenses that darken while inside a vehicle. If they require glasses while driving, they need to wear glasses during this experiment.

18. Do you have normal, or corrected to normal, hearing in both ears? YES _____ NO _____ *Criterion: Must have normal or corrected to normal hearing in both ears.*
19. Are you comfortable reading, writing, and speaking English? YES _____ NO _____ *Criterion: Must be able to read, write, and speak English comfortably. If the screener finds during the phone interview, the caller is struggling with their ability to communicate fluently in English, then the screener should avoid scheduling this person.*
20. Do you work for an automotive company or supplier that is involved in the design, engineering, or development of automotive-related technologies? YES _____ NO _____ If yes, who:___________________________________ *Criterion: Must not be employed by an automotive company or supplier*

Appendix F. W-9 Tax Form

Virginia Tech
VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

VENDOR REGISTRATION
Substitute Form W-9
Mail or Fax completed form to:
300 Turner St NW, Suite 3300, Blacksburg, VA 24061
Phone: (540) 231-2544/Fax: (540) 231-7221

Legal Name: ____________________
(as it appears on your tax return)

Trade Name: ____________________
(DBA)

Mail PURCHASE ORDERS and BIDS to:		Mail PAYMENTS to:	
PO Telephone # *(preferably toll free)*	PO Fax # *(preferably toll free)*	Email address:	

Taxpayer Identification Number:		
Employer Identification Number(EIN):	AND/OR	**Social Security Number (SSN):**

Entity Type (one MUST be checked)

___ Corporation	__LLC	__Partnership
	If "LLC" is checked, type **MUST** be marked below:	
___ Government Entity	___ C Corporation (C)	___ Sole Proprietor
	___ S Corporation (S)	
___ Non-Profit Organization	___ Partnership (P)	X_ Individual (see below)

For Individuals ONLY:
____I am a U.S. Citizen, **or**
____I have been granted permanent residency (green card holder), **or**
____I am a Resident Alien for tax purpose; obtained appropriate permissions from my sponsor. I have contacted the international tax specialist at 540-231-3754 or jakunz@vt.edu to discuss additional documentation that is required by federal law.

Business Classification Type (check ALL that apply): *for descriptions see: http://www.purch.vt.edu/Vendor/class.html*

_____ Large Business _____Small Business _____ Minority owned Business _____ Women Owned Business _____Other

Certification: Under penalties of perjury, I certify that:
(1) The number(s) shown on this form is my correct taxpayer identification number(s) (or I am waiting for a number to be issued to me), ***and*** (2) The organization entity and all other information provided is accurate, ***and*** (3) I am not subject to backup withholding either because I have not been notified that I am subject to backup withholding as a result of a failure to report all interest or dividends, or the Internal Revenue Service has notified me that I am no longer subject to backup withholding, **and** (4) I am exempt from FATCA reporting.

You must cross out item (3) above if you have been notified by IRS that you are currently subject to backup withholding because of underreporting interest or dividends on your tax return.

All vendors and employees of the University should be aware of the requirements to abide by The Virginia Conflict of Interest Act. The applicable code can be reviewed at http://law.lis.virginia.gov/vacodepopularnames/state-and-local-government-conflict-of-interests-act

____________________ ____________________
Authorized Signature *Title*

____________________ ____________________ ____________
Printed or Typed Name *Phone Number* *Date*

Appendix G. Informed Consent Form

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

Informed Consent for Participants in Research Involving Human Subjects

Title of Project: Assessing Alternative Approaches for Conveying Highly Automated Vehicles' 'Intentions' (AV Viz)

Investigators: Zac Doerzaph and Luke Neurauter

I. THE PURPOSE OF THIS RESEARCH PROJECT

This study will investigate how the displaying of driving information to users of highly automated vehicles (HAVs) impacts their levels of comfort and trust. HAVs, often called autonomous vehicles, drive themselves and do not allow users much control over what happens besides choosing the driving destination. Perhaps because of this lack of control, potential users say that they would not want to ride in an autonomous vehicle due to a lack of trust in the vehicle. This research project will examine how different ways of displaying what the car 'sees' and how it makes decisions affects users' trust in the vehicle. The results of this study will help identify display types that increase users' trust in automated driving systems.

II. PROCEDURES

During your time here you will be asked to perform the following tasks.

1. Review the Informed Consent form. Ask any questions you may have, sign the Informed Consent Forms with the experimenter if you agree to participate.
2. Complete a hearing and vision assessment.
3. Complete a Virginia Tech W9 tax form. This is required by Virginia Tech in order to process compensation.
4. Complete a pre-drive questionnaire
5. Participate in one test session with up to two other participants on the Virginia Smart Roads, a controlled, closed to the public test track here at VTTI.
6. The test session involves riding as a passenger in an automated vehicle developed by employees of the Virginia Tech Transportation Institute as it drives along a set of prescribed routes in a controlled environment. While you are riding on the Smart Road you will encounter different staged scenarios (for example a pedestrian crossing the road).
7. After each route you will be asked to answer questions about your opinions of the display systems and overall comfort level and trust of the automated vehicle.
8. Follow instructions provided by experimenters assisting with the test sessions.
9. Complete a final questionnaire about your testing experience.

It is important that you understand we are not evaluating you in any way. We are collecting information about how different vehicle information display types affect comfort and trust of automated vehicles. Any questions you answer will contribute to the design and assessment of these displays. Therefore, we ask that you answer truthfully to the best of your abilities. This experiment is expected to last approximately 2 hours.

III. RISKS

As a participant, you may be exposed to the following risks or discomforts by volunteering for this research:

1. The risks involved are similar to those one would experience while riding in a vehicle moving at low speeds (<35mph).
2. Possible discomfort riding in an automated vehicle without readily available vehicle controls.
3. It is possible the automated vehicle may strike one of the soft foam targets used in the experiment.
4. The risk of injury during transport to or within the test site.
5. The risk associated with events such as equipment failure, wild animals entering the road, and weather changes. If at any point in the session the experimenter believes that continuing the session would endanger you or the equipment, he/she will stop the testing.
6. If you are pregnant you should talk to your physician and discuss this consent form with them before deciding about participation.

The following precautions will be taken to ensure minimal risk to you:

1. An experimenter will always monitor you and the automated vehicle.
2. There will be a button available to stop the vehicle at any time.
3. All objects that the vehicle will be interacting with are soft foam and designed to be struck without causing damage to the vehicle or its occupants.
4. Study area will be clutter free to the extent possible, and an experimenter will be available to assist at any time.
5. You will be encouraged to take breaks if so desired.
6. The experiment will run only during clear weather and roadway conditions.
7. You may decide not to participate or to cease participation at any time without penalty.
8. In the event of a medical emergency, or at your request, the experimenter will arrange medical transportation to a nearby hospital emergency room. You can elect to undergo examination by medical personnel in the emergency room. The experimenter has a cell phone in case of an emergency.
9. Vehicle speeds will be limited to under 35 mph
10. The study takes place on a closed test track. All other vehicles on the track will be part of the research study.
11. A first-aid kit will be available at the study site or in the experiment vehicles.

Participants in a study are considered volunteers, regardless of whether they receive compensation for their participation; under Commonwealth of Virginia law, workers compensation does not apply to volunteers; therefore, if not in an automobile, the participants are responsible for their own medical insurance for bodily injury. Appropriate health insurance is strongly recommended to cover these types of expenses. For example, if you were injured outside of an automobile during the project, the cost of transportation to the hospital emergency room would be covered by your insurance.

In the event of an accident or injury in an automobile (during transport to and from the test site), the automobile liability coverage for property damage and personal injury is provided. The total policy amount per occurrence is $2,000,000. This coverage (unless the other party was at fault,

which would mean all expenses would go to the insurer of the other party's vehicle) would apply in case of an accident for all volunteers and would cover medical expenses up to the policy limit. For example, if you were injured in an automobile owned or leased by Virginia Tech, the cost of transportation to the hospital emergency room would be covered by this policy.

IV. BENEFITS

While there are no direct benefits to you from this research, you may find the experiment interesting. No promise or guarantee of benefits is made to encourage you to participate. Participation in this study will contribute to the improvement of human machine interaction systems for future highly automated vehicles.

V. EXTENT OF ANONYMITY AND CONFIDENTIALITY

Data gathered in this experiment will be treated with confidentiality. Shortly after participation, your name will be separated from your data. A coding scheme will be employed to identify the data by participant number only (e.g., Participant No. 1). You may elect to have your data withdrawn from the study if you so desire, but you must inform the experimenters immediately of this decision so that the data may be promptly removed.

It is possible that the Institutional Review Board (IRB) may view this study's collected data for auditing purposes. The IRB is responsible for the oversight of the protection of human subjects involved in research.

Data collected by this project will be uploaded and archived in a Safe-D UTC data repository maintained by Virginia Tech Transportation Institute. A dataset may also be made publicly available. The public dataset will be de-identified and will not contain any information that might lead to the identification of an individual participant.

Data collected during this research project, including video and audio data, will be made available to external researchers. Data availability will be governed by a data sharing agreement. At no time will the researchers release data identifiable to you or the digital video of your image to anyone that has not agreed to abide by a data sharing agreement including IRB approval. The data collected will be retained indefinitely. Also, video and audio data that may identify you may be shown by VTTI staff, but not released, for research or reporting purposes such as presentations.

VI. COMPENSATION

You will be compensated $60 for complete participation. If you choose to withdraw before completing the study or if the study is terminated early for any reason, you will be compensated for the portion of time of the study for which you participated at the rate of $30 per hour, and if less than one hour, you will receive a minimum compensation of $30. All compensation, whether for the full amount of $60 or any partial amount, will be issued using a pre-loaded MasterCard. Please allow up to 1 full business day for activation of the card. Once activated, this card cannot be used past its expiration date. The issuing bank will also begin deducting a monthly service fee of $4.50 after three months of inactivity.

If compensation is in excess of $600 dollars in any one calendar year, then by law, Virginia Tech is required to file Form 1099 with the IRS. For any amount less than $600, it is up to you as the participant to report any additional income as Virginia Tech will not file Form 1099 with the IRS.

VII. FREEDOM TO WITHDRAW
As a participant in this research, you are free to withdraw at any time without penalty. If you choose to withdraw, you will be compensated for the portion of time of the study for which you participated. Furthermore, you are free not to answer any question or respond to experimental situations without penalty. If you choose to withdraw, please inform the experimenter of this decision and he/she will provide you with transportation back to the building.

VIII. APPROVAL OF RESEARCH
Before data can be collected, this research must be approved, as required, by the Institutional Review Board for Research Involving Human Subjects at Virginia Tech and by the Virginia Tech Transportation Institute. You should know that this approval has been obtained. This form is valid for the period listed at the bottom of the page.

IX. PARTICIPANT'S RESPONSIBILITIES
If you voluntarily agree to participate in this study, you will have the following responsibilities:

1. To follow the experimental procedures as well as you can.
2. To inform the experimenter if you have difficulties of any type.
3. To abstain from any substances that will impair your ability to participate.

X. PARTICIPANT'S PERMISSION AND ACKNOWLEDGMENTS
Check all that apply:

- ☐ I am not under the influence of any substances or taking any medications that may impair my ability to participate safely in this experiment.
- ☐ I am in good health and not aware of any health conditions that would increase my risk including, but not limited to lingering effects of a heart condition.
- ☐ I have informed the experimenter of any concerns/questions I have about this study.
- ☐ If I am pregnant, I acknowledge that I have either discussed my participation with my physician, or that I accept any additional risks due to pregnancy.

XI. QUESTIONS OR CONCERNS
Should you have any questions about this study, you may contact the Principal Investigator:

Zac Doerzaph, zdoerzaph@vtti.vt.edu, 540-231-1046
Luke Neurauter, lneurauter@vtti.vt.edu, 540-231-1522

Should you have any questions or concerns about the study's conduct or your rights as a research subject, or need to report a research-related injury or event, you may contact the Virginia Tech Institutional Review Board at irb@vt.edu or (540) 231-3732.

XII. Subject's Permission
I have read and understand the Informed Consent and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent for participation in this project.

If I participate, I may withdraw at any time without penalty. I agree to abide by the rules of this project.

____
Participant Signature Date

____
Experimenter Signature Date

Appendix H. Hearing and Vision Assessment & Score Sheets

Hearing Test

Next we are going to be performing an informal hearing test. This test will take no more than ten minutes, and I ask that you please stay as still and as quiet as possible so that your hearing through the headphones is not affected.

You will hear a series of three tones at several different sound levels. Please press this button as soon as you hear the sound. Press the button firmly and release, like this. Do not hold the button down. You can hold the button in either hand, whichever is the most comfortable for you.

Please do not guess, as this will cause the test to stop, and we will have to re-start the test from the beginning. I will let you know when the test is over, and I will then remove the headphones.

Please have a seat in this chair and face the wall. So that the headphones are positioned properly, I am going to place them on your ears from the back of your head. After I do so, please adjust them so that each earpiece is directly over your ear canal and there is no open space between.

Before I fit the headphones to your head, do you have any questions? Please remove your _________ (glasses, earrings, hair clips, rubber bands, hat, etc.) so that they don't get in the way of the headset.

- **Ensure that the speaker in each headphone is placed directly over the ear canal and adjust the headband if needed.**

1. **Turn the audiometer.**

2. **To start the test, press the button labeled AUTO. To pause, press the MAN button and resume the test by pressing the AUTO button again.**

3. **The test consists of sounds played at 1 KHz, 500 Hz, 1 KHz (repeated for accuracy), 2 KHz, 3 KHz, 4 KHz, 6 KHz, and 8 KHz. Each frequency level is given in a series of three tones, and the decibel level of the following three tones is either increased or decreased based on the participant's response. A series of sounds is played to the right ear first, and then played to the left ear.**

4. **If the participant pushes the button when there is not a tone ("false positive"), the audiometer will beep and display FALSE RESPONSES. In this case, the experimenter should explain that**

   the participant should not guess. Then, the experimenter should begin the test again.

5. **When the test is completed, TEST COMPLETE will be displayed and an audible beep will be presented.**

The test has finished, you can put the button on the table and remove the headset from your head.

AV Viz

<u>Hearing Measurement</u>

1. **Hearing Test:**

<u>Right Ear</u>

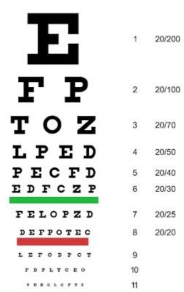
- 1 KHz: __________
- 500 Hz: __________
- 1 KHz: __________
- 2 KHz: __________
- 3 KHz: __________
- 4 KHz: __________
- 6 KHz: __________
- 8 KHz: __________

<u>Left Ear</u>

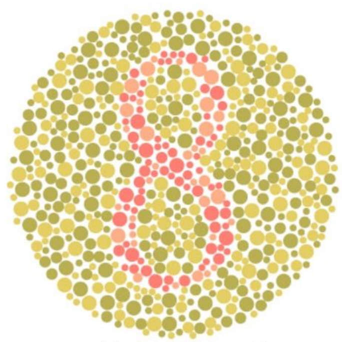
- 1 KHz: __________
- 500 Hz: __________
- 1 KHz: __________
- 2 KHz: __________
- 3 KHz: __________
- 4 KHz: __________
- 6 KHz: __________
- 8 KHz: __________

<u>AV Viz Vision Test Protocol</u>

Now we will be administering the vision test. Today we will be screening for both acuity (overall sight clarity) and color blindness.



Ex. Visual Acuity Test



Ex. Color Blindness Test

First we will be testing for visual acuity. For this test, please put your heels against the wall [direct them to wall opposite of vision chart] *and wear the eyewear you would normally use for driving (e.g. glasses, contact lenses, nothing;* ***no sunglasses****).*

Using ***both of your eyes****, please read aloud the smallest sized line of letters that you can.*

[After the participant reads the line]:
Please read the letters aloud in the next line.

[If the participant reads those correctly, have them continue reading through the lines until they make a mistake]
[If they make a mistake, allow them to try the line again]
[If they make another mistake in the same line, the last fully correct line of letters read is their acuity score]
[Record acuity score on Participant Packet sheet]

Thank you for your cooperation. Next we will be administering the color blindness test. For this test, we will have you look at a series of eight different colored circles. In each circle, you should see a number made up of a different color. Please say the number aloud as we work through each circle. Let's get started.
[Flip through book, allowing participants to say the numbers]
[Record participant results and # of book on Participant Packet sheet]

Vision/Hearing/Measurement

1 Acuity Test (must be better than or equal to 20/40)

- Acuity Score:________

2 Ishihara Test for Color Blindness

1._____	4._____	7.____
2._____	5._____	8._____
3._____	6._____	Book: __________

--Driver's license Valid YES NO

Appendix I. Pre-Test Questionnaire

Prior Exposure to AVs/Advanced Technology

1. Have you ever driven or ridden in a vehicle with automated features (adaptive cruise control, lane keeping assist, automatic emergency braking etc.)?
   a. Yes
   b. No
2. If answered yes to the above question, please list what type of features you have experienced:

____

Prior Exposure to Ride Share

3. Have you ever used a ride share service such as Uber or Lyft?
   a. Yes
   b. No

Behavioral Evaluation (circle)

4. I am up to date on the newest technology.

1	2	3	4	5	6	7
Strongly Disagree			Neutral			Strongly Agree

5. I would be comfortable riding in a fully automated vehicle (e.g. no driver or steering wheel)

1	2	3	4	5	6	7
Strongly Disagree			Neutral			Strongly Agree

6. Fully autonomous vehicles would make our roadways safer.

1	2	3	4	5	6	7
Strongly Disagree			Neutral			Strongly Agree

7. Fully autonomous vehicles would be cheaper in the long run for consumers.

1	2	3	4	5	6	7
Strongly Disagree			Neutral			Strongly Agree

8. Fully autonomous vehicles would help the environment.

1	2	3	4	5	6	7
Strongly Disagree			Neutral			Strongly Agree

Sensation Seeking (circle which pertains most to you)

A. I would like a job which would require a lot of traveling
B. I would prefer a job in one location.

A. I am invigorated by a brisk, cold day.
B. I can't wait to get into the indoors on a cold day.

A. I often wish I could be a mountain climber.
B. I can't understand people who risk their lives climbing mountains.

A. I dislike all body odors.
B. I like some of the earthy body smells.

A. I get bored seeing the same faces.
B. I like the comfortable familiarity of everyday friends.

A. I like to explore a strange city or section of town by myself, even if it means getting lost.
B. I prefer a guide when I am in a place I don't know well.

A. I would like to take up the sport of water-skiing
B. I would not like to take up water skiing.

A. When I go on a trip, I like to plan my route and timetable fairly carefully.
B. I would like to take off on a trip with no preplanned of definite routes, or timetable.

A. I would like to learn to fly an airplane.
B. I would not like to learn to fly an airplane.

A. I would not like to be hypnotized.
B. I would like to have the experience of being hypnotized.

A. The most important goal of life is to live it to the fullest and experience as much of it as you can.
B. The most important goal of life is to find peace and happiness.

A. I would like to try parachute jumping.
B. I would never want to try jumping out of a plane, with or without a parachute.

A. I enter cold water gradually, giving myself time to get used to it.
B. I like to dive or jump right into the ocean or a cold pool.

A. I prefer friends who are excitingly unpredictable.
B. I prefer friends who are reliable and predictable.

A. When I go on a vacation, I prefer the comfort of a good room and bed.
B. When I go on a vacation, I would prefer the change of camping out.

A. The essence of good art is in its clarity, symmetry of form, and harmony of colors.
B. I often find beauty in the "clashing" colors and irregular forms of modern paintings.

A. I prefer people who are emotionally expressive even if they are a bit unstable.
B. I prefer people who are calm and even tempered.
A. A good painting should shock or jolt the senses.
B. A good painting should give one a feeling of peace and security.

A. People who ride motorcycles must have some kind of an unconscious need to hurt themselves.
B. I would like to drive or ride on a motorcycle.

Locus of Control (circle which you agree most with)

A. Many of the unhappy things in people's lives are partly due to bad luck.
B. People's misfortunes result from the mistakes they make.

A. One of the major reasons why we have wars is because people don't take enough interest in politics.
B. There will always be wars, no matter how hard people try to prevent them.

A. In the long run, people get the respect they deserve in this world.
B. Unfortunately, an individual's worth often passes unrecognized no matter how hard he tries.

A. The idea that teachers are unfair to students is nonsense.
B. Most students don't realize the extent to which their grades are influenced by accidental happenings.

A. No matter how hard you try, some people just don't like you.

B. People who can't get others to like them don't understand how to get along with others.

A. Without the right breaks, one cannot be an effective leader.
B. Capable people who fail to become leaders have not taken advantage of their opportunities.

A. I have often found that what is going to happen will happen.
B. Trusting to fate has never turned out as well for me as making a decision to take a definite course of action.

A. In the case of the well prepared student, there is rarely, if ever, such a thing as an unfair test.
B. Many times exam questions tend to be so unrelated to course work that studying is really useless.

A. Becoming a success is a matter of hard work; luck has little or nothing to do with it.
B. Getting a good job depends mainly on being in the right place at the right time.

A. The average citizen can have an influence in government decisions.
B. This world is run by the few people in power, and there is not much the little guy can do about it.

A. When I make plans, I am almost certain that I can make them work.
B. It is not always wise to plan too far ahead because many things turn out to be a matter of luck anyway.

A. In my case, getting what I want has little or nothing to do with luck.
B. Many times we might just as well decide what to do by flipping a coin.

A. What happens to me is my own doing.
B. Sometimes I feel that I don't have enough control over the direction my life is taking.

Appendix J. Post-Trial Questionnaires

No HMI

1. I felt **comfortable** during the previous scenario.

1	2	3	4	5	6	7
Strongly Disagree			Neutral			Strongly Agree

2. I felt **safe** during the previous scenario.

1	2	3	4	5	6	7
Strongly Disagree			Neutral			Strongly Agree

3. I **trusted** the vehicle during the previous scenario.

1	2	3	4	5	6	7
Strongly Disagree			Neutral			Strongly Agree

4. I was **aware of my surroundings** during the previous scenario.

1	2	3	4	5	6	7
Strongly Disagree			Neutral			Strongly Agree

5. Additional information about the driving environment (e.g. detection of pedestrians, other vehicles, hazards in the roadways) would have increased my **comfort** in the vehicle during the previous scenario.

1	2	3	4	5	6	7
Strongly Disagree			Neutral			Strongly Agree

6. Additional information about the driving environment (e.g. detection of pedestrians, other vehicles, hazards in the roadways) would have made me feel **safer** during the previous scenario.

1	2	3	4	5	6	7
Strongly Disagree			Neutral			Strongly Agree

7. Additional information about the driving environment (e.g. detection of pedestrians, other vehicles, hazards in the roadways) would have made me more **aware of my surroundings** the previous scenario.

1	2	3	4	5	6	7
Strongly Disagree			Neutral			Strongly Agree

8. Additional information about the driving environment (e.g. detection of pedestrians, other vehicles, hazards in the roadways) would have increased my **trust** in the vehicle the previous scenario.

1	2	3	4	5	6	7
Strongly Disagree			Neutral			Strongly Agree

9. The vehicle reacted appropriately to all environmental stimuli (e.g. pedestrians, other vehicles, hazards in the roadway) during the previous scenario.

1	2	3	4	5	6	7
Strongly Disagree			Neutral			Strongly Agree

10. As a passenger, it was clear to me when the vehicle detected pedestrians/vehicles/other important objects during the previous scenario.

1	2	3	4	5	6	7
Strongly Disagree			Neutral			Strongly Agree

11. As a passenger, it was clear to me which path the vehicle would take while driving during the previous scenario.

1	2	3	4	5	6	7
Strongly Disagree			Neutral			Strongly Agree

12. As a passenger, it was clear to me when the vehicle was supposed to stop during the previous scenario.

1	2	3	4	5	6	7
Strongly Disagree			Neutral			Strongly Agree

14. I felt the need to press the "stop" button during the previous scenario.

1	2	3	4	5	6	7
Strongly Disagree			Neutral			Strongly Agree

15. What, if any, additional information would have improved your experience in the previous scenario?

HMI

1. I felt **comfortable** during the previous scenario.

1	2	3	4	5	6	7
Strongly Disagree			Neutral			Strongly Agree

2. I felt **safe** during the previous scenario.

1	2	3	4	5	6	7
Strongly Disagree			Neutral			Strongly Agree

3. I **trusted** the vehicle during the previous scenario.

1	2	3	4	5	6	7
Strongly Disagree			Neutral			Strongly Agree

4. I was **aware of my surroundings** during the previous scenario.

1	2	3	4	5	6	7
Strongly Disagree			Neutral			Strongly Agree

5. The information provided by the human machine interface (HMI) increased my **comfort** in the vehicle during the previous scenario.

1	2	3	4	5	6	7
Strongly Disagree			Neutral			Strongly Agree

6. The information provided by the human machine interface (HMI) made me feel **safe** during the previous scenario.

1	2	3	4	5	6	7
Strongly Disagree			Neutral			Strongly Agree

7. The information provided by the human machine interface (HMI) made me more **aware of my surroundings** during the previous scenario.

1	2	3	4	5	6	7
Strongly Disagree			Neutral			Strongly Agree

8. The information provided by the human machine interface (HMI) increased my **trust** in the vehicle during the previous scenario.

1	2	3	4	5	6	7
Strongly Disagree			Neutral			Strongly Agree

9. The vehicle reacted appropriately to all environmental stimuli (e.g. pedestrians, other vehicles, hazards in the roadway) during the previous scenario.

1	2	3	4	5	6	7
Strongly Disagree			Neutral			Strongly Agree

10. As a passenger, it was clear to me when the vehicle detected pedestrians/vehicles/other important objects during the previous scenario.

1	2	3	4	5	6	7
Strongly Disagree			Neutral			Strongly Agree

11. As a passenger, it was clear to me which path the vehicle would take while driving during the previous scenario.

1	2	3	4	5	6	7
Strongly Disagree			Neutral			Strongly Agree

12. As a passenger, it was clear to me when the vehicle was supposed to stop during the previous scenario.

1	2	3	4	5	6	7
Strongly Disagree			Neutral			Strongly Agree

13. The human machine interface (HMI) seemed to be functioning appropriately during the previous scenario.

1	2	3	4	5	6	7
Strongly Disagree			Neutral			Strongly Agree

14. I felt the need to press the "stop" button during the previous scenario.

1	2	3	4	5	6	7
Strongly Disagree			Neutral			Strongly Agree

16. Do you have any feedback about the HMI during the previous scenario?

Post-Surprise

1. What just happened?

2. Do you recall what actions you took during the scenario?

3. Did you notice anything before, during, or after the scenario?

4. The vehicle adequately detected the pedestrian at the crosswalk.

1	2	3	4	5	6	7
Strongly Disagree			Neutral			Strongly Agree

5. I felt comfortable during the previous scenario.

1	2	3	4	5	6	7
Strongly Disagree			Neutral			Strongly Agree

6. I felt safe during the previous scenario.

1	2	3	4	5	6	7
Strongly Disagree			Neutral			Strongly Agree

7. I trusted the vehicle during the previous scenario.

1	2	3	4	5	6	7
Strongly Disagree			Neutral			Strongly Agree

8. I was aware of my surroundings during the previous scenario.

1	2	3	4	5	6	7
Strongly Disagree			Neutral			Strongly Agree

9. The vehicle reacted appropriately to all environmental stimuli (e.g. pedestrians, other vehicles, hazards in the roadway) during the previous scenario.

1	2	3	4	5	6	7
Strongly Disagree			Neutral			Strongly Agree

10. As a passenger, it was clear to me when the vehicle detected pedestrians/vehicles/other important objects during the previous scenario.

1	2	3	4	5	6	7
Strongly Disagree			Neutral			Strongly Agree

11. As a passenger, it was clear to me which path the vehicle would take while driving during the previous scenario.

1	2	3	4	5	6	7
Strongly Disagree			Neutral			Strongly Agree

12. As a passenger, it was clear to me when the vehicle was supposed to stop during the previous scenario.

1	2	3	4	5	6	7
Strongly Disagree			Neutral			Strongly Agree

13. I felt the need to press the "stop" button during the previous scenario.

1	2	3	4	5	6	7
Strongly Disagree			Neutral			Strongly Agree

14. The HMI seemed to be functioning appropriately during the previous scenario.

1	2	3	4	5	6	7
Strongly Disagree			Neutral			Strongly Agree

Appendix K. Unexpected Event Debrief

To be read to participants after the undetected obstacle scenario

We apologize for not being able to tell you about the event that just occurred before it did. As we noted on the consent form the scenarios in this study do include hitting some of the soft targets. We deliberately staged a situation where the remote-control pedestrian would be struck by this vehicle. This study is meant to look at how effective different user interface concepts are at communicating important information to the user. Particularly for this event we wanted to see how difficult it would be for users to notice that the vehicle was not detecting a potential threat. To ensure your safety, this object was created from a soft material such that it would not cause harm to you or this vehicle. Additionally, the speed of the vehicle was kept intentionally low for impact to further reduce any potential risk of damage or injury.

The results of this study will contribute to our understanding of how people use and understand different interface concepts for displaying what automated vehicles 'see' as they are driving around.

We ask that you do not talk about the details of this study to others after your participation because this may invalidate future data that may be collected.

Appendix L. Safety Driver Debrief

To read to participants if you [Front Seat Researcher] need to intervene and bring the vehicle to a stop:

Since I just stopped the vehicle, I should tell you that I am not a participant in this study. I am a researcher here at VTTI and I am riding in the vehicle to make sure it is always functioning exactly as intended. Although the vehicle has been extensively tested and validated, we feel that having a human safety monitor is important for maintaining the safest testing environment possible. As always, participant safety is our number one priority. I apologize that I was not able to tell you I am not a participant in the study, but we feel this was necessary in order to make sure your reactions to how the vehicle behaves are as natural as possible.

I stopped the vehicle just now because it was not performing to my expectations and I thought the safest thing to do was end the trial. I'll radio the other researcher now and we will take you both back to the building and begin processing your payment for participating today.

Again, I apologize for not being able to tell you I was not a participant, but I hope you can understand why we thought this was necessary.

Appendix M. Python Code for Statistical Analysis

This code was used to perform statistical analyses on HMI condition vs. comfort. All codes written used similar syntax and methods for creating bar graphs and performing ANOVAs/post-hoc statistical tests.

```
import pandas as pd
import scipy.stats as stats
import statsmodels.api as sm
from statsmodels.formula.api import ols
import matplotlib.pyplot as plt
from scipy.stats import ttest_ind
import seaborn as sns
from statsmodels.stats.multicomp import pairwise_tukeyhsd
from statsmodels.stats.multicomp import MultiComparison

#Comparing HMI conditions to reported levels of comfort
#Scenario 3 data removed from analysis

#Uploading csv file datasets
df=pd.read_csv("Raw Data.csv") #raw data
df2=pd.read_csv("No Surprise Data.csv") #data w/ scenario 3 removed
df3=pd.read_csv("Baseline- No Surprise.csv")
df4=pd.read_csv("HMI 1.2-4_No Surprise.csv")

#Changing numerical variables to categorical variables
df['HMI_Condition']=pd.Categorical(df['HMI_Condition'])
df2['HMI_Condition']=pd.Categorical(df2['HMI_Condition'])
df3['HMI_Condition']=pd.Categorical(df3['HMI_Condition'])
df4['HMI_Condition']=pd.Categorical(df4['HMI_Condition'])

#Code to automatically label values on bar graphs
def autolabel(ax, orientation='horizontal', counts=None):
  # Get y-axis height to calculate label position from.
  (y_bottom, y_top) = ax.get_ylim()
  y_height = y_top - y_bottom

  print(len(ax.patches), len(counts))

  if counts == None:
    for rect in ax.patches:
      height = rect.get_height()

      # Fraction of axis height taken up by this rectangle
      p_height = (height / y_height)

      # Position our label near the bottom of the bar
      label_position = y_height * 0.4

      ax.text(rect.get_x() + rect.get_width() / 2., label_position,
```

```
                "%.1f" % height,
                ha='center', va='bottom',
                rotation=orientation)

        return

    for rect, count in zip(ax.patches, counts):
        print(count)
        height = rect.get_height()

        # Fraction of axis height taken up by this rectangle
        p_height = (height / y_height)

        # Position our label near the bottom of the bar
        label_position = y_height * 0.4

        ax.text(rect.get_x() + rect.get_width() / 2., height+y_height * 0.06,
                "%.1f" % height,
                ha='center', va='bottom',
                rotation=orientation)
        label_position = y_height * 0.05
        ax.text(rect.get_x() + rect.get_width() / 2., label_position,
                'n={0}'.format(count),
                ha='center', va='bottom',
                rotation=orientation)

#Comfort
tdf1_1_comfort = df2[df2['HMI_Condition'] == 1.1].Comfort #selecting cases for baseline w/
knowledge
tdf1_2_comfort = df2[df2['HMI_Condition'] == 1.2].Comfort #selecting cases for baseline
w/o knowledge
tdf2_comfort = df2[df2['HMI_Condition'] == 2].Comfort #selecting cases for visual only HMI
tdf3_comfort = df2[df2['HMI_Condition'] == 3].Comfort #selecting cases for audio only HMI
tdf4_comfort = df2[df2['HMI_Condition'] == 4].Comfort #selecting cases for mixed modal
HMI

#Finding counts of comfort responses for each HMI condition
count11=tdf1_1_comfort.count()
count12=tdf1_2_comfort.count()
count2=tdf2_comfort.count()
count3=tdf3_comfort.count()
count4=tdf4_comfort.count()

#Creating bar graph of HMI condition vs. comfort
ax=sns.barplot(data=df2, x="HMI_Condition", y="Comfort", ci=95)
plt.ylim(0,7.5)
plt.title("HMI Condition vs. Comfort")
plt.xlabel("HMI Condition")
autolabel(ax, orientation='horizontal', counts=[count11, count12, count2, count3, count4])
plt.savefig("HMI vs. Comfort.png", dpi=300, bbox_inches='tight')

#One-way ANOVA
stats.f_oneway(tdf1_1_comfort,tdf1_2_comfort,tdf2_comfort, tdf3_comfort, tdf4_comfort)

#OLS Model
hmi_comfort=ols('Comfort ~ HMI_Condition', data=df2).fit()
hmi_comfort.summary()
hmi_comfort_aov=sm.stats.anova_lm(hmi_comfort,typ=2)
hmi_comfort_aov

#Tukey HSD test
mc = MultiComparison(df2['Comfort'], df2['HMI_Condition'])
mc_results = mc.tukeyhsd()
print(mc_results)

#T-tests
comfort1112=ttest_ind(tdf1_1_comfort, tdf1_2_comfort) #sig
comfort112=ttest_ind(tdf1_1_comfort, tdf2_comfort) #sig
comfort113=ttest_ind(tdf1_1_comfort, tdf3_comfort)
comfort114=ttest_ind(tdf1_1_comfort, tdf4_comfort)
comfort122=ttest_ind(tdf1_2_comfort, tdf2_comfort)
comfort123=ttest_ind(tdf1_2_comfort, tdf3_comfort) #sig
comfort124=ttest_ind(tdf1_2_comfort, tdf4_comfort)
comfort23=ttest_ind(tdf2_comfort, tdf3_comfort) #sig
comfort24=ttest_ind(tdf2_comfort, tdf4_comfort)
comfort34=ttest_ind(tdf3_comfort, tdf4_comfort)

print(comfort1112)
print(comfort112)
print(comfort113)
print(comfort114)
print(comfort122)
print(comfort123)
print(comfort124)
print(comfort23)
print(comfort24)
print(comfort34)
```

Appendix N. R Code

```
df_all <-read.csv("HMI 1.2-4_No Surprise, No T1.csv")
library(lme4)
library(car)
library(nlme)
library(multcomp)

str(df_all)

df_all$HMI_Condition <-as.factor(df_all$HMI_Condition)
df_all$Scenario <-as.factor(df_all$Scenario)
df_all$Trial<-as.factor(df_all$Trial)
df_all$SS_Score <-as.factor(df_all$SS_Score)
df_all$LC_Score <-as.factor(df_all$LC_Score)
df_all$Ride_Drive_AV <-as.factor(df_all$Ride_Drive_AV)
df_all$Comfort_Riding_HAV <-as.factor(df_all$Ride_Drive_AV)

#Comfort
lmm_global_comfort <-lmer(Comfort~HMI_Condition+Scenario+Trial+(1|Participant_ID), data=df_all)
summary(lmm_global_comfort)
Anova(lmm_global_comfort) #scenario sig
tukey_global_comfortscenario <-glht(lmm_global_comfort, linfct = mcp(Scenario = "Tukey"))
summary(tukey_global_comfortscenario) #Scenario 4 vs. 2

#Safety
lmm_global_safety <-lmer(Safety~HMI_Condition+Scenario+Trial+(1|Participant_ID), data=df_all)
summary(lmm_global_safety)
Anova(lmm_global_safety)

#Trust
lmm_global_trust <-lmer(Trust~HMI_Condition+Scenario+Trial+(1|Participant_ID), data=df_all)
summary(lmm_global_trust)
Anova(lmm_global_trust) #scenario sig
tukey_global_trustscenario <-glht(lmm_global_trust, linfct = mcp(Scenario = "Tukey"))
summary(tukey_global_trustscenario) #4 vs. 2

#Awareness
lmm_global_aware <-lmer(Awareness~HMI_Condition+Scenario+Trial+(1|Participant_ID), data=df_all)
summary(lmm_global_aware)
Anova(lmm_global_aware)
```

Appendix O. Statistical Analyses

1.1 is the “with knowledge” condition, 1.2 is the “without knowledge” condition, 2.0 is the visual-only HMI condition, 3.0 is the audio-only HMI condition, and 4.0 is the mixed-modal HMI condition. Significance is highlighted. Additional statistical metrics are available upon request.

OLS Models- Main Effects

HMI vs. Comfort, Safety, Trust, and Situational Awareness (CSTA)

Independent variables (IV)=HMI Condition, dependent variables (DV)=participants’ reported levels of comfort, safety, trust, situational awareness obtained from the post-trial survey. Each model had 189 observations (obs) with 4 degrees of freedom (df). The $df_{residuals}$=184.

Dependent Variable	p-value	f-statistic	R-squared	Sum-Squares	Sum-Square (Residuals)
Comfort	0.0080	3.553	0.072	21.37	276.73
Safety	0.0007	5.009	0.098	22.60	207.51
Trust	0.0003	5.655	0.109	37.36	303.89
Situational Awareness	0.3650	1.086	0.023	2.94	124.38

<u>Tukey HSD Results</u>

Comfort

```
Multiple Comparison of Means - Tukey HSD,FWER=0.05
==============================================
```

```
group1 group2 meandiff  lower   upper  reject
---------------------------------------------
 1.1    1.2   -0.5464  -1.2567  0.1639 False
 1.1    2.0   -0.8589  -1.6853 -0.0325  True
 1.1    3.0    0.0786  -0.7478  0.905  False
 1.1    4.0   -0.5176  -1.3924  0.3572 False
 1.2    2.0   -0.3125   -1.044  0.419  False
 1.2    3.0    0.625   -0.1065  1.3565 False
 1.2    4.0    0.0288  -0.7569  0.8146 False
 2.0    3.0    0.9375   0.0928  1.7822  True
 2.0    4.0    0.3413  -0.5507  1.2334 False
 3.0    4.0   -0.5962  -1.4882  0.2959 False
```

Safety

```
Multiple Comparison of Means - Tukey HSD,FWER=0.05
=============================================
group1 group2 meandiff  lower   upper  reject
---------------------------------------------
 1.1    1.2   -0.4576  -1.0727  0.1575 False
 1.1    2.0   -0.9107  -1.6263 -0.1951  True
 1.1    3.0    0.1205  -0.5951  0.8361 False
 1.1    4.0    -0.478  -1.2355  0.2795 False
 1.2    2.0   -0.4531  -1.0866  0.1803 False
 1.2    3.0    0.5781  -0.0553  1.2116 False
 1.2    4.0   -0.0204  -0.7009   0.66  False
 2.0    3.0    1.0312   0.2998  1.7627  True
 2.0    4.0    0.4327  -0.3398  1.2052 False
 3.0    4.0   -0.5986  -1.3711  0.1739 False
---------------------------------------------
```

Trust

```
Multiple Comparison of Means - Tukey HSD,FWER=0.05
=============================================
group1 group2 meandiff  lower   upper  reject
---------------------------------------------
 1.1    1.2   -0.7263  -1.4707  0.018  False
 1.1    2.0   -1.2732  -2.1392 -0.4072  True
 1.1    3.0   -0.0857  -0.9517  0.7803 False
 1.1    4.0    -0.778  -1.6947  0.1387 False
 1.2    2.0   -0.5469  -1.3135  0.2197 False
 1.2    3.0    0.6406   -0.126  1.4072 False
 1.2    4.0   -0.0517  -0.8751  0.7718 False
 2.0    3.0    1.1875   0.3023  2.0727  True
 2.0    4.0    0.4952  -0.4396   1.43  False
 3.0    4.0   -0.6923  -1.6271  0.2425 False
---------------------------------------------
```

No HMI vs. CSTA

<u>Tukey HSD Tests</u>

Comfort

```
Multiple Comparison of Means - Tukey HSD,FWER=0.05
=============================================
```

```
group1 group2 meandiff  lower   upper  reject
---------------------------------------------
 1.1    1.2   -0.5464  -1.0331 -0.0597  True
---------------------------------------------
```

Safety

```
Multiple Comparison of Means - Tukey HSD,FWER=0.05
=============================================
group1 group2 meandiff  lower   upper  reject
---------------------------------------------
 1.1    1.2   -0.4576  -0.8418 -0.0734  True
---------------------------------------------
```

Trust

```
Multiple Comparison of Means - Tukey HSD,FWER=0.05
=============================================
group1 group2 meandiff  lower   upper  reject
---------------------------------------------
 1.1    1.2   -0.7263  -1.1971 -0.2556  True
---------------------------------------------
```

Situational Awareness

```
Multiple Comparison of Means - Tukey HSD,FWER=0.05
============================================
group1 group2 meandiff  lower  upper  reject
--------------------------------------------
 1.1    1.2   -0.2929  -0.6283 0.0426 False
--------------------------------------------
```

Trial vs. CSTA

For Trial vs. CSTA, statistical analysis was performed including data both from Trial #6 (i.e., the surprise event) and without. The analyses done with data from Trial #6 produced significant results and analyses done without data from Trial #6 produced insignificant results. Therefore, Trial #6 was the only influence on results. Analyses shown below are those not including Trial #6 data.

IV=trial number, DV=participants' reported levels of comfort, safety, trust, and situational awareness. Obs_{model}= 154, df_{model}=4, $df_{residuals}$=149.

Dependent Variable	p-value	f-statistic	R-squared	Sum-Squares	Sum-Square (Residuals)
Comfort	0.703	0.545	0.014	3.93	268.73
Safety	0.912	0.245	0.007	1.38	210.18
Trust	0.948	0.180	0.005	1.44	296.47
Situational Awareness	0.719	0.523	0.014	1.61	114.93

Scenario vs. CSTA

Similar to Trial vs. CSTA, for Scenario vs. CSTA, statistical analyses were performed both with and without data from the surprise event. This dataset was the only one that produced significant results, therefore the surprise event was found to be the only influence on reported metrics. Analyses shown below do not include the surprise event data.

IV=scenario type, DV=participants' reported levels of comfort, safety, trust, and situational awareness. Obs_{model}= 154, df_{model}=4, $df_{residuals}$=149.

Dependent Variable	p-value	f-statistic	R-squared	Sum-Squares	Sum-Square (Residuals)
Comfort	0.404	1.01	0.026	7.20	265.46
Safety	0.774	0.448	0.012	2.52	209.05
Trust	0.327	1.17	0.030	9.07	288.83
Situational Awareness	0.854	0.335	0.009	1.04	115.51

Need to Press Stop Button

IV=HMI conditions, trial number, scenario type; DV=participants' reported need to press the stop button. Obs_{model}=154, df_{model}=4, $df_{residuals}$=149.

Independent Variable	p-value	f-statistic	R-squared	Sum-Squares	Sum-Square (Residuals)
HMI Condition	0.073	2.37	0.045	3.35	70.73
Trial	0.985	0.091	0.002	0.180	73.90
Scenario Type	0.935	0.206	0.005	0.407	73.68

HMI vs. Information Provided Increasing CSTA

IV=HMI condition; DV=participants' reported levels of comfort, safety, trust, and situational awareness. $Obs_{comfort}$=90/$df_{residuals}$=87, $Obs_{safety, trust, awareness}$=89/$df_{residuals}$=86, df_{model}=2.

Dependent Variable	p-value	f-statistic	R-squared	Sum-Squares	Sum-Square (Residuals)
Comfort	0.0003	9.04	0.172	29.44	141.68
Safety	9.37E-06	13.29	0.236	41.07	132.93
Trust	4.61E-05	11.24	0.207	43.30	165.65
Situational Awareness	0.168	1.82	0.041	8.92	210.63

Tukey HSD Results

Comfort

```
Multiple Comparison of Means - Tukey HSD,FWER=0.05
============================================
group1 group2 meandiff  lower   upper  reject
--------------------------------------------
  2      3      1.2188   0.458  1.9795  True
  2      4      1.1635    0.36  1.9669  True
  3      4     -0.0553  -0.8587 0.7482 False
--------------------------------------------
```

Safety

```
Multiple Comparison of Means - Tukey HSD,FWER=0.05
=============================================
group1 group2 meandiff  lower  upper  reject
---------------------------------------------
  2      3     1.4375   0.6962 2.1788  True
  2      4     1.3863   0.5948 2.1777  True
  3      4    -0.0512  -0.8427 0.7402 False
---------------------------------------------
```

Trust

```
Multiple Comparison of Means - Tukey HSD,FWER=0.05
=============================================
group1 group2 meandiff  lower  upper  reject
---------------------------------------------
  2      3     1.625    0.7975 2.4525  True
  2      4     1.0538   0.1702 1.9373  True
  3      4    -0.5712  -1.4548 0.3123 False
---------------------------------------------
```

HMI vs. Clarity of "Intentions"

IV=HMI condition; DV=clarity of vehicle detection of obstacles, planned path, and intention to stop. $Obs_{obst}=152/df_{residuals}=148$, $obs_{path,stop}=154/df_{residuals}=150$, $df_{model}=3$.

Dependent Variable	p-value	f-statistic	R-squared	Sum-Squares	Sum-Square (Residuals)
Clarity of Obstacles	9.71E-07	11.34	0.187	88.14	383.41
Clarity of Planned Path	0.0003	6.80	0.120	57.58	423.41
Clarity of Stops	2.64E-07	12.43	0.199	93.47	376.06

Tukey HSD Results

Obstacles

```
Multiple Comparison of Means - Tukey HSD,FWER=0.05
=============================================
group1 group2 meandiff  lower  upper  reject
---------------------------------------------
 1.2    2.0    0.7128  -0.1952 1.6207 False
 1.2    3.0    1.8065   0.8986 2.7145  True
 1.2    4.0    1.579    0.5904 2.5677  True
 2.0    3.0    1.0938   0.0481 2.1394  True
 2.0    4.0    0.8662  -0.2502 1.9827 False
 3.0    4.0   -0.2275  -1.3439 0.8889 False
---------------------------------------------
```

Path

```
Multiple Comparison of Means - Tukey HSD,FWER=0.05
=============================================
group1 group2 meandiff  lower  upper  reject
---------------------------------------------
 1.2    2.0    0.3125  -0.6326 1.2576 False
 1.2    3.0     1.5     0.5549 2.4451  True
```

```
 1.2    4.0    1.0889   0.0737 2.1042  True
 2.0    3.0    1.1875   0.0962 2.2788  True
 2.0    4.0    0.7764  -0.3761 1.929  False
 3.0    4.0   -0.4111  -1.5636 0.7415 False
-------------------------------------------
```

Stops

```
Multiple Comparison of Means - Tukey HSD,FWER=0.05
============================================
group1 group2 meandiff  lower  upper  reject
--------------------------------------------
 1.2    2.0    0.625   -0.2657 1.5157 False
 1.2    3.0    1.5312   0.6405 2.422   True
 1.2    4.0    1.9519   0.9952 2.9087  True
 2.0    3.0    0.9062  -0.1222 1.9347 False
 2.0    4.0    1.3269   0.2407 2.4131  True
 3.0    4.0    0.4207  -0.6655 1.5069 False
--------------------------------------------
```

Sensation-Seeking vs. CSTA

IV=Sensation-seeking level (high, mid, low); DV=participants' reported metrics of comfort, safety, trust, and situational awareness. Obs_{model}=149, $df_{residuals}$=146, df_{model}=2.

Dependent Variable	p-value	f-statistic	R-squared	Sum-Squares	Sum-Square (Residuals)
Comfort	3.10E-05	11.16	0.133	36.03	235.77
Safety	4.51E-07	16.18	0.181	38.10	171.94
Trust	0.0002	9.11	0.111	32.78	262.65
Situational Awareness	0.725	0.323	0.004	0.503	113.81

Tukey HSD Results

Comfort

```
Multiple Comparison of Means - Tukey HSD,FWER=0.05
=============================================
group1 group2 meandiff  lower   upper  reject
---------------------------------------------
 High   Low   -0.7327  -1.5284  0.063  False
 High   Mid   -0.8636  -1.5268 -0.2004  True
 Low    Mid   -0.1309  -0.9063  0.6445 False
---------------------------------------------
```

Safety

```
Multiple Comparison of Means - Tukey HSD,FWER=0.05
=============================================
group1 group2 meandiff  lower   upper  reject
---------------------------------------------
 High   Low   -0.9038  -1.6305 -0.1771  True
 High   Mid   -0.9109  -1.5166 -0.3052  True
 Low    Mid   -0.0071  -0.7153  0.701  False
---------------------------------------------
```

Trust

```
Multiple Comparison of Means - Tukey HSD,FWER=0.05
=============================================
group1 group2 meandiff  lower  upper  reject
---------------------------------------------
 High   Low   -0.5016   -1.373 0.3698 False
 High   Mid   -0.6951  -1.4214 0.0312 False
 Low    Mid   -0.1935  -1.0426 0.6557 False
---------------------------------------------
```

Locus of Control vs. CSTA

IV=Locus of control designation (internal, mixed, external); DV=participants' reported metrics of comfort, safety, trust, and situational awareness. Obs_{model}=149, $df_{residuals}$=146, df_{model}=2.

Dependent Variable	p-value	f-statistic	R-squared	Sum-Squares	Sum-Square (Residuals)
Comfort	0.083	2.54	0.034	9.12	262.68
Safety	0.242	1.44	0.019	4.05	205.99
Trust	0.744	0.296	0.004	1.19	294.23
Situational Awareness	0.004	5.68	0.072	8.25	106.06

Tukey HSD Results

Situational Awareness

```
Multiple Comparison of Means - Tukey HSD,FWER=0.05
=================================================
 group1   group2  meandiff  lower  upper  reject
-------------------------------------------------
External Internal  0.4674   0.0134 0.9215  True
External  Mixed    0.6639   0.1608 1.167   True
Internal  Mixed    0.1965  -0.2291 0.6221 False
-------------------------------------------------
```

Previous Exposure to AV vs. CSTA

Tukey HSD Results

Comfort

```
Multiple Comparison of Means - Tukey HSD,FWER=0.05
==============================================
group1 group2 meandiff  lower   upper  reject
----------------------------------------------
  N       Y    -0.8188  -1.2404 -0.3971  True
----------------------------------------------
```

Safety

```
Multiple Comparison of Means - Tukey HSD,FWER=0.05
==============================================
group1 group2 meandiff  lower   upper  reject
----------------------------------------------
  N       Y    -0.6549  -1.0295 -0.2803  True
----------------------------------------------
```

Trust

```
Multiple Comparison of Means - Tukey HSD,FWER=0.05
============================================
group1 group2 meandiff  lower  upper  reject
--------------------------------------------
  N       Y     -0.4986  -0.9533 -0.044   True
--------------------------------------------
```

Situational Awareness

```
Multiple Comparison of Means - Tukey HSD,FWER=0.05
===========================================
group1 group2 meandiff lower  upper  reject
-------------------------------------------
  N       Y     -0.2633  -0.549 0.0223 False
-------------------------------------------
```

Initial Comfort vs. CSTA

IV=Initial comfort level (low, mid, high); DV=participants' reported metrics of comfort, safety, trust, and situational awareness. Obs_{model}=154, $df_{residuals}$=151, df_{model}=2.

Dependent Variable	p-value	f-statistic	R-squared	Sum-Squares	Sum-Square (Residuals)
Comfort	3.30E-06	13.74	0.154	41.98	230.68
Safety	3.11E-06	13.81	0.155	32.71	178.85
Trust	7.51E-06	12.77	0.145	43.10	254.80
Situational Awareness	0.0002	8.97	0.106	12.38	104.17

<u>Tukey HSD Results</u>

Comfort

```
Multiple Comparison of Means - Tukey HSD,FWER=0.05
=============================================
group1 group2 meandiff  lower   upper  reject
---------------------------------------------
 High   Low   -0.3707  -1.7185  0.9771 False
 High   Mid   -1.0663  -1.5481 -0.5844   True
 Low    Mid   -0.6955   -2.052  0.6609 False
---------------------------------------------
```

Safety

```
Multiple Comparison of Means - Tukey HSD,FWER=0.05
=============================================
group1 group2 meandiff  lower   upper  reject
---------------------------------------------
 High   Low   -0.6805  -1.8673  0.5063 False
 High   Mid   -0.9372  -1.3615 -0.5129   True
 Low    Mid   -0.2567  -1.4511  0.9377 False
---------------------------------------------
```

Trust

```
Multiple Comparison of Means - Tukey HSD,FWER=0.05
=============================================
group1 group2 meandiff  lower   upper  reject
---------------------------------------------
```

```
 High   Low   -1.0659  -2.4824  0.3507 False
 High   Mid   -1.0599  -1.5663 -0.5535  True
 Low    Mid    0.006   -1.4196  1.4316 False
---------------------------------------------
```

Situational Awareness

```
Multiple Comparison of Means - Tukey HSD,FWER=0.05
============================================
group1 group2 meandiff  lower  upper  reject
--------------------------------------------
 High   Low      0.3    -0.6057 1.2057 False
 High   Mid   -0.5448  -0.8686 -0.221  True
 Low    Mid   -0.8448  -1.7563 0.0667 False
```

OLS Models- Interaction Effects

Dependent Variable	**Independent Variable**	**P-value**
Comfort	HMI Condition	0.028
	Scenario Type	0.479
	Trial	0.967
Safety	HMI Condition	0.005
	Scenario Type	0.767
	Trial	0.977
Trust	HMI Condition	0.010
	Scenario Type	0.228
	Trial	0.964
Situational Awareness	HMI Condition	0.650
	Scenario Type	0.859
	Trial	0.738

Tukey HSD Results

Dependent Variable	**HMI Condition Combination**	**p-value**
Comfort	No HMI-Visual	0.323

	No HMI-Audio	0.559
	No HMI-Mixed	0.938
	Visual-Audio	0.016
	Visual-Mixed	0.728
	Audio-Mixed	0.270
Safety	No HMI-Visual	0.158
	No HMI-Audio	0.411
	No HMI-Mixed	0.949
	Visual-Audio	0.002
	Visual-Mixed	0.469
	Audio-Mixed	0.191
Trust	No HMI-Visual	0.241
	No HMI-Audio	0.426
	No HMI-Mixed	0.972
	Visual-Audio	0.005
	Visual-Mixed	0.536
	Audio-Mixed	0.241

Linear-Mixed Effects Models

The linear-mixed effects model examined the impact of a combination of independent variables on a single dependent variable. IV: HMI condition+scenario type+trial, DV: participants' reported levels of comfort, safety, trust, and situational awareness:

```
Formula: Comfort ~ HMI_Condition + Scenario + Trial + (1 | Participant_ID)
```

Dependent Variable	p-value (HMI Condition)	p-value (Scenario)	p-value (Trial)
Comfort	0.351	0.045	0.958
Safety	0.209	0.273	0.993
Trust	0.236	0.016	0.888
Situational Awareness	0.899	0.553	0.332

Tukey HSD Results

Comfort

Scenario 1	Scenario 2	P-value
Following Lead Vehicle	Ped Xing	0.039
Left Turns	Ped Xing	0.957
Passenger Pick Up	Ped Xing	0.600
Left Turns	Following Lead Vehicle	0.133
Passenger Pick Up	Following Lead Vehicle	0.485
Passenger Pick Up	Left Turns	0.882

Trust

Scenario 1	Scenario 2	P-value
Following Lead Vehicle	Ped Xing	0.011
Left Turns	Ped Xing	0.862
Passenger Pick Up	Ped Xing	0.411
Left Turns	Following Lead Vehicle	0.095
Passenger Pick Up	Following Lead Vehicle	0.417
Passenger Pick Up	Left Turns	0.868

Appendix P. Participant-Specific Analysis Data

Comfort

PID	T1	T2	T3	T4	T5	T2 vs. T1	T3 vs. T2	T4 vs. T3	T5 vs. T4	Sum	Trend
P01	6	6	6	6	6	0	0	0	0	0	None
P02	5	6	6	6	6	1	0	0	0	1	Increased
P03	7	7	7	7	7	0	0	0	0	0	None
P04	6	6	6	6	6	0	0	0	0	0	None
P05	5	5	6	6	5	0	1	0	-1	0	None
P06	5	4	5	3	4	-1	1	-2	1	-1	Decreased
P07	5	6	6	5	4	1	0	-1	-1	-1	Decreased
P08	7	7	7	7	7	0	0	0	0	0	None
P09	6	6	6	6	6	0	0	0	0	0	None
P10	2	3	5	2	3	1	2	-3	1	1	Increased
P11	5	5	5	5	5	0	0	0	0	0	None
P12	6	5	6	6	5	-1	1	0	-1	-1	Decreased
P13	7	7	7	7	7	0	0	0	0	0	None
P14	2	3	4	4	5	1	1	0	1	3	Increased
P15	4	5	5	5	5	1	0	0	0	1	Increased
P16	7	7	6	7	7	0	-1	1	0	0	None
P17	6	7	3	7	7	1	-4	4	0	1	Increased
P18	7	7	7	7	7	0	0	0	0	0	None
P19	7	7	7	7	7	0	0	0	0	0	None
P20	6	6	6	7	7	0	0	1	0	1	Increased

P21	6	7	7	7	7	1	0	0	0	1	Increased
P22	3	5	7	7	7	2	2	0	0	4	Increased
P23	4	6	5	5	5	2	-1	0	0	1	Increased
P24	5	4	6	5	4	-1	2	-1	-1	-1	Decreased
P25	6	6	5	5	5	0	-1	0	0	-1	Decreased
P26	7	6	4	6	7	-1	-2	2	1	0	None
P27	7	7	7	7	5	0	0	0	-2	-2	Decreased
P28	6	6	7	7	5	0	1	0	-2	-1	Decreased
P29	7	7	7	7	7	0	0	0	0	0	None
P30	3	5	3	4	4	2	-2	1	0	1	Increased

Safety

PID	T1	T2	T3	T4	T5	T2 vs. T1	T3 vs. T2	T4 vs. T3	T5 vs. T4	Sum	Trend
P01	5	6	6	6	6	1	0	0	0	1	Increased
P02	5	5	6	6	6	0	1	0	0	1	Increased
P03	7	7	7	7	7	0	0	0	0	0	None
P04	6	6	6	6	6	0	0	0	0	0	None
P05	5	6	6	6	5	1	0	0	-1	0	None
P06	5	5	5	5	5	0	0	0	0	0	None
P07	6	6	6	5	4	0	0	-1	-1	-2	Decreased
P08	7	7	7	7	7	0	0	0	0	0	None
P09	7	6	6	6	7	-1	0	0	1	0	None
P10	4	5	5	2	4	1	0	-3	2	0	None
P11	5	5	5	5	6	0	0	0	1	1	Increased
P12	6	5	6	6	5	-1	1	0	-1	-1	Decreased
P13	7	7	7	7	7	0	0	0	0	0	None
P14	5	3	4	5	6	-2	1	1	1	1	Increased
P15	5	4	5	3	4	-1	1	-2	1	-1	Decreased
P16	7	7	6	7	6	0	-1	1	-1	-1	Decreased
P17	7	7	6	7	7	0	-1	1	0	0	None
P18	7	7	7	7	7	0	0	0	0	0	None
P19	7	7	7	7	7	0	0	0	0	0	None
P20	6	6	6	7	7	0	0	1	0	1	Increased
P21	6	7	7	7	7	1	0	0	0	1	Increased
P22	3	6	7	7	7	3	1	0	0	4	Increased
P23	4	6	6	5	5	2	0	-1	0	1	Increased
P24	6	4	6	5	4	-2	2	-1	-1	-2	Decreased
P25	6	6	5	5	5	0	-1	0	0	-1	Decreased
P26	6	6	4	7	7	0	-2	3	0	1	Increased
P27	7	7	7	7	7	0	0	0	0	0	None
P28	6	6	7	7	5	0	1	0	-2	-1	Decreased
P29	7	7	7	7	7	0	0	0	0	0	None

P30	3	5	3	4	4	2	-2	1	0	1	Increased

Trust

PID	T1	T2	T3	T4	T5	T2 vs. T1	T3 vs. T2	T4 vs. T3	T5 vs. T4	Sum	Trend
P01	5	6	6	6	6	1	0	0	0	1	Increased
P02	4	5	5	5	5	1	0	0	0	1	Increased
P03	6	7	7	7	7	1	0	0	0	1	Increased
P04	6	6	5	6	6	0	-1	1	0	0	None
P05	5	5	5	5	4	0	0	0	-1	-1	Decreased
P06	4	4	5	4	4	0	1	-1	0	0	None
P07	6	4	6	3	3	-2	2	-3	0	-3	Decreased
P08	7	7	7	7	7	0	0	0	0	0	None
P09	6	6	6	6	6	0	0	0	0	0	None
P10	4	5	4	2	3	1	-1	-2	1	-1	Decreased
P11	5	5	5	5	5	0	0	0	0	0	None
P12	4	4	5	5	3	0	1	0	-2	-1	Decreased
P13	6	7	7	7	7	1	0	0	0	1	Increased
P14	4	3	5	5	4	-1	2	0	-1	0	None
P15	5	3	3	2	2	-2	0	-1	0	-3	Decreased
P16	7	6	6	7	5	-1	0	1	-2	-2	Decreased
P17	6	6	1	6	7	0	-5	5	1	1	Increased
P18	7	7	7	7	7	0	0	0	0	0	None
P19	7	7	7	7	7	0	0	0	0	0	None
P20	6	6	6	6	7	0	0	0	1	1	Increased
P21	5	6	7	7	7	1	1	0	0	2	Increased
P22	3	5	7	5	7	2	2	-2	2	4	Increased
P23	4	6	5	5	5	2	-1	0	0	1	Increased
P24	6	4	6	6	3	-2	2	0	-3	-3	Decreased
P25	4	5	4	5	3	1	-1	1	-2	-1	Decreased
P26	6	6	3	6	7	0	-3	3	1	1	Increased
P27	7	7	6	5	6	0	-1	-1	1	-1	Decreased
P28	5	6	7	7	5	1	1	0	-2	0	None
P29	6	5	6	7	7	-1	1	1	0	1	Increased
P30	3	4	3	5	4	1	-1	2	-1	1	Increased

Situational Awareness

PID	T1	T2	T3	T4	T5	T2 vs. T1	T3 vs. T2	T4 vs. T3	T5 vs. T4	Sum	Trend
P01	6	6	6	6	6	0	0	0	0	0	None
P02	6	7	7	7	7	1	0	0	0	1	Increased
P03	7	7	7	7	7	0	0	0	0	0	None

P04	6	6	6	6	6	0	0	0	0	0	None
P05	6	7	7	7	7	1	0	0	0	1	Increased
P06	5	6	4	5	5	1	-2	1	0	0	None
P07	6	4	4	4	4	-2	0	0	0	-2	Decreased
P08	7	7	7	7	7	0	0	0	0	0	None
P09	6	6	7	6	7	0	1	-1	1	1	Increased
P10	7	6	5	4	5	-1	-1	-1	1	-2	Decreased
P11	6	6	6	6	6	0	0	0	0	0	None
P12	6	7	6	7	7	1	-1	1	0	1	Increased
P13	7	7	7	7	7	0	0	0	0	0	None
P14	6	6	6	6	7	0	0	0	1	1	Increased
P15	7	7	6	6	4	0	-1	0	-2	-3	Decreased
P16	7	7	5	7	6	0	-2	2	-1	-1	Decreased
P17	7	7	6	6	6	0	-1	0	0	-1	Decreased
P18	7	7	6	7	7	0	-1	1	0	0	None
P19	7	7	6	7	7	0	-1	1	0	0	None
P20	6	7	7	7	7	1	0	0	0	1	Increased
P21	7	7	7	5	6	0	0	-2	1	-1	Decreased
P22	5	4	7	6	7	-1	3	-1	1	2	Increased
P23	6	5	5	4	5	-1	0	-1	1	-1	Decreased
P24	7	7	6	6	7	0	-1	0	1	0	None
P25	7	6	6	6	6	-1	0	0	0	-1	Decreased
P26	7	7	7	7	7	0	0	0	0	0	None
P27	7	7	7	7	7	0	0	0	0	0	None
P28	7	6	6	7	6	-1	0	1	-1	-1	Decreased
P29	5	7	7	7	7	2	0	0	0	2	Increased
P30	5	5	5	5	6	0	0	0	1	1	Increased

Appendix Q. Coded Qualitative Data

No HMI- Primary

HMI_Conditi	Scena	Additional Information Wanted	Want More Info	Want More Info (	Matc	Undesirable Vehicle Dynamics (R	Undesirable Vehicle Dynamics	Match
1.2	6	Turn signals	1	1	Y		0	Y
1.2	2	Turn signals, road hazard/pedestrian detection, light/buzzer	1	1	Y		0	Y
1.2	5	Turn signals, hazard/pedestrian detected signal	1	1	Y		0	Y
1.2	4	Less "stabby" braking, turn signals, "hazard detected" info	1	1	Y	1	1	Y
1.2	1	Steering wheel rattles a bit		0	Y	1	1	Y
1.2	4	Rattling steering wheel (I figure this of course wouldn't be in future designs)		0	Y	1	1	Y
1.2	5	Have the vehicle automatically signal when turning	1	1	Y	0	0	Y
1.2	2	Automated signaling to tell which way it's turning would be good. Vehicle stopped mostly in crosswalk	1	1	Y	1	1	Y
1.2	6	Signaling direction would be nice	1	1	Y		0	Y
1.2	1	Just knowing the steering wheel creaks before starting		0	Y	1	1	Y
1.2	4	The steering wheel noises are a bit disctracting		0	Y	1	1	Y
1.2	1	Felt like it drove over road lines		0	Y	1	1	Y
1.2	2	How close the car should be to crosswalk		0	Y	1	1	Y
1.2	5	That car knew it was driving on lane lines		0	Y	1	1	Y
1.2	4	What color traffic light was on, why lane switch, why pause at re-entry off of highway	1	1	Y	0	0	Y
1.2	1	Being able to see in front of the vehicle, music	1	1	Y		0	Y
1.2	4	Turn signals, where is the car going? where's the route going?	1	1	Y		0	Y
1.2	5	Visuals on what the car is sensing and where	1	1	Y		0	Y
1.2	2	Did the car sense the crosswalk or human or both?	1	1	Y		0	Y
1.2	6	Where are you going? How do you know the right passenger is getting in the car?	1	1	Y		0	Y
1.2	1	Consistency w/ lane markings		0	Y	1	1	Y
1.2	1	The handling of the terrain, cornering, and lane changing seemed less than pinpointed		0	Y	1	1	Y
1.2	1	Being able to see the road	1	1	Y		0	Y
1.2	1	Less steering wheel noise and jerking of car/brakes		0	Y	1	1	Y
1.2	1	Noisy, braking was not smooth		0	Y	1	1	Y
1.2	1	Being able to hear turn signals if they were used. Not sure if they were	1	1	Y		0	Y
1.2	1	The sound from the wheel was a little annoying		0	Y	1	1	Y
1.2	1	Minimal steering wheel sounds. Reducing the clicking on the wheel and abrupt changes on the road		0	Y	1	1	Y
1.2	1	Know when/where the vehicle was going	1	1	Y		0	Y
1.2	1	Signals when turning. Views of the path car was seeing vs. taken	1	1	Y		0	Y
1.2	1	None. Very impressed		0	Y		0	Y
1.2	1	Using signals to indicate turns	1	1	Y		0	Y
1.2	1	Being able to see our adherance to the road lines. Quieter servos	1	1	Y	1	1	Y
1.2	1	Use of signal lights	1	1	Y		0	Y

No HMI- Secondary, Additional Information Wanted

Additional Information Wanted	Turn Signals	Turn Signals	Match?	Music	Music	Match?	Navigation/Maps	Navigation/Maps	Match?	Hazard Detection	Hazard Detection	Match?
Turn signals	1	1	Y	0	0	Y	0	0	Y		0	Y
Turn signals, road hazard/pedestrian detection, light/buzzer	1	1	Y	0	0	Y	0	0	Y	1	1	Y
Turn signals, hazard/pedestrian detected signal	1	1	Y	0	0	Y	0	0	Y	1	1	Y
Less "stabby" braking, turn signals, "hazard detected" info	1	1	Y	0	0	Y	0	0	Y	1	1	Y
Have the vehicle automatically signal when turning	1	1	Y	0	0	Y	0	0	Y		0	Y
Automated signaling to tell which way it's turning would be good. Vehicle stopped mostly in crosswalk	1	1	Y	0	0	Y	0	0	Y		0	Y
Signaling direction would be nice	1	1	Y	0	0	Y	0	0	Y		0	Y
What color traffic light was on, why lane switch, why pause at re-entry off of highway	0	0	Y	0	0	Y	1	1	Y		0	Y
Being able to see in front of the vehicle, music	0	0	Y	1	1	Y	0	1	N		0	Y
Turn signals, where is the car going? where's the route going?	1	1	Y	0	0	Y	1	1	Y		0	Y
Visuals on what the car is sensing and where	0	0	Y	0	0	Y	0	0	Y	1	1	Y
Did the car sense the crosswalk or human or both?	0	0	Y	0	0	Y	1	0	N	1	1	Y
Where are you going? How do you know the right passenger is getting in the car?	0	0	Y	0	0	Y	1	1	Y		0	Y
Being able to see the road	0	0	Y	0	0	Y	1	1	Y		0	Y
Being able to hear turn signals if they were used. Not sure if they were	1	1	Y	0	0	Y	0	0	Y		0	Y
Know when/where the vehicle was going	0	0	Y	0	0	Y	1	1	Y		0	Y
Signals when turning. Views of the path car was seeing vs. taken	1	1	Y	0	0	Y	1	1	Y		0	Y
Using signals to indicate turns	1	1	Y	0	0	Y	0	0	Y		0	Y
Being able to see our adherance to the road lines. Quieter servos	0	0	Y	0	0	Y	0	1	N		0	Y
Use of signal lights	1	1	Y	0	0	Y	0	0	Y		0	Y

No HMI- Secondary, Undesirable Vehicle Dynamics

Additional Information Wanted	Following Lane Lines	Following Lane Lines	Match?	Steering Noise	Steering Noise	Match?	Speeds/Braking/Turning	Speeds/Braking/Turning	Match?	Location of Vehicle	Location of Vehicle	Match?
Less "stabby" braking, turn signals, "hazard detected" info		0	Y		0	Y	1	1	Y		0	Y
Steering wheel rattles a bit		0	Y	1	1	Y	0	0	Y		0	Y
Rattling steering wheel (I figure this of course wouldn't be in future designs)		0	Y	1	1	Y	0	0	Y		0	Y
Automated signaling to tell which way it's turning would be good. Vehicle stopped mostly in crosswalk		0	Y		0	Y	0	0	Y	1	1	Y
Just knowing the steering wheel creaks before starting		0	Y	1	1	Y	0	0	Y		0	Y
The steering wheel noises are a bit distracting		0	Y	1	1	Y	0	0	Y		0	Y
Felt like it drove over road lines	1	1	Y		0	Y	0	0	Y		0	Y
How close the car should be to crosswalk		0	Y		0	Y	0	0	Y	1	1	Y
That car knew it was driving on lane lines	1	1	Y		0	Y	0	0	Y		0	Y
Consistency w/ lane markings	1	1	Y		0	Y	0	0	Y		0	Y
The handling of the terrain, cornering, and lane changing seemed less than pinpointed		0	Y		0	Y	1	1	Y		0	Y
Less steering wheel noise and jerking of car/brakes		0	Y	1	1	Y	1	1	Y		0	Y
Noisy, braking was not smooth		0	Y	1	1	Y	1	1	Y		0	Y
The sound from the wheel was a little annoying		0	Y	1	1	Y	0	0	Y		0	Y
Minimal steering wheel sounds. Reducing the clicking on the wheel and abrupt changes on the road		0	Y	1	1	Y	0	1	N		0	Y
Being able to see our adherance to the road lines. Quieter servos	1	1	Y	1	1	Y	0	0	Y		0	Y

HMI- Primary

Scenario	HMI_Feedback	HMI Not Accurate	HMI Not Accurate2	Match	Undesirable Vehicle Dynamics	Undesirable Vehicle Dynamics3	Match?2	Need/Want More Info	[illegible]	Match?3	Added Comfort	Added Comfort?	Match?4
6	No route or stop indications. Made ride more uncertain		0	Y		0	Y	1	1	Y		0	Y
4	Delay between HMI and car position	1	1	Y		0	Y		0	Y		0	Y
4	HMI differed from the road slightly	1	1	Y		0	Y		0	Y		0	Y
6	HMI broke illusion of data being real, tester appeared a few seconds after screen indicated approach	1	1	Y		0	Y		0	Y		0	Y
2	The vehicle struggled to stay in its lane and misrepresented its orientation within multiple lanes	1	1	Y	1	1	Y		0	Y		0	Y
4	Vehicle failed to show animal on HMI that had wandered onto the track, seemingly did not detect animal at all	1	1	Y		0	Y	1	0	N		0	Y
6	HMI misrepresented the location of the approaching "passenger"	1	1	Y		0	Y		0	Y		0	Y
5	Screen doesn't seem acurate	1	1	Y		0	Y		0	Y		0	Y
4	Use blinkers		0	Y		0	Y	1	1	Y		0	Y
2	Stay in lane		0	Y	1	1	Y		0	Y		0	Y
6	The initial take off jerk abrasively. There seemes to be a complete disregard for the lanes		0	Y	1	1	Y		0	Y		0	Y
4	I was nervous every time new items like cones were present. I wasn't sure if the car was going to know but it always did		0	Y		0	Y	0	1	N		0	Y
4	Sharp turns are a bit "ahhh"		0	Y	1	1	Y		0	Y		0	Y
5	Not sure why the vehicle turned when the people started walking		0	Y	1	0	N	0	1	N		0	Y
2	The car stayed in the lines better. Yay!		0	Y		0	Y		0	Y		0	Y
6	The vehicle stopped in the crosswalk. The rideshare HMI person was not accurate at all, it was actually a bit alarming	1	1	Y	1	1	Y		0	Y		0	Y
2	While I felt safe riding in the vehicle, the HMI did not stay in the lines. I believe since I was aware it is a closed course I did not worry about wrecking		0	Y	1	1	Y		0	Y		0	Y
4	I felt the HMI slowed even when it was not necessary. The HMI doesn't use signals and the crossing over the line made me less comfortable		0	Y	0	1	N		0	Y		0	Y
6	The HMI seems to stop even when there is not a stop sign and/or pedestrian. I am assuming that it stops when there should be a sign		0	Y		0	Y		0	Y		0	Y
5	The HMI did not turn tight enough and I worried it would hit the pedestrian I wish the HMI had a turn signal or used it		0	Y		0	Y		0	Y		0	Y
4	Thought a human should be prompted beofre proceeding in the wrong lane to go around an obstacle. Would not make me feel safe		0	Y	1	1	Y	0	1	N		0	Y
6	Didn't beep the first time when pedestrian was detected but did on this run	0	1	N		0	Y		0	Y		0	Y
5	The more we ride, the more "safe and comfortable" I feel with it driving		0	Y		0	Y		0	Y	1	1	Y
4	Audible signals for starting and ending ride added comfort/trust in vehicle. Still wish I could hear turn signals if used		0	Y		0	Y	1	1	Y	1	1	Y
2	Still unclear route at times. I cannot determine which turn/which way we will turn		0	Y		0	Y	1	1	Y		0	Y
6	Still cannot detect route/turns		0	Y		0	Y	1	1	Y		0	Y
4	I'm not sure what the HMI is?		0	Y		0	Y		0	Y		0	Y
2	I didn't know until this scenario that the HMI was just sounds and not also the screen so I thought it wasn't functioning properly bc the screen was on windows only		0	Y		0	Y		0	Y		0	Y
2	The lanes on the display as related to the car's actual position does not make me trust the system. They are fairly significantly different. The path of the pedestrian on the display was different than its actual path on the road. Sounds of the HMI are a bit abrupt; not really intuitive and more like "danger" than notification	1	1	Y		0	Y		0	Y		0	Y
4	Turns are being overcorrected by vehicle and the visual of this occurance on the screens makes me trust the vehicle less and less even though the visual in general improves trust	0	1	N	1	1	Y		0	Y	1	1	Y
6	Timing appears more scripted than system reacting to actual stimulus	0	1	N		0	Y		0	Y		0	Y
5	My safety and trust were reduced bc the vehicle went wide during the turn while approaching pedestrians. The visual on the screen showed going outside the lines which was appropriate but decreased my trust in the vehicle		0	Y	1	1	Y		0	Y		0	Y
2	Car starts too sudden. Taking curves or switching lanes is too rough. I feel the car should've stopped farther away from the pedestrian. Too rough when making turns. Accelerating and braking is in intervals; needs to be more consistent. It felt like the car hesitated when it needed to stop.		0	Y	1	1	Y		0	Y		0	Y
4	The car makes very wide turns sometimes getting on the other lane or outside the paved road (so it seemed). When we initially stopped the time to check for oncoming traffic, it was appropriate. It yielded to pedestrians. The only thing I don't trust is the turns, the steering wheel does not make a smooth circle		0	Y	1	1	Y		0	Y		0	Y
6	The car did allow time for the passenger to get in and input information. I felt it waited too long to detect a pedestrian; it even stopped on the white lines. Still making very wide turns		0	Y	1	1	Y		0	Y		0	Y
5	The HMI needs to alert at a sooner rate. Sometimes it is right after the car has started slowing down. I feel it should be more of an alert.	0	1	N		0	Y	1	0	N		0	Y
4	The HMI does not always show the same thing as what is going on outside	1	1	Y		0	Y		0	Y		0	Y
5	There is a ground hog beside the two gravel piles		0	Y		0	Y		0	Y		0	Y
4	It's disconcerting that the vehicle doesn't follow lanes or audibly indicate		0	Y	1	1	Y	1	1	Y		0	Y
6	The other car and human movements seem unnatural	0	1	N		0	Y		0	Y		0	Y
4	Car drove often outside the lines and over the median		0	Y	1	1	Y		0	Y		0	Y
4	Signal lights would help		0	Y		0	Y	1	1	Y		0	Y
5	Lane control, rode in the middle of 2 lanes instead of picking one to stay in		0	Y	1	1	Y		0	Y		0	Y
6	The same feeling about the lane selection and the signal light for where the vehicle was traveling. Also the turns are a little rough		0	Y	1	1	Y		0	Y		0	Y
2	The not staying in one lane and not using signal lights keeps me from knowing what the next move is and makes me feel less comfortable		0	Y	1	1	Y	1	1	Y		0	Y

HMI- Secondary, Inaccurate HMI

HMI	HMI_Feedback	Vehicle Position	Vehicle Position	Match?	External Stimuli Position	External Stimuli Position	Match?	Timing/Dynamics	Timing/Dynamics of Stimuli	Match?
2	Delay between HMI and car position	1	1	Y	0	0	Y		0	Y
2	HMI differed from the road slightly	0	1	N	1	0	N		0	Y
2	HMI broke illusion of data being real, tester appeared a few seconds after screen indicated approach	0	0	Y	0	0	Y	1	1	Y
2	The vehicle struggled to stay in its lane and misrepresented its orientation within mulitple lanes	1	1	Y	0	0	Y		0	Y
2	Vehicle failed to show animal on HMI that had wandered onto the track, seemingly did not detect animal at all	0	0	Y	1	1	Y		0	Y
2	HMI misrepresented the location of the approaching "passenger"	0	0	Y	1	1	Y		0	Y
2	Screen doesn't seem acurate	0	0	Y	0	0	Y		0	Y
2	The vehicle stopped in the crosswalk. The rideshare HMI person was not accurate at all, it was actually a bit alarming	0	0	Y	0	0	Y		0	Y
3	Didn't beep the first time when pedestrian was detected but did on this run	0	0	Y	0	1	N		0	Y
4	The lanes on the display as related to the car's actual position does not make me trust the system. They are fairly signficiantly different. The path of the pedestrian on the display was different than its actual path on the road. Sounds of the HMI are a bit abrupt; not really intuitive and more like "danger" than notification	0	1	N	1	1	Y	1	1	Y
4	Turns are being overcorrected by vehicle and the visual of this occurance on the screens makes me trust the vehicle less and less even though the visual in general improves trust	0	0	Y	0	0	Y		0	Y
4	Timing appears more scripted than system reacting to actual stimulus	0	0	Y	0	0	Y	0	1	N
4	The HMI needs to alert at a sooner rate. Sometimes it is right after the car has started slowing down. I feel it should be more of an alert.	0	0	Y	0	0	Y		0	Y
4	The HMI does not always show the same thing as what is going on outside	0	0	Y	1	1	Y		0	Y
4	The other car and human movements seem unnatural	0	0	Y	1	1	Y		0	Y

HMI- Secondary, Undesirable Vehicle Dynamics

HMI	HMI_Feedback	Following Lane Lines	Following Lane Lines	Match?	Speeds/Braking/ Turning	Speeds/Braking/ Turning	Match?	Location of Vehicle	Location of Vehicle	Match?
2	The vehicle struggled to stay in its lane and misrepresented its orientation within mulitple lanes	1	1	Y		0	Y	1	0	N
2	Stay in lane	1	1	Y		0	Y		0	Y
2	The initial take off jersk abrasively. There seemes to be a complete disregard for the lanes	1	1	Y	0	1	N		0	Y
2	Sharp turns are a bit "ahhh!"		0	Y	1	1	Y		0	Y
2	Not sure why the vehicle turned when the people started walking		0	Y		0	Y		0	Y
2	The vehicle stopped in the crosswalk. The rideshare HMI person was not accurate at all, it was actually a bit alarming		0	Y		0	Y	1	1	Y
2	While I felt safe riding in the vehicle, the HMI did not stay in the lines. I believe since I was aware it is a closed course I did not worry about wrecking	1	1	Y		0	Y		0	Y
2	I felt the HMI slowed even when it was not necessary. The HMI doesn't use signals and the crossing over the line made me less comfortable		0			0		0	1	N
3	Thought a human should be prompted beofre proceeding in the wrong lane to go around an obstacle. Would not make me feel safe		0	Y		0	Y		0	Y
4	Turns are being overcorrected by vehicle and the visual of this occurance on the screens makes me trust the vehicle less and less even though the visual in general improves trust	0	0	Y	1	1	Y		0	Y
4	My safety and trust were reduced bc the vehicle went wide during the turn while approaching pedestrians. The visual on the screen showed going outside the lines which was appropriate but decreased my trust in the vehicle.		0	Y	1	1	Y		0	Y
4	Car starts too sudden. Taking curves or switching lanes is too rough. I feel the car should've stopped farther away from the pedestrian. Too rough when making turns. Accelerating and braking is in intervals; needs to be more consistent. It felt like the car hesitated when it needed to stop.		0	Y	1	1	Y	1	1	Y
4	The car makes very wide turns sometimes getting on the other lane or outside the paved road (so it seemed). When we initially stopped the time to check for oncoming traffic, it was appropriate. It yielded to pedestrians. The only thing I don't trust is the turns, the steering wheel does not make a smooth circle	1	1	Y	1	1	Y		0	Y
4	The car did allow time for the passenger to get in and input information. I felt it waited too long to detect a pedestrian; it even stopped on the white lines. Still making very wide turns	1	1	Y		0	Y		0	Y
4	It's disconcerting that the vehicle doesn't follow lanes or audibly indicate	1	1	Y		0	Y		0	Y
4	Car drove often outside the lines and over the median	1	1	Y		0	Y		0	Y
4	Lane control, rode in the middle of 2 lanes instead of picking one to stay in	1	1	Y		0	Y		0	Y
4	The same feeling about the lane selection and the signal light for where the vehicle was traveling. Also the turns are a little rough	0	1	N	1	1	Y	1	0	N
4	The not staying in one lane and not using signal lights keeps me from knowing what the next move is and makes me feel less comfortable	0	1	N	0	0	Y	0	0	Y

HMI- Secondary, Additional Information Wanted

HMI	HMI_Feedback	Turn Signals	Turn Signals	Match?	Navigation/Maps	Navigation/Maps	Match?	Hazard Detection	Hazard Detection	Match?
2	No route or stop indications. Made ride more uncertain		0	Y	1	1	Y		0	Y
2	Vehicle failed to show animal on HMI that had wandered onto the track, seemingly did not detect animal at all		0	Y		0	Y	1	0	N
2	Use blinkers	1	1	Y		0	Y			Y
2	I was nervous every time new items like cones were present. I wasn't sure if the car was going to know but it always did		0	Y		0	Y	1	1	Y
2	Not sure why the vehicle turned when the people started walking		0	Y		0	Y			Y
3	Thought a human should be prompted beofre proceeding in the wrong lane to go around an obstacle. Would not make me feel safe		0	Y		0	Y	1	1	Y
3	Audible signals for starting and ending ride added comfort/trust in vehicle. Still wish I could hear turn signals if used	1	1	Y		0	Y			Y
3	Still unclear route at times. I cannot determine which turns/which way we will turn		0	Y	1	1	Y			Y
3	Still cannot detect route/turns		0	Y	1	1	Y			Y
4	The HMI needs to alert at a sooner rate. Sometimes it is right after the car has started slowing down. I feel it should be more of an alert.		0	Y		0	Y		0	Y
4	It's disconcerting that the vehicle doesn't follow lanes or audibly indicate	1	0	N		0	Y	0	1	N
4	Signal lights would help	1	1	Y		0	Y			Y
4	The not staying in one lane and not using signal lights keeps me from knowing what the next move is and makes me feel less comfortable	1	1	Y	1	1	Y			Y

Appendix R. Researchers' Scores and Cohen's Kappa Values

No HMI- Wanted More Information

	Researcher 1	Researcher 2	k	Agreement
Desire for turn signals	12	12	1	Perfect
Improved hazard detection	5	5	1	Perfect
Improved navigation/maps	7	8	0.68	Substantial
More entertainment options (e.g., music)	1	1	1	Perfect

No HMI- Undesirable Vehicle Dynamics

	Researcher 1	Researcher 2	k	Agreement
Steering wheel noise	9	9	1	Perfect
Inability to stay within lane lines	5	5	1	Perfect
Incorrect location of vehicle during stops (e.g., "the vehicle stopped mostly in the crosswalk")	2	2	1	Perfect
Rough/inconsistent speeds, braking, turns	4	5	0.84	Near perfect

HMI

Inaccurate HMI

	Researcher 1	Researcher 2	k	Agreement
Incorrect vehicle position	2	4	0.59	Moderate
Incorrect external stimuli position (e.g., presence/location of environmental factors	6	6	0.72	Substantial
Incorrect timing/dynamics of external stimuli	2	3	0.76	Substantial

Undesirable Vehicle Dynamics

	Researcher 1	Researcher 2	k	Agreement
Inability to stay within lane lines	9	11	0.79	Substantial
Rough/inconsistent speeds, braking, turns	6	7	0.88	Near perfect
Incorrect position of vehicle	4	3	0.48	Moderate

Wanted More Information

	Researcher 1	Researcher 2	k	Agreement
Desire for turn signals	5	4	0.83	Near perfect
Improved navigation/maps	4	4	1	Perfect
Improved hazard detection	3	3	0.56	Moderate

Appendix S. Surprise Event Analysis Data

Pre-Strike

Session Info		Pre-Strike Reaction					
PID	HMI	No Reaction	Stop Button	Verbal Comment	Facial Expression	Other	Explain
P01	No HMI	X					
P02	No HMI	X					
P03	No HMI	X					
P04	No HMI				X		Confusion/concern
P05	No HMI				X		Confusion, laughed
P06	Visual-Only	X					
P07	Visual-Only	X					
P08	Visual-Only	X					
P09	Visual-Only			X	X		Shocked/confused expression, screamed "oh my god"
P10	Visual-Only	X					
P11	Visual-Only	X					
P12	Audio-Only				X		Interested, laughed
P13	Audio-Only		X				Pressed stop button
P14	Audio-Only			X			“Great”
P15	Mixed-Modal				X	X	Confusion, kept glancing to visual HMI to see if obstacle was there
P16	Mixed-Modal					X	Glancing back and forth from HMI to (presumably) windshield
P17	Mixed-Modal	X					Not paying attn. to road. Looking out window

Post-Strike

Session Info		**Post-Strike Reaction**					
PID	HMI	No Reaction	Stop Button	Verbal Comment	Facial Expression	Other	Explain
P01	No HMI				X		Confusion, smile/laughed
P02	No HMI			X	X		Confusion, smile/laughed, “whew”
P03	No HMI				X		Confusion, smile/laughed
P04	No HMI				X		Discomfort, smile/laugh
P05	No HMI				X		Confusion, smile/laughed
P06	Visual-Only				X		Discomfort
P07	Visual-Only			X			"Oh yeah, okay"
P08	Visual-Only				X		
P09	Visual-Only				X		Smile/laugh
P10	Visual-Only				X	X	Shocked, confusion, put hands up in the air
P11	Visual-Only			X	X		Confusion, “okay?”
P12	Audio-Only					X	Confusion
P13	Audio-Only			X			"I hit the button to try and save him"
P14	Audio-Only			X	X		Confusion, smile/laugh, “good job”
P15	Mixed-Modal				X		Confusion
P16	Mixed-Modal				X		Confusion
P17	Mixed-Modal				X		Smile/laugh

Appendix T. IRB Approval Letters

VIRGINIA TECH.

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

MEMORANDUM

DATE: March 6, 2019

TO: Michael Lucas Neurauter, Zachary Richard Doerzaph

FROM: Virginia Tech Institutional Review Board (FWA00000572, expires January 29, 2021)

PROTOCOL TITLE: Assessing Alternate Approaches for Conveying Automated Vehicle 'Intentions' (AV Viz)

IRB NUMBER: 18-1145

Effective January 14, 2019, the Virginia Tech Institution Review Board (IRB), at a convened meeting, approved the New Application request for the above-mentioned research protocol.

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

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

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

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

(Please review responsibilities before beginning your research.)

PROTOCOL INFORMATION:

Approved As: **Full Review**
Protocol Approval Date: **February 28, 2019**
Protocol Expiration Date: **January 13, 2020**
Continuing Review Due Date*: **December 30, 2019**

*Date a Continuing Review application is due to the IRB office if human subject activities covered under this protocol, including data analysis, are to continue beyond the Protocol Expiration Date.

ASSOCIATED FUNDING:

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

Invent the Future

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY
An equal opportunity, affirmative action institution

Date*	OSP Number	Sponsor	Grant Comparison Conducted?
03/06/2019	PJAOSCOI	US Department of Transportation (Title: National Safety UTC)	Compared on 03/06/2019

* Date this proposal number was compared, assessed as not requiring comparison, or comparison information was revised.

If this protocol is to cover any other grant proposals, please contact the HRPP office (irb@vt.edu) immediately.

VIRGINIA TECH.

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

MEMORANDUM

DATE: April 23, 2019

TO: Michael Lucas Neurauter, Zachary Richard Doerzaph

FROM: Virginia Tech Institutional Review Board (FWA00000572, expires January 29, 2021)

PROTOCOL TITLE: Assessing Alternate Approaches for Conveying Automated Vehicle 'Intentions' (AV Viz)

IRB NUMBER: **18-1145**

Effective April 23, 2019, the Virginia Tech Institution Review Board (IRB) approved the Amendment request for the above-mentioned research protocol.

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

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

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

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

(Please review responsibilities before beginning your research.)

PROTOCOL INFORMATION:

Approved As: **Full Review**
Protocol Approval Date: **February 28, 2019**
Protocol Expiration Date: **January 13, 2020**
Continuing Review Due Date*: **December 30, 2019**

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ASSOCIATED FUNDING:

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

Invent the Future

SPECIAL INSTRUCTIONS:

This amendment, submitted April 17, 2019, changes the research protocol to reflect the new baseline vs. non-baseline questionnaires and the elimination of the post-test questionnaire. Data collection instruments were also changed by breaking down surveys into two separate types, adding questions to both along with rewording, and eliminating the post-test survey.

Date*	OSP Number	Sponsor	Grant Comparison Conducted?
03/06/2019	PJAOSCOI	US Department of Transportation (Title: National Safety UTC)	Compared on 03/06/2019

* Date this proposal number was compared, assessed as not requiring comparison, or comparison information was revised.

If this protocol is to cover any other grant proposals, please contact the HRPP office (irb@vt.edu) immediately.