Assessing Alternate Approaches for Conveying Automated Vehicle 'Intentions'

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16. Abstract

One of the biggest highly automated vehicle (HAV) market barriers may be a lack of user trust in the automated driving system itself. Research has shown that this lack of faith in the system primarily stems from a lack of system transparency while the vehicle is in motion—users are not informed how the car will react in an upcoming scenario—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 on and control over the vehicle. To improve user trust and perceptions of comfort and safety, this study evaluated human-machine interface (HMI) systems, focused on visual and auditory displays, to better relay the perceived driving environment and the automated vehicle "intentions" to the user. These HMI systems were then implemented into a HAV developed at the Virginia Tech Transportation Institute and tested with volunteer participants on the Smart Roads.

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Abstract

One of the biggest highly automated vehicle (HAV) market barriers may be a lack of user trust in the automated driving system itself. Research has shown that this lack of faith in the system primarily stems from a lack of system transparency while the vehicle is in motion—users are not informed how the car will react in an upcoming scenario—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 on and control over the vehicle. To improve user trust and perceptions of comfort and safety, this study evaluated human-machine interface (HMI) systems, focused on visual and auditory displays, to better relay the perceived driving environment and the automated vehicle "intentions" to the user. These HMI systems were then implemented into a HAV developed at the Virginia Tech Transportation Institute and tested with volunteer participants on the Smart Roads.

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Introduction and Background

According to the Centers for Disease Control, 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 shows that, in 2017, there were over 37,000 roadway fatalities, with a majority resulting from human error (NHTSA, 2018). 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), and 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. The first wave of these passenger HAVs are 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).

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. They also have the capacity to benefit 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).

While HAVs and SAVs 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). Low HAV user acceptance primarily stems from the lack of user trust and various safety concerns that arise while interacting with the system. User-centric systems that aim to increase vehicle-to-user communication, thereby increasing user trust and comfort, could be a key component to maximizing HAV benefits and limiting their drawbacks.

HAV human-machine-interfaces (HMIs) were designed to communicate system-states and critical information to a user through a variety of modalities. These types of interfaces constantly provide feedback to the user about the system, allowing them to remain "in-the-loop" with the aim of encouraging 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, HMIs are transitioning 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 to keep them more "in-the-loop" in terms of how the vehicle is perceiving and reacting to external stimuli. It is reasonable to argue that keeping drivers in-the-loop is only important for lower levels of automated vehicles (AVs) since, in theory, HAV users should not have to make critical decisions and thus do not need to know the details of the vehicle's intentions, a term used in this study to refer to the vehicle's perception of the roadway and subsequent actions performed by the automated systems.

Development and testing of improved HMIs are important, specifically in scenarios unique to rideshare and public transit vehicles, where a rider may have limited access to the primary vehicle control systems beyond setting a destination and may only be able to provide minimal input while in motion (e.g., emergency stop button). 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 study developed and examined a variety of HMI strategies focused on visual and auditory communication. Volunteer participants who were naive to HAVs experienced the HMI systems across realistic driving scenarios, during which researchers gauged their 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 three 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 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 the HMI that gave 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.

Method

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., pedestrian) presence. Both sections of the road can be seen in Figure 1.

Figure 1. 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 2, which was converted into an HAV by the Center for Technology Development team at VTTI. This vehicle leveraged VTTI's Automated Vehicle Research Platform, a system designed to permit rapid prototyping and testing of AV perception, control, and interface strategies.

Figure 2. Cadillac SRX test vehicle.

The vehicle was configured with a focus on this project's research questions. Thus, for simplicity, it was programed to drive predetermined paths, without the aid of a driver, by following differential GPS (DGPS) waypoints, and coming 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 (i.e., allowing the vehicle to turn), depressed the linear actuators in the brakes (i.e., allowing the vehicle to decelerate and come to a stop), and adjusted an electronic throttle (i.e., allowing for acceleration and speed adjustments). Although this vehicle represented a higher level of automation than was available 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 SAE level 4 or level 5 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 level 4 or level 5 features (Steinfeld, Jenkins, & Scassellati, 2009; Green & Wei-Haas, 1985; Salber & Coutaz, 1993). Indeed, this ruse resulted in participants' belief that they were riding in a HAV with no driver in the front seat that was equipped with fully functioning perception, decision, and response systems.

During experimentation, to further simulate a rideshare scenario and the associated lack of rider access to vehicle controls, the two volunteer participants sat in the rear seats of the vehicle (e.g., behind the driver's and front passenger's seats), with the driver's seat empty. A trained experimenter, posing as a third participant, sat in the passenger seat. This passenger seat experimenter underwent the same pre-study check-in as the naive participants, creating a ruse that a third participant was part of the study and just happened to be asked to sit up front. In reality, this experimenter closely monitored the vehicle systems and ensured study safety at all times.

Video screens, as seen in Figure 3, were installed onto the back of the front seat headrests to display visual information and produce auditory alerts to represent the different HMI conditions. The in-vehicle computer was fed raw vehicle data, which was 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 3. Video screens installed for HMI conditions.

Since the test vehicle was a research tool and had not undergone a functional safety validation, additional safety mechanisms were included. Two manual stop buttons were installed into the vehicle, as seen in

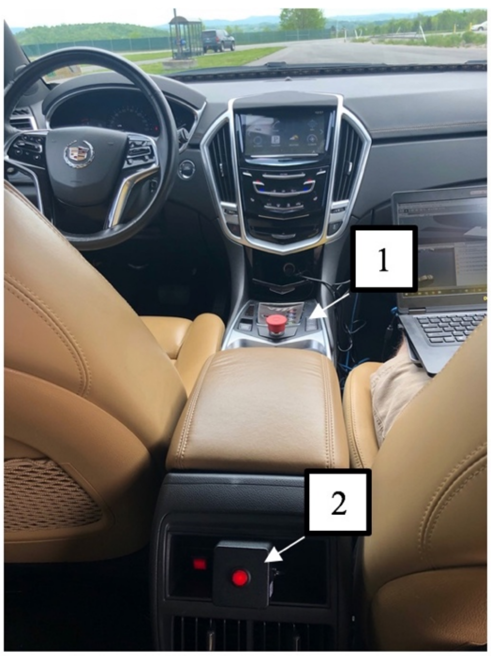

Figure 4—(1) one in front of the center console and (2) one on the back of the armrest console. The front stop button, accessible by the passenger seat experimenter, was designed to immediately and completely shut down all vehicle automation but apply no braking. If the front button was pressed, the passenger seat experimenter 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 while steering as needed by reaching across the passenger cabin. Accessible by the naive participants, 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 second stop button, which will be discussed in further detail later, was to provide the study participants a mechanism for stopping the vehicle if they perceived the need for an emergency stop—a factor which was investigated during this experiment.

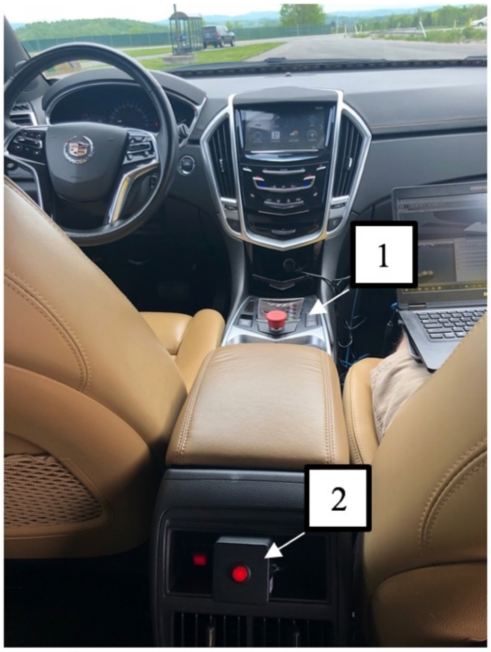

Figure 4. Stop button locations in the test vehicle.

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, encouraged the occupants to believe that the vehicle was operating completely autonomously; in reality, a majority of the information presented was preprogrammed by researchers. The information presented via the HMI systems was preprogrammed to appear either (1) at a set point in time by using test session length, (2) at a location along the driving path by using DGPS coordinates of the vehicle, or (3) at a certain vehicle speed by leveraging vehicle data collected by the data acquisition system. Each participant only experienced one of the following HMI conditions (e.g., between-subject conditions) 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 feeling of safety in the HAV. Due to trends emerging within the early phase of the data collection, two conditions were ultimately run: “with knowledge” and “without knowledge.”

For the original “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 (it was explained that this was due to the prototype nature of the steering system). Researchers also emphasized the fact that the testing environment was a controlled-access research test track. For the “without knowledge” condition, researchers updated the protocol to omit this information.

With careful analysis during the early portion of data collection, researchers realized that providing participants with information, which emphasized their safety within the experiment and explained some atypical vehicle behavior, was artificially elevating subjective measures. Researchers concluded that these elevated metrics for the no HMI condition could cause a lack of result sensitivity when other HMI conditions were later introduced to participants.

Participants who experienced the “without knowledge, no HMI” condition reported more neutral measures, therefore providing researchers with a more effective foundation on which to base other HMI comparisons. Thus, the “without knowledge, no HMI” condition was considered the “true” control of the experiment and was used in most analyses. The research team also felt that removing the experiment/implementation-specific information was more representative of a rider’s experience for a future commercial system and would produce more generalizable results. The more minimal on-boarding process used for the “without knowledge” condition was duplicated for the rest of the HMI conditions; however, the “with knowledge” condition was retained for some specific analyses, as described later.

Visual-Only

The visual HMI displayed driving-relevant information on the headrest-mounted screens, including such information as the predicted driving path (Figure 5), 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.

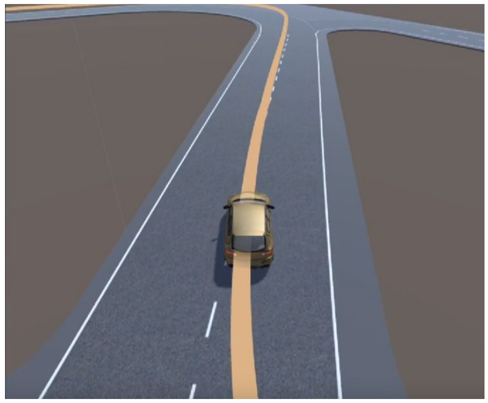

Figure 5. Vehicle path shown on the visual HMI.

Additionally, the visual HMI condition relied heavily on the creation of 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, such as the traffic cones that created a lane shift during the "work zone" scenario, were preprogrammed into specific scenarios. These types of roadway obstacles and fixtures were typically not available in other mapping programs (e.g., Google Maps) or in other HMI systems available on the market when this research was performed (e.g., Tesla Autopilot screen).

Audio-Only

The auditory HMI condition used a series of tones, developed in-house by VTTI researchers, that played through the speakers of the headrest-mounted screens to indicate 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, as seen in Figure 6, which indicated where key events (e.g., pedestrian crossing) would occur. When the vehicle entered or exited these "fences," a specific tone was cued to play.

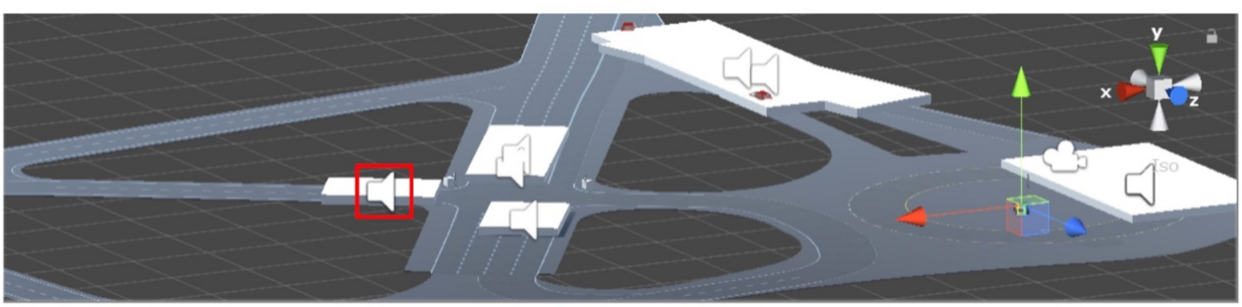

Figure 6. Unity geofenced areas which designated when an auditory cue would be played, as indicated by the "speaker" symbol (boxed in red).

Few sources have reported 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 7. Driving information was conveyed by images displayed on the screen and tones played through the screen's speakers.

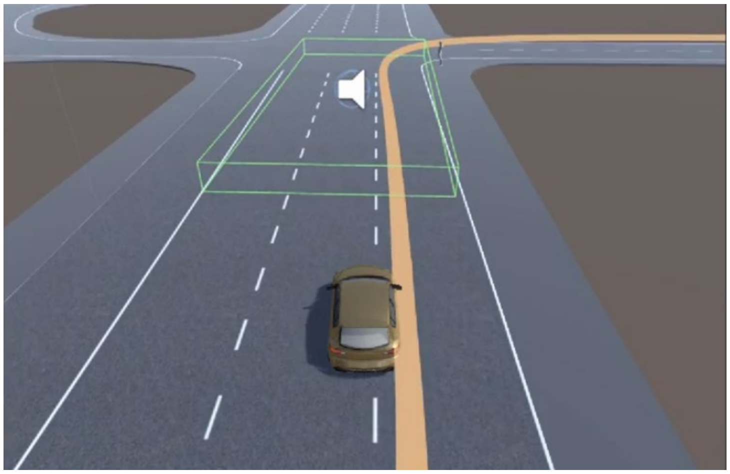

Figure 7. Geofence to indicate audio and visual cues of pedestrian crossing. Participants could not see the geofenced areas on their HMI version.

Study Participants

For this study, there were 37 participants ranging in age from 25–38, as seen in Table 1. Practical limitations precluded the inclusion of a full range of potential occupant ages. Thus, the age range selected for this study represents the population most likely to use rideshare vehicles (Krueger, Rashidi, & Rose, 2016; Shahee, Chan, & Gaynor, 2016; Smith, 2016). It is important that future research considers the unique needs of a broader occupant age range. Participants were recruited from the general public and had limited knowledge of AVs and no prior experience with HAVs.

Table 1. Planned 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

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. 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 participants' experiences. Scenario descriptions and diagrams can be found in Appendix A: Scenario Diagrams and Descriptions.

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 is shown in Table 2 (Allen, 2017). Researchers developed two random scenario orders and then reversed them, creating two additional orders. Each HMI condition used these same four scenario orders. These can be seen in the full experimental matrix in

Appendix B: Experimental Matrix.

Table 2. Example Scenario Matrix for "No HMI" Condition

Participant #	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6
P08	Baseline	Ped Xing	Following Lead Vehicle	Passenger Pick Up	Left Turns	Surprise
P09	Baseline	Ped Xing	Following Lead Vehicle	Passenger Pick Up	Left Turns	Surprise
P10	Baseline	Left Turns	Passenger Pick Up	Following Lead Vehicle	Ped Xing	Surprise
P11	Baseline	Left Turns	Passenger Pick Up	Following Lead Vehicle	Ped Xing	Surprise
P12	Baseline	Passenger Pick Up	Ped Xing	Left Turns	Following Lead Vehicle	Surprise
P13	Baseline	Passenger Pick Up	Ped Xing	Left Turns	Following Lead Vehicle	Surprise
P14	Baseline	Following Lead Vehicle	Left Turns	Ped Xing	Passenger Pick Up	Surprise
P15	Baseline	Following Lead Vehicle	Left Turns	Ped Xing	Passenger Pick Up	Surprise

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

Sessions always began with the "no HMI" 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. During the surprise event, the vehicle failed to communicate the presence of an obstacle in the driving path to the user and ultimately ran over the obstacle. The goal of this 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 a corrective action, such as pressing the stop button.

Heavy Vehicle Remote Evasive Maneuvering Object (HV-REMO)

To simulate pedestrian crossings, an inflatable human-shaped target was used (see Figure 8). This "pedestrian" was maneuvered using a remotely operated base, called the Heavy Vehicle Remote Evasive Maneuvering Object (HV-REMO), controlled by an on-road experimenter. Soft targets are attached to the remotely operated base with Velcro, and the mechanism can be run-over or impacted with a vehicle with minimal to no damage 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 8. HV-REMO base on the Smart Roads (left). Soft target attachment used for this project (right).

Experimental Procedure

During experimental sessions, 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 test sessions are detailed.

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 so that participants felt 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, which in some scenarios acted as an additional 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 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, creating the ruse that they were simply another participant in the study.

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 the steering wheel from the passenger seat). Before experimentation began, safety drivers were trained by researchers on potential failures that could occur and how to react in emergency situations. In addition, safety drivers were seasoned VTTI researchers with additional institutional safety training. Because of the safety drivers' extensive safety training and prior vehicle-research experiences, identifying test vehicle malfunctions and conducting the appropriate steps for intervention was at their discretion. In the three instances when intervention was necessary, after stopping the vehicle, the safety driver did the following: (1) if the intervention was mild and not perceivable by participants, they continued to act as a participant and called the moderator on the two-way radio or (2) if the intervention was perceivable, they revealed themselves as a VTTI researcher to the participants by reading a prewritten ruse debrief script, 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. 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 was conducted. Those who were interested and eligible were scheduled to come to VTTI to participate in a testing session lasting approximately 1.5 hours.

Upon the arrival of all scheduled participants (two at a time), and with the safety driver posing as a participant, the group was directed by the moderator to a subject prep room. These rooms are IRB-approved rooms located at VTTI used by researchers for filling out onboarding participant paperwork and performing pre-session evaluations. First, W-9 tax forms, 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 C: Informed Consent Form) and to complete hearing and vision assessments. Finally, participants were asked to complete a brief pre-test questionnaire (Appendix D: Pre-Test Questionnaire), which included scaled-down sensation-seeking and locus of control questionnaires, 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 HAVs 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 the 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 participants.

Participants were then led to a Chevy Tahoe vehicle for transportation to the Surface Street section of the Smart Roads where the Cadillac SRX research vehicle was parked 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 in order to mitigate risk of biasing any 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 (Appendix A: Baseline) with no HMI systems engaged to allow participants to become more comfortable with the vehicle and vehicle maneuvers.

Following every trial scenario, including the baseline route, the moderator approached the vehicle and administered a paper-based, post-trial questionnaire (Appendix E: Post-Trial Questionnaire) individually to each participant for them to evaluate the HMI system, or lack thereof, their perceived level of comfort, safety, trust, and situational awareness, and 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 entered 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 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).

Data Analysis Methods

Qualitative, subjective data was collected during test sessions to determine relationships between independent and dependent variables (Appendix F: Independent and Dependent Variables). A majority of data was collected through the surveys distributed pre-test and post-trial.

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 type scale with anchor words, as seen in Figure 9.

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

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

Figure 9. Sample Likert-scale question posed to participants during the post-trial questionnaire.

Scores of 1 indicated "strong disagreement;" scores from 2–3 represented "disagreement;" a score of 4 was "neutral;" scores from 5–6 were "agreement;" and scores of 7 were "strong agreement." 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 analyses, in the form of analysis of variance and post-hoc Tukey honest significant difference calculations, were performed to determine whether specific variables had significant effects on participants' responses.

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. A deductive qualitative analysis paired with inter-rater reliability was employed to determine these patterns.

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 that experienced by participants during the other session scenarios and trial, and survey data was therefore removed from analysis, unless stated, so as to not skew the results. A separate analysis, included below, was conducted considering the surprise event data.

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, as shown in Figure 10.

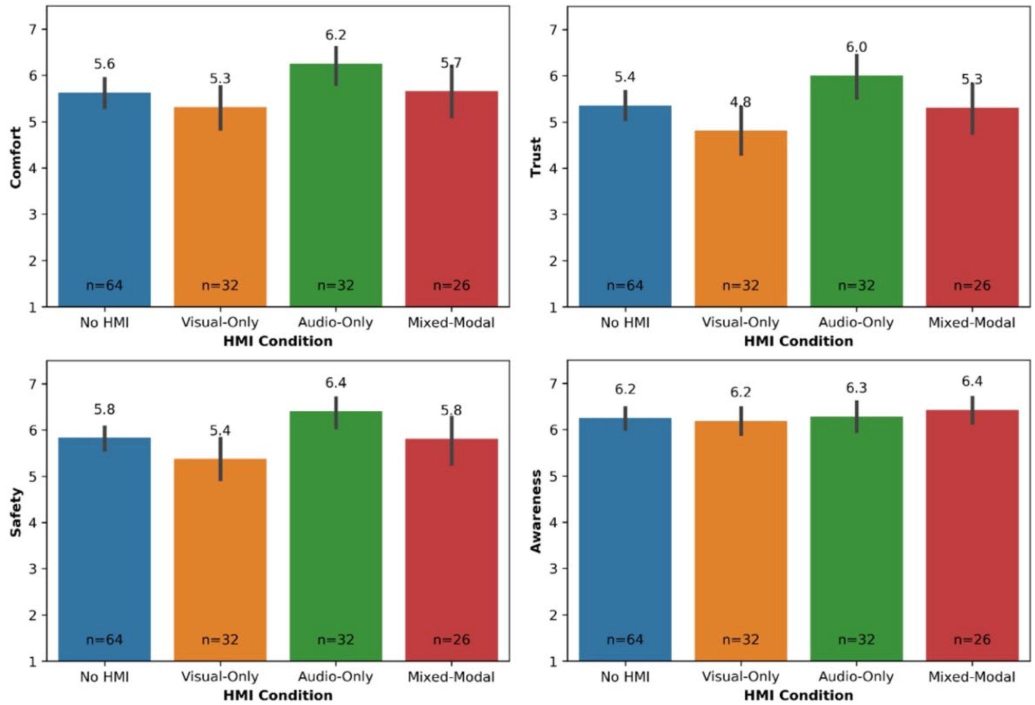

Figure 10. HMI condition compared to self-reported levels of comfort (top-left), trust (top-right), safety (bottom-left), and situational awareness (bottom-right).

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, even when compared to the no HMI condition. Prior to this result, researchers 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 intent information.

Perceived situational awareness was not significantly affected by any HMI condition; however, this finding should be interpreted with caution. Prior to the session, situational awareness was not operationally defined for participants and no strategies for objectively quantifying it were implemented into the experimental design. Therefore, participants may have had different perspectives of what situational awareness represented when questioned during post-experiment surveys.

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. 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 rather than 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 any misalignment on the roadway. In addition, participants may have preferred the audio cues compared to the visual information because they are simple enough to quickly comprehend and do not require any looking away from the roadway to be fully understood.

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) thereby 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 to travel, when it would start/stop) and its perceptions of the roadway (i.e., hazard detection), as seen in Figure 11. 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.

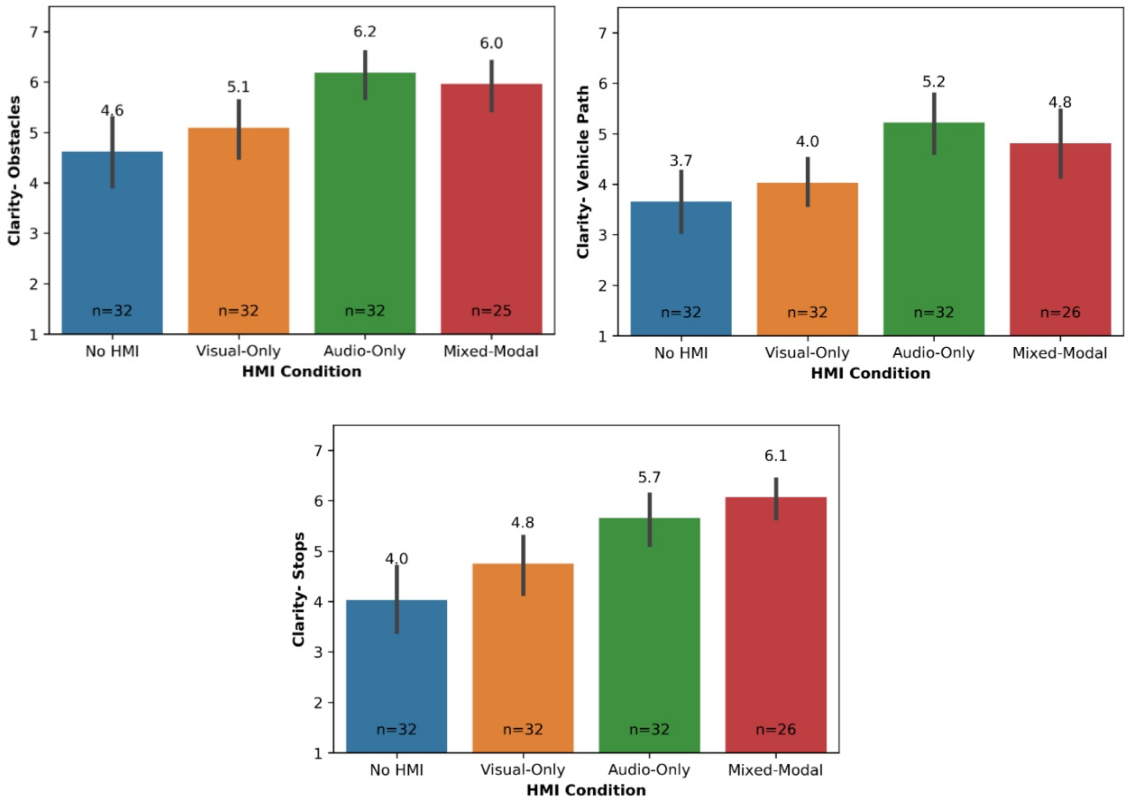

Figure 11. HMI condition compared to how clear it was at communicating the presence of obstacles in the roadway (top-left), the planned vehicle path (top-right), and intention to stop (bottom).

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 communicating the vehicle's intentions to stop and visual stimuli communicating 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 audio-only 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.

Factors Influencing Users' HAV Acceptance

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 19-question survey distributed as part of the pre-session questionnaire. Participants with scores from 1–7 were rated as having "low" sensation-seeking tendencies (i.e., do not take as many risks), those with scores from 8–11 were rated as having "mid" tendencies (i.e., exhibit neutral sensation-seeking tendencies), and participants with scores from 1—19 were rated as having "high" tendencies (i.e., more likely to demonstrate riskier behaviors). Sensation-seeking levels compared to reported metrics can be seen in Figure 12.

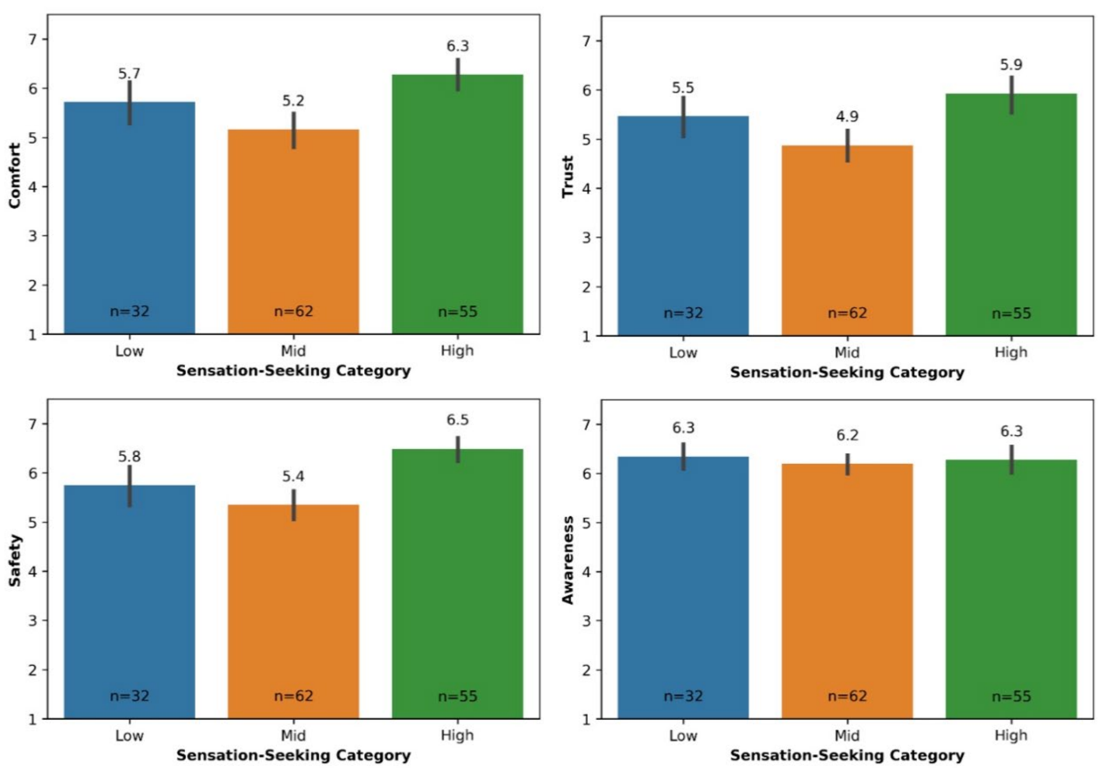

Figure 12. Sensation-seeking category compared to participants' reported levels of comfort (top-left), trust (top-right), safety (bottom-left), and situational awareness (bottom-right).

Those ranked higher on the sensation seeking scale 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 exhibited only 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.

This study was the first time a majority of the participants had been a part of vehicle research on the Smart Road. Taking that, and the fact that the vehicle was framed as a prototype, into account, 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.

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 13.

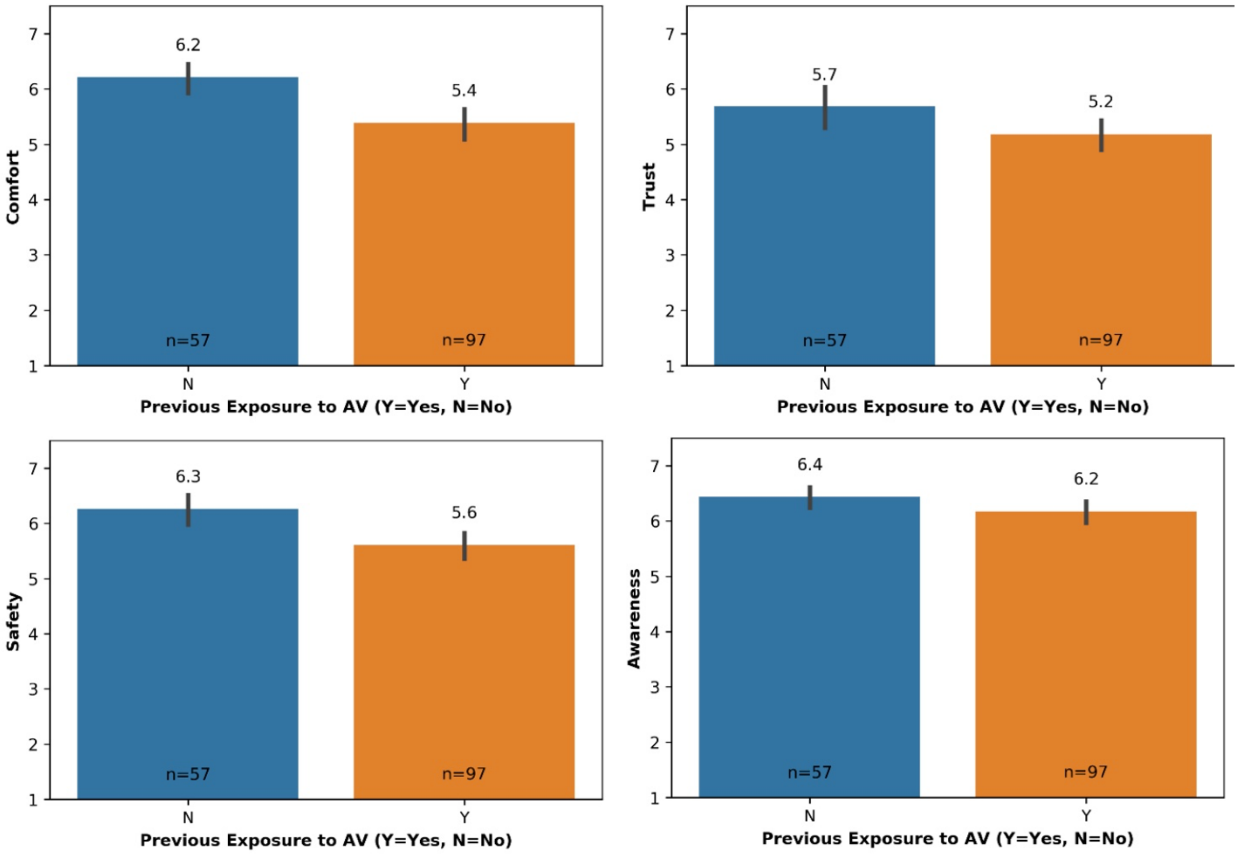

Figure 13. Previous exposure to AVs or AV technology compared to comfort (top-left), trust (top-right), safety (bottom-left), and situational awareness (bottom-right).

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 individuals with previous experience or exposure to a technology should have higher levels of comfort and trust than individuals for whom the technology is unfamiliar. According to the Technology Acceptance Model and the Unified Theory of Acceptance and Use of Technology, 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 AVs 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).

Surprise Event

To gain a better understanding of participant behavior during the surprise event and determine if there were any unintended bystander effects (where the presence of others discourages an individual from intervening in an emergency situation) 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 for 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 3.

Table 3. 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 one 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 inflatable "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, showing a lack 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 participants who 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 stop 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 the 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 that 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 that the vehicle had 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 participants' situational awareness, 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 4 below.

Table 4. 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

The post-strike data shows 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 that the vehicle did not react to the obstacle in an appropriate manner.

Conclusions and Recommendations

This report 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 (i.e., HAV). 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 AVs, and initial comfort level, affected reported feelings of comfort, trust, safety, and situational awareness.

The results of this study indicate that HAV users greatly benefit 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, which 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 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 should still be present even in situations where they are difficult to observe from non-driving positions. 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 only HMI systems, but also future HAVs.

Although results show that information presented via audio alerts resulted in 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 were present during this study and numerous pathways of future work have been identified, but this study represents the first of its kind in examining HAV HMI systems in a high-fidelity environment. No other public studies have been conducted which place volunteer participants in a physical test vehicle, capable of driving multiple routes with varying speeds, without an occupant in the driver's seat. Results obtained through this real-world representative testing are generalizable 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.

Additional Products

The Education and Workforce Development (EWD) and Technology Transfer (T2) products created as part of this project are described below and are listed on the Safe-D website here. The final project dataset is located on the Safe-D Dataverse.

Education and Workforce Development Products

From this project, students further developed professional writing and presentation skills. Over five different poster and podium presentations on this study were given to a range of audiences and in a variety of different environments. In addition, this project was developed into a master's Thesis, a critical component of a student team member's gradation.

Technology Transfer Products

As mentioned previously, numerous presentations, both podium talks and posters, about this project have been delivered. These presentations have been given to a variety of different audiences, such as students, academics in the transportation field, and government officials. In addition, a Thesis was formulated based on this project and will be published on the Virginia Tech Electronic Thesis and Dissertation (ETD) portal. The team members are currently writing an academic journal article with plans to have it published in a transportation research journal. In addition, a one-page summary of the project and its conclusions is being written. This one-page document will be easily distributable to industrial professionals and academics.

Data Products

The data uploaded to the Dataverse includes participant responses to surveys distributed during each testing session. Different surveys were distributed before the testing session began ("pre-session questionnaire"), after each trial ("post-trial questionnaire"), and after the surprise event ("post-surprise questionnaire"). Data from this project is available from the VTTI Safe-D Dataverse listed under project #VTTI-03-082. The dataset can be accessed at: https://doi.org/10.15787/VTT1/Z5DZAJ.

References

Abe, G., Itor, M., & Tanaka, K. (2002). Dynamics of Drivers' Trust in Warning Systems. *IFAC Proceedings Volumes, 35*(1), 363-368.

Abraham, H., Seppelt, B., Mehler, B., & Reimer, B. (2017). What's in a Name: Vehicle Technology Branding & Consumer Expectations for Automation. *AutomotiveUI '17: Proceedings of the 9th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*, (pp. 226-234). Oldenburg, Germany.

Agatz, N., Erera, A., Savelsbergh, M., & Wang, X. (2011). Dynamic ride-sharing: A simulation study in metro Atlanta. *Transportation Research Part B, 45*, 1450-1464.

Allen, M. (2017). Counterbalancing. In *The SAGE Encyclopedia of Communication Research Methods.*

Bansal, P., Kockkelman, K., & Singh, A. (2016). Assessing public opinions of and interest in new vehicle technologies: An Austin perspective. *Transportation Research Part C, 67*, 1-14.

Blanco, M., Atwood, J., Vasquez, H., Trimble, T., Fitchett, V., Radlbeck, J., . . . Russell, S. (2016). Automated Vehicles: Take-Over Request and System Prompt Evaluation. In *Road Vehicle Automation 3* (pp. 111-119).

Brush, B., & Niles, J. (2016). *Ontario Must Prepare for Vehicle Automation.* Vaughn, Ontario: Residential and Civil Construction Alliance of Ontario.

Chao, E. L. (2018, July 10). Autonomous Vehicle Symposium.

Cunningham, M., & Regan, M. (2015). Autonomous Vehicles: Human Factors Issues and Future Research. *Proceedings of the 2015 Australasian Road Safety Conference.* Gold Coast, Australia.

Davis, F. (1989). Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology. *MIS Quarterly, 13*(3), 319-340.

Dzindolet, M., Peterson, S., Pomranky, R., Pierce, L., & Beck, H. (2003). The role of trust in automation reliance. *International Journal of Human-Computer Studies*, 697-718.

Fagnant, D., Kockelman, K., & Bansal, P. (2015). Operations of a shared autonomous vehicle fleet for the Austin, Texas, market. *Transportation Research Board*, 98-106.

Green, P., & Wei-Haas, L. (1985). The Rapid Development of User Interfaces: Experience with the Wizard of Oz Technique. *Proceedings of the Human Factors Society 29th Annual Meeting*, (pp. 470-474).

Jain, A., Ransal, R., Kumar, A., & Singh, K. (2015). A comparative sutdy of visual and auditory reaction times on the basis of gender and physical activity levels of first year students. *International Journal of Applied Basic Medical Research*, 124-127.

Johnson, J., Sanchez, J., Fisk, A., & Rogers, W. (2004). Type of Automation Failure: The Effects on Trust and Reliance in Automation. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 48*(18), 2163-2167.

Krisher, T. (2018). *Uber approved to resume autonomous car tests in Pittsburgh.* Associated Press. From https://www.apnews.com/88b38deec8b946db98aa1fab29e00bbc

Krueger, R., Rashidi, T., & Rose, J. (2016). Preferences for shared autonomous vehicles. *Transportation Research Part C, 69*, 343-355.

Kyriakidis, M., Happee, R., & De Winter, J. (2015). Public Opinion on Automated Driving: Results of an International Questionnaire Among 5000 Respondents. *Transportation Research Part F, 32*, 127-140.

Leahy, W., & Sweller, J. (2011). Cognitive load theory, modality of presentation and the transient information effect. *Aplied Cognitive Psychology, 25*(6), 943-951.

Litman, T. (2015). Autonomous Vehicle Implementation Predictions: Implications for Transport Planning. *Transportation Research Board 94th Annual Meeting.* Washington, D.C. From https://trid.trb.org/view/1338043

Madhavan, P., Wiegmann, D., & Lacson, F. (2006). Automation Failures on Tasks Easily Performed by Operators Undermine Trust in Automated Aids. *Human Facotrs, 48*(2), 241-256.

Merat, N., Madigan, R., & Nordoff, S. (2017). Human Factors, User Requirements, and User Acceptance of Ride-Sharing in Automated Vehicles. *International Transport Forum*.

Mousavi, S., Low, R., & Sweller, J. (1995). Reducing Cognitive Load by Mixing Auditory and Visual Presentation Modes. *Journal of Educational Psychology*, 319-334.

Munsey, C. (2006). Frisky, but more risky: High sensation-seekers' quest for new experiences leads some to the high-stress jobs society needs done but makes others vulnerable to reckless behavior. *American Psychological Association*, 40.

NHTSA. (2018). *2017 Fatal Motor Vehicle Crashes: Overview.* USDOT. From https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812603

Noble, A., Dingus, T., & Doerzaph, Z. (2016). Influence of In-Vehicle Adaptive Stop Display on Driving Behavior and Safety. *IEEE Transactions on Intelligent Transportation Systems, 17*(10), 2767-2776.

Nordhoff, S., Van Arem, B., & Happee, R. (2016). A Conceptual Model to Explain, Predict, and Improve User Acceptance of Driverless Vehicles. *Transportation Research Board 95th Annual Meeting.* Washington, D.C.

Norman, D. (1990). *The "Problem" of Automation: Inappropriate Feedback and Interaction, Not "Overautomation".* La Jolla, California: Institute for Cognitive Science.

Owens, J., Antin, J., Doerzaph, Z., & Willis, S. (2015). Cross-generational acceptance of and interest in advanced vehicle technologies: A nationwide survey. *Transportation Research Part F, 35*, 139-151.

Palmer, K., Dessouky, M., & Abdelmaguid, T. (2004). Impacts of Management Practices and Advanced Technoogies on Demand Reponsive Transit Systems. *Transportation Research Part A: Policy and Practice, 38*(7), 495-509. From . http://www.sciencedirect.com/science/article/pii/S0965856404000369

Parasuraman, R., & Riley, V. (1997). Humans and Automation: Use, Misuse, Disuse, and Abuse. *Human Factors, 39*(2), 230-253.

Pew Research Center. (2017). *Automation in Everyday Life.* From https://www.pewinternet.org/2017/10/04/automation-in-everyday-life/pi_2017-10-04_automation_3-05/

Posner, M., Nissen, M., & Klein, R. (1976). Visual dominance: An information-processing account of its origins and significance. *Psychological Review, 83*(2), 157-171.

Rotter, J. (1966). Generalized Expectancies for Internal Versus External Control of Reinforcement. *Psychological Monographs: General and Applied, 80*(1).

Rudin-Brown, C., & Parker, H. (2004). Behavioural adaptation to adaptive cruise control (ACC): implications for preventive strategies. *Transportation Research Part F, 7*(2), 59-76.

Salber, D., & Coutaz, J. (1993). Applying the Wizard of Oz technique to the study of multimodal systems. *International Conference on Human-Computer Interaction*, (pp. 219-230).

Sauer, J., Chavaillaz, A., & Wastell, D. (2016). Experience of automation failures in training: effects on trust, automation bias, complacency and performance. *Ergonomics, 59*(6), 767-780.

Schram, R., Williams, A., & Ratingen, M. (2013). *Implementation of Autonomous Emergency Braking (AEB), The Next Step in EURO NCAP's Safety Assessment.* NCAP P-NCAP Working Group.

Shahee, S., Chan, N., & Gaynor, T. (2016). Casual carpooling in the San Francisco Bay Area: Understanding user characteristics, behaviors, and motivations. *Transport Policy, 51*, 165-173.

Shelton, J., & Kumar, G. (2010). Comparison between Auditory and Visual Simple Reaction Times. *Neurosceince & Medicine*, 30-32.

Shladover, S., & Bishop, R. (2015). Road Transport Automation as a Public-Private Enterprise. *EU-US Symposium on Automated Vehicles.*

Smith, A. (2016, May 19). *On-demand: Ride-hailing apps*. From Pew Research Center: https://www.pewinternet.org/2016/05/19/on-demand-ride-hailing-apps/

Spence, C. (2009). Explaining the Colavita visual dominance effect. *Progress in Brain Research, 176*, 245-258.

Stanton, N., & Young, M. (2005). Driver behaviour with adaptive cruise control. *Ergonomics*, 1294-1313.

Steinfeld, A., Jenkins, O., & Scassellati, B. (2009). The oz of wizard: simulating the human for interaction research. *Proceedings of the 4th ACM/IEEE International Conference on Human Robot Interaction*, (pp. 101-108). La Jolla, CA.

Sternlund, S., Strandroth, J., Rizzi, M., Lie, A., & Tingvall, C. (2016). The effectiveness of lane departure warning systems- A reduction in real-world passenger car injury crashes. *Traffic Injury Prevention*, 225-229. doi:https://doi.org/10.1080/15389588.2016.1230672

University of Michigan. (2018). *Mcity Driverless Shuttle: A Case Study.*

Venkatesh, V., & Davis, F. (2000). A Theoretical Extension of the Technology Acceptance Model: Four Longitudinal Field Studies. *Management Science, 46*(2), 186-204.

Venkatesh, V., Morris, M., Davis, G., & Davis, F. (2003). User Acceptance of Information Technology: Toward a Unified View. *MIS Quarterly, 27*(3), 425-478.

Volvo Cars. (2018, September 5). *Volvo 360c Safety Story Animation*. From Volvo Cars Global Newsroom: https://www.media.volvocars.com/global/en-gb/search/results?SearchType=0&SearchText=360c&Status=-1&SearchByDate=0&SortBy=0

Xu, J., Murphy, S., Kochanek, K., Bastian, B., & Arias, E. (2018). *Deaths: Final Data for 2016.* National Vital Statistics Reports. From https://www.cdc.gov/nchs/data/nvsr/nvsr67/nvsr67_05.pdf

Zakharenko, R. (2016). Self-driving cars will change cities. *Regional Science and Urban Economics*, 26-37.

Zmud, J., Sener, I., & Wagner, J. (2016). *Consumer Acceptance and Travel Behavior Impacts of Automated Vehicles.* Texas A&M Transportation Institute.

Zuckerman, M., Eysenck, S., & Eysenck, H. (1978). Sensation Seeking in England and America: Cross-cultural, Age, and Sex Comparisons. *Journal of Consulting and Clinical Psychology, 46*(1), 139-149.

Appendix

Appendix A: Scenario Diagrams and Descriptions

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. 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.

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 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.

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, simulating 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. 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.

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. 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.

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.

Appendix B: 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						

<table>
<tr><td rowspan="4"></td><td>P28</td><td>M</td><td>L</td><td rowspan="2">Baseline</td><td rowspan="2">Passenger Pick Up</td><td rowspan="2">Ped X-ing</td><td rowspan="2">Left Turns</td><td rowspan="2">Following Lead Vehicle</td><td rowspan="2">Surprise</td></tr>
<tr><td>P29</td><td>F</td><td>R</td></tr>
<tr><td>P30</td><td>M</td><td>L</td><td rowspan="2">Baseline</td><td rowspan="2">Following Lead Vehicle</td><td rowspan="2">Left Turns</td><td rowspan="2">Ped X-ing</td><td rowspan="2">Passenger Pick Up</td><td rowspan="2">Surprise</td></tr>
<tr><td>P31</td><td>F</td><td>R</td></tr>
<tr><td rowspan="6">Mixed-Modal</td><td>P32</td><td>M</td><td>R</td><td rowspan="2">Baseline</td><td rowspan="2">Ped X-ing</td><td rowspan="2">Following Lead Vehicle</td><td rowspan="2">Passenger Pick Up</td><td rowspan="2">Left Turns</td><td rowspan="2">Surprise</td></tr>
<tr><td>P33</td><td>F</td><td>L</td></tr>
<tr><td>P34</td><td>M</td><td>R</td><td rowspan="2">Baseline</td><td rowspan="2">Left Turns</td><td rowspan="2">Passenger Pick Up</td><td rowspan="2">Following Lead Vehicle</td><td rowspan="2">Ped X-ing</td><td rowspan="2">Surprise</td></tr>
<tr><td>P35</td><td>F</td><td>L</td></tr>
<tr><td>P36</td><td>M</td><td>L</td><td rowspan="2">Baseline</td><td rowspan="2">Passenger Pick Up</td><td rowspan="2">Ped X-ing</td><td rowspan="2">Left Turns</td><td rowspan="2">Following Lead Vehicle</td><td rowspan="2">Surprise</td></tr>
<tr><td>P37</td><td>F</td><td>R</td></tr>
</table>

Appendix C: 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 D: 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 E: Post-Trial Questionnaire

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 F: Independent and Dependent 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

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