The RRADS Platform: A Real Road Autonomous Driving Simulator

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ABSTRACT

This platform paper introduces a methodology for simulating an autonomous vehicle on open public roads. The paper outlines the technology and protocol needed for running these simulations, and describes an instance where the Real Road Autonomous Driving Simulator (RRADS) was used to evaluate 3 prototypes in a between-participant study design. 35 participants were interviewed at length before and after entering the RRADS. Although our study did not use overt deception—the consent form clearly states that a licensed driver is operating the vehicle—the protocol was designed to support suspension of disbelief. Several participants who did not read the consent form clearly strongly believed that they were interacting with a fully autonomous vehicle.

The RRADS platform provides a lens onto the attitudes and concerns that people in real-world autonomous vehicles might have, and also points to ways that a protocol deliberately using misdirection can gain ecologically valid reactions from study participants.

Author Keywords

On-The-Road Simulation; Experimentation; Wizard-of-Oz; Research Protocols

ACM Classification Keywords

H.5.2 [Information interfaces and presentation (e.g., HCI)]: User Interfaces – Prototyping.

INTRODUCTION

In order to design effective interfaces for emerging autonomous vehicle technology we must study human interactions with autonomous vehicles. Currently there are few platforms available to support such research. Virtual lab-based simulations excel at creating highly structured and controlled events for studying possible human-vehicular interactions [1]. However, virtual simulations struggle to replicate inertial forces experienced in real world scenarios. Ecological validity is difficult to attain with digital projections of pedestrians and vehicles. This can affect the outcome of simulation studies. For these reasons, we were interested in developing a low-cost, safe, and reliable methodology for creating a physical, rather than a digital, simulation of an autonomous vehicle.

PRIOR WORK

On-Road Autonomous Driving Studies

Based on our research, this is the first published study detailing a system used to explore driver interaction with an on-road, autonomous car. Previous studies around automotive interfaces do not include interaction with autonomous vehicles. The bulk of autonomous car studies focus on sensor system and algorithm development.

There have been recent reports in the press detailing drives in functioning autonomous vehicles capable of highway driving [2]. A description of visual displays employed by the car was given, including displays of car state (human control vs. autonomous) and handoff information (time to release control, time to retake control). However, no mention is made of experimental interfaces being tested. In addition, we have not found any reports detailing driver interaction and interface systems for autonomous cars driving in urban environments as opposed to straight, cruise control style highway driving.

Wizard of Oz and Driving Studies

The RRADS platform proposes an on road, Wizard of Oz autonomous car simulation environment. In Wizard of Oz studies, participants are told that they are interacting with a computer system through an interface, when in fact a human operator—the wizard, mediates their interactions. The name "Wizard of Oz" comes from the novels of L. Frank Baum. The Wizard is believed by all of the denizens of the Land of Oz to be a magical being where in fact he is an ordinary man employing a variety of tricks to project an illusory reality [3].

The use of "the wizard in the loop" of the experimental set up allows both the participant and the experimenters more freedom of expression, or more systematic constraints, than would be possible with a real computer-operated system [4]. This technique can be used for testing systems, or also as an iterative design methodology.

Sometimes the use of the wizard is done with the participant's a priori knowledge, and sometimes not. The Wizard of Oz technique is modified from "experimenter-in-the-loop" techniques pioneered at John Hopkins, in Human Factor's Professor Alphonse Chapanis' Communications Research Lab [5]. In early natural-language-processing studies, the use of the Wizard of Oz technique allowed developers to simulate an interface and thereby induce participants to generate language samples in the context of an actual task [6]. In the realm of design research, Wizard of Oz-style techniques allowed designers of computer-aided design systems to simulate the tasks and rules of operation for an interactive drawing system using only text and graphical communication over closed-circuit television. “Doing so provides a comparatively cheap simulator, with the remarkable advantages of the human operator’s flexibility, memory and intelligence, and which can be reprogrammed to give a wide range of computer roles merely by changing the rules of operation.” [7]

In the automotive user interface space, the Wizard of Oz technique has been used to evaluate user expectations and develop natural language technology systems. Wizard of Oz methodology was used by designers of VICO (Virtual Intelligent Co-Driver) to evaluate user expectations [8], by developers of speech-based in-car entertainment systems by researchers at TU Munich [9] and other natural-language in-vehicle technology systems [10], by researchers developing gesture-based interfaces for secondary tasks in a car environment [11], to prototype in-car controls and displays [12] and by researchers looking at the intermodal differences in distraction tasks while controlling automotive UIs as shown in [13].

The RRADS platform employs Wizard of Oz control to create the illusion of an autonomous vehicle system that is capable of driving and navigating public roadways. The system can be adapted to provide information to the driver and can incorporate interface prototypes directly into the testing platform. As an example, we used the RRADS platform to evaluate the effectiveness of haptic pre queuing technology at increasing trust in drivers.

Haptic Feedback for Automotive Information Interfaces

Haptic feedback through the use of vibration has been explored as possible driver feedback systems in the context of improving spatial awareness [14, 15] and collision avoidance [16, 17]. These studies were conducted in both simulation and on-road environments, respectively. Our use of on-road, in-traffic testing aims to provide an ecologically valid environment for testing novel haptic feedback systems in autonomous vehicles. Although new feedback mechanisms can be initially tested in simulation environments, on-road testing is required to validate that drivers or passengers can distinguish haptic feedback from vibrations due to road conditions.

For example, vibro-tactile seat arrays have been tested in traffic on both brick and smooth roads with drivers being able to confidently identify various vibration patterns [18]. Hogema et al. employ the use of a rear seat experimenter to supervise an automated system triggering the vibration patterns to test how well drivers could perceive the vibrations.

In previous studies, haptic feedback systems have been focused on drivers actively engaged in the task of driving. The RRADS platform allowed us to extend this testing paradigm by allowing us to focus on drivers who have activated the autonomous mode feature in their vehicle. These drivers are essentially passengers of an autonomous car.

THE RRADS PLATFORM

Overview

We developed The Real Road Autonomous Driving Simulator (RRADS) to explore attitudes and concerns that people may have in real-world autonomous vehicles. We ran the RRADS following a traditional Wizard of Oz methodology [19]. The RRADS involved two Wizards and a single vehicle. The Driving Wizard, drives the vehicle while the Interaction Wizard sits in the rear. Three GoPro cameras recorded road events, the participant’s reactions, and the actions of the Wizards. A partition made of stiff, opaque material obfuscates the participant’s view of the driver.

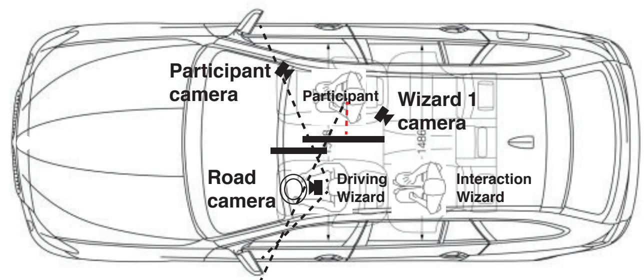

Figure 1 – Driving Wizard, Interaction Wizard, and Participant locations with sightlines and camera placement.

The Wizards

The Driving Wizard

The Driving Wizard must be an experienced and licensed driver. Before running the study, they must thoroughly familiarize themselves with the selected roadways. The driving style of the Driving Wizard must be standardized between participants. The Wizard must be able to accelerate and decelerate at a constant rate, remain at stop signs for a pre-determined amount of time. A running timer prominently displayed on the console of the vehicle may be a helpful way to ensure consistency. To aid in suspending belief about the autonomous capabilities of the car, the presence of the Driving Wizard should be obfuscated.

The Interaction Wizard

The Interaction Wizard’s primary role is to provide a foil to the Driving Wizard. Should the participant require assistance or wish to terminate the study at any time, the Interaction Wizard is there to support the participant. The Interaction Wizard also can activate any prototype interfaces that may be under test and monitor the recording equipment while on the road.

We recommend that Driving and Interaction Wizards work as a team to practice and learn the course together. If a prototype interface must be activated during a critical event, such as decelerating at a traffic light, the Interaction Wizard and the Driving Wizard must work together to seamlessly integrate the deceleration of the vehicle and the activation of the prototype.

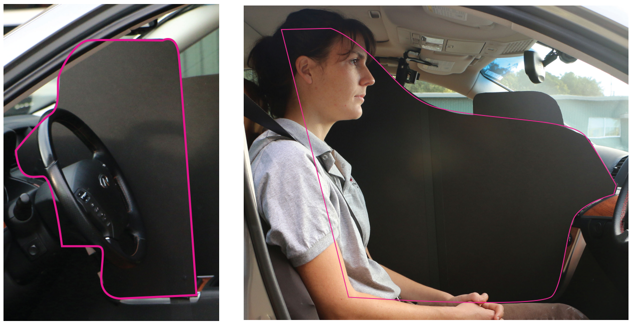

Figure 2 – Driver and participant partitions.

The Vehicle

Vehicle Characteristics

It may be worth considering the nature of your experiment when choosing a vehicle. The RRADS can be run in any vehicle equipped with the necessary sight lines and the ability to install a partition, but the physical attributes of a specific car, such as the characteristics of the engine sound or suspension system may strongly color results. There is no such thing as a "neutral" vehicle, so the biases inherent to a specific vehicle should be taken into account.

As an example, we ran the RRADS in two vehicles: A 2008 Jeep Compass and a 2012 Infiniti M45. We found that although the RRADS was effective and provided ecologically valid results in both vehicles, the participants reported markedly different qualitative experiences in the two control cases. The Infinity's lower suspension system seemed to allow the car to decelerate more smoothly, while the deceleration in the Jeep felt more abrupt. This disparity occurred despite having the same Driving Wizard piloting both vehicles using the same driving style.

Partition Design

The partition must be designed to prevent the participant from seeing the Driving Wizard, while still allowing the Driving Wizard to use all mirrors and to see through the rear passenger windows. It is imperative to not compromise the wizard's driving ability while conducting on-the-road experiments.

We found that the partitions are best deployed in a staggered configuration. This maximizes visibility for the Driving Wizard while still keeping hands and head hidden from view.

The partitions illustrated in Figure 2 are installed in the Infiniti M45 and are calibrated to a Driving Wizard measured 180cm. These partitions successfully prevented participants who were 180cm or shorter from seeing the Driving Wizard. Participants exceeding 180cm were able to look over the partitions and were excluded from the study.

The height of the Driving Wizard may effectively limit the height of the participants. In this instance, taller partitions blocked the Driving Wizard's access to the passenger side rear-view mirror.

The partitions are made from stiff, 2cm thick foam core board. They affixed to the interior of the vehicle using gaffer's tape. This adhesive prevented the partitions from moving during the operation of the vehicle, but could be removed if needed. Other materials, such as particleboard or plywood, would also be appropriate materials for partitions. It is important to note that the partition designs in **Error! Reference source not found.** are merely guidelines for future studies. Every partition pairing must be configured to a specific vehicle's console geometry and calibrated to the height of the Driving Wizard.

Seat Position and Sight Lines

The seat of the Driving Wizard must be slightly forward of the participant in order to have full view of all the necessary sight lines. This positioning will also minimize the participant's awareness of the Driving Wizard indicated by sightlines shown in **Error! Reference source not found.**.

Passenger Side Alterations

Figure 3 – Passenger seat with steering wheel, tablet, and face capturing camera.

A steering wheel on the participant's side of the vehicle, shown in Figure 3, provides an important queue that they are something other than a passenger. We found that even a simple alteration, such as non-functional steering wheel taped to the dash, can enhance the overall effectiveness of the simulation.

Additional alterations may include a semi-functional steering system, pedals in the passenger foot well, or a right-hand-drive vehicle.

CAMERA RECORDING

Camera Placement

Three HD Go Pro cameras are employed throughout the cabin of the vehicle in order to record the events of the on-the-road experiment. Locations of the cameras are shown in **Error! Reference source not found.**.

The *Participant Camera* is affixed to the windshield to the right of the passenger using a suction mount. The camera is set up in such a way as to record the facial expressions and hand motions of the participant. A small visor is installed above the camera's lens in order to protect the video from lens flare when in direct sun.

The *Driving Wizard Camera* clips to the sun visor directly above the driver's head. This attachment point allows a clear view of the road, as well as the speedometer and steering wheel maneuvers made by the Driving Wizard.

The *Interaction Wizard Camera,* mounts to the rear right corner of the vehicle. It is positioned to record the actions of the Interaction Wizard as well as the interior cabin events.

Figure 4 – Camera views: Interaction Wizard View (top right), Driving View (bottom left), Participant View (bottom right).

Recording

The GoPro Cameras record onto local SD cards, as well as directly to an in-vehicle laptop. The three cameras are connected directly to a 4-channel video processor, shown in Figure 4, connected to an h.264 USB video encoder. The video processor as well as the laptop is powered by an AC power adapter drawing current from the vehicle. The Interaction Wizard can monitor the recordings during the drive via the laptop, ensuring that the instrumentation is working properly throughout the study.

THE RRADS METHODOLGY

The RRADS protocol procedure has three main sections: Meet-and-Greet, On-the-Road, and Exit Interview. Each one of these sections supports suspension of disbelief.

The Meet-and-Greet

Consent

At the start of a session, a participant is greeted, the study is explained, and a consent form is signed. The consent form outlines the nature of the study and the risks and benefits of participation.

Overt deception is not necessarily required for participants to suspend disbelief. The consent form explains that a licensed driver simulates the autonomous driving of the vehicle. We also inform the participant that that the research associates interact with the car as though it is fully autonomous, and ask that the participant do the same.

Approaching RRADS

After the interview, the researcher leads the participant to the RRADS, approaching it from the passenger side doors. The vehicle is parked along the curbside with the Driving Wizard inside but not visible through the windows of the car while the Interaction Wizard is standing by the rear passenger door, as seen in Figure 5. The researcher introduces the Interaction Wizard as a research associate. The participant is told that the Interaction Wizard will be monitoring the autonomous system, and is asked to only interact with the Interaction Wizard in case of emergency.

Once the Interaction Wizard enters the vehicle, the participant can take a seat. The participant's seat should already be located in the appropriate place for the partitions to effectively screen the Driving Wizard's presence. The researcher then asks the Interaction Wizard if all the car's systems are working.

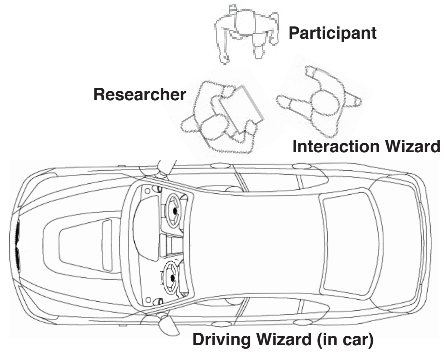

Figure 5 – Configuration for approaching RRADS.

This allows the researcher to make sure that the cameras are capturing the participant's face and are properly recording. The statement also helps further the illusion of the autonomous vehicle.

On-the-Road

Course Selection

The On-the-Road portion of the RRADS protocol provides both quantitative and qualitative research opportunities on the open road. For controlled studies, the route that the vehicle will take must be tested and well known to the Driving Wizard and the Interaction Wizard. The pre-selected course should be predictable and safe. Pedestrians, traffic lights, changes in speed limits, and high-density traffic can be a source of opportunity or complication to a study design.

Residential neighborhoods in particular may mitigate many of the unpredictable elements inherent to a study on public roadways. The low speeds found in these areas can facilitate consistent driving patterns between participants. Single-lane roads diminish the chances of unwanted cut-off events or being forced to accommodate the unexpected maneuvers of other vehicles.

Returning Home

The researcher should be waiting along the roadside when the vehicle completes the course. Their presence will draw participant's attention as the car comes to a stop. The researcher should open the participant's door and engage them in light conversation to allow time for the Driving Wizard to drive away without being seen. The Interaction Wizard should not exit the vehicle at this time.

Avoiding Hazards

While on the road, the Driving Wizard should abide by all posted signs and follow traffic laws. As with any driving, there are risks inherent to conducting a study on a public roadway. Should an emergency occur, another vehicle should be on-call to retrieve the participant at any timFe.

Exit Interview

A qualitative exit interview provides an opportunity to uncover the salient points to the passenger's experience. Qualitative pilot phrases, such as "how did the drive go, in general terms?" can yield in-depth narrative responses that can be mined post facto.

THE RRADS IN ACTION: A STUDY OF HAPTIC PRE QUEUE PROTOTYPES

Aims and Objectives

We employed the RRADS platform to evaluate physical pre queuing systems in autonomous vehicles. Although these prototypes are not the focus of this method paper, they serve as an example for the kinds of on-the-road interventions that are possible using the RRADS. In the process, the validity of the RRADS platform was explored.

Study Design

Prototype Devices

We used the RRADS platform to evaluate the effect that physical pre queuing systems in an autonomous vehicle would have on trust. The study evaluated three physical prototypes in terms of their comfort and efficacy. The devises were designed to alert participants to the autonomous vehicles' starts, stops, and turns.

The first prototype is a pneumatic base in the foot well of the car that tilts in the direction that the car is about to move in. The second prototype is a vibration array embedded into the passenger's seat back exhibiting various vibration patterns corresponding with vehicle movement. The third prototype is a pneumatic device that displaces the participant's shoulders to indicate if the vehicle would turn right or left. This was an in-between participant study design.

In all cases the participant was asked to watch a short movie while in the vehicle to distract them from on-road visual cues such as stop signs and turning lanes.

Study Description

The prototype devices were installed in a 2008 Jeep Compass and a 2012 Infiniti M45. The vehicles were instrumented following the RRADS methodology.

After signing the consent form, participants were asked a series of questions in an interview format that allowed researchers to better understand their relationship to vehicles and driving. This was a qualitative diagnostic interview aimed at identifying the attitudes, expectations and previous experiences that the participant may have regarding autonomous driving technology.

Participants approached the vehicle following the RRADS protocol. Once seated, the vehicle greeted the participant using one of the prototype devices, or in the control case, a revving of the car engine. This process allowed the researcher to be sure that the prototypes were working as expected, and that the participant had no objections to continuing with the study.

Course Selection

The course took approximately 15 minutes to complete. In this study, the vehicle drove through a residential neighborhood averaging 25 mph. During the drive, participants encountered stop signs, traffic lights, construction vehicles, cyclists, and pedestrians. A total of 14 critical events were pre queued as shown in Figure 6. We chose to have the Driving Wizard drive in a conservative, smooth manner, similar to a professional limo driver, for all conditions. The Driving Wizard drove the same course, using the same driving pattern and speed, for all participants.

When key moments arrived, such as the acceleration of the vehicle from a stop sign, the Interaction Wizard activated the prototype being tested. In the control cases, no indication of the event was given, other than the normal revving of the engine and the motion of the vehicle itself.

Participants were asked to use hand gestures to indicate what they thought the car was about to do during the drive. If they believed that the vehicle would turn left, they were to raise their left hand and say, "Left". If they believed the vehicle would turn right, they were to raise their right hand and say "Right". If they believed that the car was about to stop or accelerate, they were to raise both hands and say "Stop" or "Go". We collected the audio and video recordings of their responses, the activation of the prototype device, and the initiation of the critical event.

After initial trials, we found that participants observed environmental cues well before the wizard was able to provide the haptic cue. In order to discourage the participants from reading environmental cues, they were asked to watch a movie on a tablet that was affixed to the passenger steering wheel, shown in **Error! Reference source not found.**. Participants were instructed to pay attention to the movie and were told that they would be questioned about the movie.

Exit Interview

Following the On-The-Road portion, participants were interviewed about their experience using a series of open-ended prompts. Participants were never asked directly if they believed the autonomous vehicle was fully autonomous. Rather, a series of prompts such as "Did you trust the vehicle?" were used to evaluate how strongly a participant believed the simulation.

Upon the conclusion of the interview, participants completed a qualitative and quantitative survey about their experience with the vehicle and the prototype devices.

Study Recruitment

Participants were recruited through advertisements in social and professional networks in [city] and the surrounding environs. In total N=35 participants were recruited, ranging in age from 18 to 36. Of the 35, 14 were men and 21 were women. A $15 gift certificate was offered as payment for participation. Participants were run in two different vehicles. A separate control case was run in each car. The vibration array haptic device was implemented in the Jeep Compass and the pneumatic floorboard and shoulder haptic devices were tested in the Infiniti M45.

Data Analysis

The aim of the data analysis was two-fold:

1. To establish the effect, if any, that haptic pre-queues had on a participant's trust of an autonomous vehicle

2. To determine the effectiveness of the RRADS at producing ecologically valid results

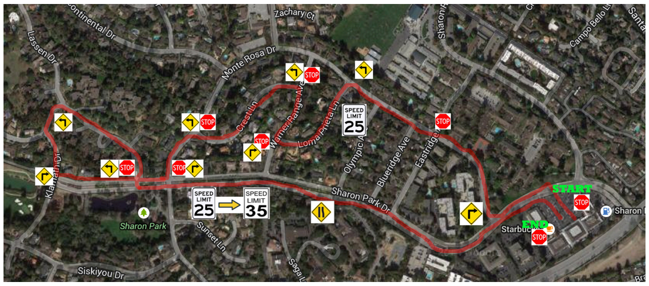

Figure 6 – Driven course with marked events.

Prototype Evaluation

We measured the trust and likeability of the haptic devices through post experiment questionnaires and participant response time to on road events captured on video. We selected the 7 most consistent critical events along the drive, and coded videos of all participants at these events.

We coded the videos for three points of data at each event; the time of experimenter's haptic cue, the time of the participant's response (using a hand gesture) and the time of the on-road event. By measuring the difference in time between the device activation and the participant's response relative to the critical event, we were able to infer how effectively a given device communicated the impending action.

RRADS Evaluation

We employed qualitative research techniques focused on evaluating the participant's subjective experience within the RRADS [20]. The Exit Interviews were transcribed in full, and specific events referred to in the interviews were validated with the video footage of the participants in the vehicles. Interviews were analyzed in terms of *Content Analysis* and *Thematic Analysis* [21]. A custom database was created in Microsoft Excel and summary themes were entered and counted.

The analysis of the interviews for major themes in the RRADS experience was based exclusively on direct quotes. This kept the researcher's interpretive role to a minimum. Quotes are included in the results below with a reference to the participant's anonymous identification number to illustrate out findings [22].

Results

Cars Talk

We found that participants guess before the event was earliest in the case of the pneumatic floorboard and the latest in the case of the vibration array. This indicates that the floorboard provided the most effective early-warning mechanism.

We had initially hypothesized that, on average, the time from the participant's response to the on-road event would be negative in the control case, as they did not receive any haptic cues. This, however, was not the case, as shown in Figure 7. We found that environmental cues from the road and from the vehicle's motion were always present and played a significant role in the participants' guesses. Hence, the average time from the participant's response to the on-road event was positive in the control case.

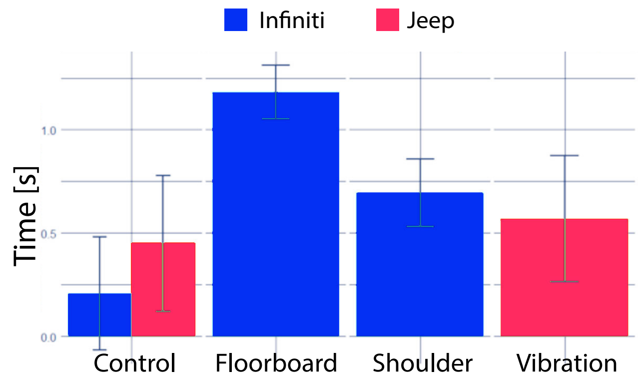

Figure 7 – Event response time for each prototype and control. Note the differences in control times for each vehicle.

Every Car is Unique

It is important to note that the two control cases have dissimilar values. We attribute this to the ride quality inherent to the physical properties of the vehicle itself. The Infiniti was designed to offer a more luxurious ride and may have isolated many of the vibrational cues from the transmission system of the car, providing fewer inherent pre queues from the vehicle's internal systems.

Trust Found in Driving Style

Trust was high through all conditions. In fact we did not find any significant statistical differences between the conditions despite the fact that several of the pre-cuing systems (especially the floor boards) were very effective pre-cuing devices. We hypothesize that this lack of difference can be attributed to consistent and conservative driving style of the driver of the RRADS platform. The signal sent from the driving style may have been so strong that it overwhelmed the signals from less significant inputs.

Smooth Driving is Safe Driving

The exit interviews revealed a group of interrelated themes concerned the concepts of smooth and safe driving. Participants often referenced the car's safe driving style when questioned about trust. When answering the prompt "Did you trust the vehicle?" approximately 30% of answers heavily correlated with descriptions of smooth driving:

I think so. The main thing was that it drove very smoothly. That was the big thing. Participant 21

This correlation also emerged when asked to elaborate further on why they trusted the vehicle:

Because it was smooth and it wasn't too fast or jerky... Participant 8

I think it was a really good driver. It was smooth. Participant 40

It didn't shutter or do anything imperfect that I would have expected it to do. Participant 43

It wasn't jerky at all, which was good. It wasn't anything sudden or things that would normally make me go oh my God, this is scary, stop… Participant 12

It was fairly fluid and everything… Participant 18

The descriptions of smooth driving also correlated with descriptions of vehicular planning and awareness:

Definitely smooth starts and stops. It sort of made it feel like the vehicle was planning what it was doing [...] when a human stops really quickly at a stop sign it's usually because they didn't realize it was there, which I do sometimes. Participant 6

It was just a very sort of calm ride. Just seemed very smooth [...] something's a bit smoother, you realize that the person or the car kind of knows what's going on. Participant 37

The Hello Effect

At the start of the study, the vehicle greeted the participant using one of the prototype devices, or, in the control case, with a revving of the engine. This was built into the study for purely practical reasons to verify that the prototype was functioning properly and did not make the participant feel uncomfortable. This interaction had an unintended effect on the participant's experience of the vehicle. Several participants cited the greeting as a source of comfort and a sign of amicability:

… I was surprised how much I trusted it. Even from the beginning, when it said, "Hello," it had enough of a personality. That one thing gave it enough personality for me to trust it Participant 40

When the car said, "Turn on," or something, and then there was the air, it just kind of shot up, and I was like, "OK, that's kind of interesting," but it's like its way of communicating with you, rather than a voice thing. Participant 29

Trust and Disbelief with RRADS

The RRADS protocol was not designed to employ deception. The partition separating the Wizard Driver from the participant was intended to help facilitate the illusion of an autonomous vehicle, rather than to deceive. However, approximately 25% of our participants believed that the RRADS was a fully autonomous vehicle. Another large portion of the participants believed the vehicle was partially autonomous and remotely controlled by the Interaction Wizard.

The prompt "Did you trust the vehicle?" was particularly helpful in uncovering how immersed participants became in the study:

I guess the computer was pretty cautious, which was pretty awesome […] It was a much better driver than most humans that I know. Participant 27

I think, had it been my first time on the road with an automated car, I would have been terrified, because I wouldn't even know if this technology worked. Participant 29

[…] It made me feel like even though it wasn't a human, it wasn't of malicious intent. Participant 40

A few participants who strongly believed the was RRADS was fully autonomous revealed reservations about autonomous technology:

I just don't fully trust that car to drive on its own. Even though I had no bad experiences with this car, it just seems strange to me still and foreign to me that a car can drive itself. Participant 31

It's more of me communicating […] it would just drift a little bit and I told it, I said, "You have to pick a lane." (laughs) Thinking my verbal cues would be helpful but I am a very verbal driver. Participant 42

During more complicated maneuvers, some participants ascribed agency to the Interaction Wizard:

There was a construction site […] The guy was waving for me to move and I was like, I don't know what to do… so I was like, "I really hope the car does something smart" The car backed up and then the guy made more hand signals. I don't know if [Interaction Wizard] or if the car did it… Participant 31

Only 4 participants out of the 35 tested indicated that they were fully aware of the Driving Wizard. This was a surprisingly low number of individuals given that the study was not designed using overt deception.

Yes. I'm not sure if that's completely fair because I knew that I wasn't alone. I'm not sure how I would feel in a vehicle that was autonomous. [But] I think I would after having a test drive like that. Participant 25

I'm in a study and this is probably very safe and there is somebody actually driving and I am in the passenger seat, so yes I trust that situation. Participant 35

DISCUSSION

Overall, results suggest that the RRADS may be an effective way to evaluate prototypes and scenarios specific to open road human-autonomous vehicle interactions. The RRADS provided a useful platform for evaluating the 3 prototype devices in an ecologically valid situation.

More interestingly, the RRADS platform pointed to influences that might be greater levers in trust than pre queuing. The Hello Effect seems to indicate that an autonomous vehicle's perceived personality and driving style may be incredibly strong and salient factors in a user's trust in a vehicle.

In addition, participants seemed to be actively evaluating the vehicle competence when it encountered complex situations. The vehicle's apparent ability to interact with construction vehicles or bicyclists seemed to reassure participants who were initially skeptical of autonomous driving technology.

FUTURE WORK

Further validation of the RRADS platform should be considered. A controlled study focused solely on the effects of specific elements in the RRADS platform leading to the suspension of disbelief may result in an even more effective protocol. Possible research topics might include the effect of:

1. Removing the partitions to reveal the Driving Wizard
2. Isolating the effects of the vehicle's suspension system
3. Varying language in the consent form to be more or less explicit about the presence of the Driving Wizard
4. Excluding the Interaction Wizard from the vehicle
5. Varying the vehicle greeting
6. Varying the RRADS driving style

Driving style seems to be of particular importance when evaluating prototypes focused on Trust. It seems worthwhile to better understand where the speeds and driving styles begin to erode participant's trust. This would provide a baseline of distrust from which to reference the effects of a given prototype. Further development of the RRADS may involve devising technology that can quantitatively standardize the Driving Wizard's driving style. This will allow for a more consistent experience between participants, and may facilitate research on the effects of driving style in human - autonomous vehicle interactions.

In addition, a study with and without a vehicle "greeting" may provide insights into the effects of personifying autonomous vehicles. This would be a useful and novel research topic for automotive interaction.

The RRADS platform may even provide a method by which to evaluate the effects of specific variations in a between-vehicle study. Physical vehicular attributes such as ride quality and the amount of sound coming from the engine can be used as levers to explore people's real-world relationships to autonomous vehicles.

CONCLUSION

The RRADS platform provides an important and low-cost solution for use in the automotive community when designing driver interactions and user experience. It can provide useful insights throughout the whole design process, and indicate which features are proving to be salient with users and which are not. In an industry where prototypes take years and thousands of dollars to develop, it is exceedingly useful to understand user interaction before large system level decision are made and developed for new vehicles. The RRADS platform acts as a low-cost rapid prototyping platform for autonomous car interaction design and testing.

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