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Vehicle Automation Emergency Scenario: Using a Driving Simulator to Assess the Impact of Hand and Foot Placement on Reaction Time

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Abstract

As vehicles with SAE level 2 of autonomy become more widely deployed, they still rely on the human driver to monitor the driving task and take control during emergencies. It is therefore necessary to examine the Human Factors affecting a driver's ability to recognize and execute a steering or pedal action in response to a dangerous situation when the autonomous system abruptly requests human intervention. This research used a driving simulator to introduce the concept of level 2 autonomy to a cohort of 60 drivers (male: 48%, female: 52%) of different age groups (teens 16 to 19: 32%, adults: 35 to 54: 37%, seniors 65+: 32%). Participants were surveyed for their perspectives on self-driving vehicles. They were then assessed on a driving simulator that mimicked SAE level 2 of autonomy. Participants' interaction with the HMI was studied. A real-life scenario was programmed so that a request to intervene was issued when automation reached its boundaries while navigating a two-way curve road (TTC = 2.2 seconds). We found that at the time of the event, only 12% of participants kept their hands on the steering wheel. Only 64% of participants had their foot close to pedals. All participants who reacted within 0.65 seconds were able to avoid the crash. All participants who reacted after 0.9 seconds crashed. As a last construct, we looked at age and gender to understand how different participants behaved while vehicle automation was engaged.

Introduction

The world of transportation has experienced in the last 10 years three innovations which will profoundly transform how people and goods are moved around. While electrification and the shared economy are new constructs, automation and the concept of self-driving is a paradigm shift in human mobility which will most likely require some dramatic changes of people's minds and perception of vehicles.

As we continue to develop vehicle automation, highly public failures continue to capture the imagination. These include the first fatal crash of a Tesla on Autopilot in Florida (May 2016) and the Uber crash in Arizona (March 2018); these crashes killed a driver and a pedestrian, respectively. To this day, a large segment of the population does not trust automated vehicles. A 2020 survey of 1,200 adults from the PAVE campaign [1] showed that 48% of Americans say they "would never get in a taxi or ride-share vehicle that was being driven autonomously and 20% of American believe they will never be safe. We propose through this work to tackle two Human Factors issues that arise as one think of vehicle automation. The first issue addressed is that of trust and education: can a driver simulator contribute to education and help mitigate fears? The second research question relates to the use of vehicles of level 2 of automation: how do drivers use the technology and how difficult is it to answer a request to intervene?

The disconnect between the self-driving technology currently developed and drivers' perception and trust is well-documented [2] . Previous studies have focused on older drivers' perceptions [3] or on parents of young children [4]. While surveys are typically conducted over the phone, they often lack some intimacy and real involvement of the participant. We leveraged our driving simulator to precisely provide a safe context in which to engage participants to share their views on the technology. Our study inquired through a semi-structured interview about the level of comfort and trust in automated technology. Our participants were asked about their knowledge of ADAS (terminology) and self-driving technology. We also inquired about their level of use of Cruise Control for drivers who owned the technology.

Vehicles with SAE level 2 of automation provide drivers assistance with the driving task through automation of both lateral and longitudinal controls. According to the SAE J3016

Taxonomy document [5], these vehicles operate within an Operational Design Domain (ODD). They can reach at any time the limits of this ODD. For this reason. Human drivers are responsible not only for the proper motion control of the car, but also the Object and Event Detection and Response (OEDR). They must continuously monitor of the Dynamic Driving Task and quickly react should the vehicle automation reach its operational boundaries. While considerable literature has been published on various safeguards to prevent severe accidents (e.g. Active Safety systems such as adaptive cruise control [6], lane assist and emergency brake assist [7], comparatively less research has investigated the Human Factors at play when interacting with level 2 vehicle automation. Previous research suggests that these factors may affect a driver's aptitude for intervening when the vehicle automation reaches its limit. Previous research suggests that these factors may affect a driver's aptitude for intervening when the vehicle automation reaches its limit [8, 9].

Driving simulators offer an important opportunity to safely expose a driver to an emergency situation and analyze their recovery performance. They allow for a safe, controlled environment where challenging—or even dangerous—traffic scenarios can be presented to drivers for dynamic interaction. In the context of research, driving simulators conveniently offer the ability to present an identical emergency situation to all test drivers; this has been impossible with all on-road studies to date. While existing literature has used proxy variables such as age and gender to assess performance when using a vehicle automation [10, 11] our approach consisted of observing drivers' behavior while using the technology. Specifically, we focused on the position of hands and feet while the lateral and longitudinal automation was engaged. We offer an analysis of a car crash and the reaction time with hand and foot placement as primary variables. In a secondary analysis, we reviewed driver behavior in light of age and gender.

This study expands on our team's 2018 study which investigated drivers' responses to an autopilot failure involving a blocked highway [12, 13]. The current study similarly used a driving simulator to expose a cohort of drivers to a well-scripted emergency scenario featuring a limit of the vehicle automation with a request to intervene, this time, in a two-way road scenario. This paper summarizes how the drivers behaved while the automated feature was engaged, using metrics including hand and feet placement, reaction time, and crash rates with breakdowns by age and gender. Both qualitative and quantitative frameworks are employed for analysis in the form of surveys, video recordings, and simulator data.

Methods

Simulator Hardware

Participants engaged with a fixed-base high fidelity driving simulator from Realtime Technologies, Inc. (RTI)®. Data was collected at 60 Hz. The driving simulator was composed of a driver seat, three-channel 46" LCD panels (180° field of view) with rearview mirror images inlaid on said panels, active

FIGURE 1 High fidelity driving simulator at CHOP

pedals, a steering system, and a rich audio environment (Figure 1). Graphics were generated by a tile-based scenario authoring software, and real-time simulation and modeling were developed with SimCreator, (RTI®). Graphics and visual rendering were interfaced at 1280 x 1024 resolution with a 60-Hz frame rate. Video recordings of the driving scene, the participants' hands on the wheel, and their feet on the pedals were captured via SimObserver, a video capturing system. This allowed for analysis of the digital video recordings along with the recorded simulator data.

The driving simulator in this study (housed within the Roberts Center for Pediatric Research) is enhanced with SimDriver [14], a software module developed by RTI that can simulate automated driving in both city and freeway driving environments. As such, this simulator offers longitudinal and lateral control which can emulate the functionality of SAE level 2 vehicles. The automated mode can be engaged and deactivated by a simple action on the flash-to-pass lever located on the left side of the steering column. It is instantaneously deactivated at any time by any action on the steering wheel or pedals.

Scenario Development

Driving scenarios were developed using SimVista Scene and Scenario Development System, Virtual Reality Modeling Language (VRML), Internet Scene Assembler (ISA, ParallelGraphics®), and Javascript scripting. The addition of scenario control objects, namely proximity, time, and time-to-collision (TTC) sensors, allowed objects to be controlled across all trials. Proximity sensors were programmed to execute instructions when the center of gravity of a vehicle was within the sensor's boundaries

This paper presents the results of a scenario that was inspired by a real-life video recorded by a driver and documented in the YouTube video "Autopilot tried to kill me!" [15]. The participant drives along a two-way road in automated mode. The vehicle cruises along a curve. At some point on that curve, the vehicle automation is unable to recognize road marks. It emits an alarm signaling the automation is no longer operating within its ODD. Request to intervene happens as an incoming vehicle approaches creating an opportunity for a head on collision. In this scenario, the participant must perform an evasive maneuver to avoid a head-on collision. In

FIGURE 2 Scenario storyboard: two-way road autopilot failure

the programmed scenario, participants are alerted 2.2 seconds before the collision with the incoming vehicle. A visual cue appeared on dashboard as well. The scenario was identical for all participants, since they all approached at the same velocity (35 mph) and faced the same challenge.

Participants

Participants were recruited from the Philadelphia, PA area from three specific age groups with gender parity maintained: teen drivers (n=19) ages 16-19 with at least three months of independent driving experience), adult drivers (n=22) ages 35-54 with at least of five years of independent driving experience, and older adult drivers (n=19) ages 65+ with at least five years of independent driving experience.

Our recruitment procedure ensured that our participants did not own a vehicle with ADAS with level 2 of autonomy. In addition, we screened out participants who may have had extensive exposure to driving video games.

Procedure

This study was approved by the Institutional Review Board of the Children's Hospital of Philadelphia. Before encountering the driving simulator, all 60 participants were interviewed to assess their prior knowledge and possible experience with vehicle automation. They were asked about their likelihood of utilizing or purchasing one. Afterward, participants were introduced to the driving simulator, first to the manual controls with a 10 to 15 minute familiarization drive. The research coordinator then instructed the participant on how to engage level 2 automation (using a multifunction lever left of the steering wheel) and deactivate it (using the same lever or using any action on the steering wheel or the pedal). A visual icon appeared on the dashboard in automated mode. In addition, the status of the automated mode was displayed on the center monitor. Participants were then asked to repeat the familiarization drive to practice engaging and de-engaging automation. They were asked to de-engage automation through all three possible ways. Only after participants demonstrated that they were comfortable turning automation on and off was experimental drive started. Participants were instructed that they "should activate or de-activate automation as they saw fit." They were told they were responsible for driving safely and it was their responsibility to avoid potential crashes. They were told an alarm would ring should the system request manual control. However, they were not made aware of a potential crash event during the experimental drive.

In the experimental phase, each participant engaged in two 15-minute drives, each of which presented a different scenario where vehicle automation was challenged resulting in the system sounding an alarm to request manual control. A highway scenario with blocked exit was presented first to participants. Results were previously reported ([12, 13]). The second experimental drive is the focus of this paper. In this scenario, vehicle automation is unable to read road marks during a curve along a curve on a two-way road. As a result, the participant's vehicle unexpectedly veers toward oncoming traffic, crossing the dividing line and requiring the driver to perform a swift evasive maneuver to bring the car back into its lane and avoid a head-on collision. After the driving simulator experiment, participants were asked to answer a short survey about their experience with the simulator and their perspectives on autonomous technology.

Data Collected

Participant's data consisted in a large collection of simulator time series. Video recordings were also gathered. These contain images of the participant's face, right foot on the pedal, and upper body at the wheel, as well as the driving scene on the display in front of the participant. Using SimObserver [16], a video and data logging software component, driving videos and numerical data were synchronized during the experiment. Lastly, participants wore an eye-tracker as they drove the simulator. The data from the simulator were packaged in numerical (csv) files and video (mpg). Variables used included Vehicle Heading, Yaw Rate, Vehicle Position, LaneOffset, HeadingError, ThrottlePressure, BrakePressure, SteeringWheelAngle, DistanceToClosestCar, AutopilotStatus, and FrameID. Driving simulator data was analyzed using Matlab version 17 [17] and Python. Videos were manually reviewed by research assistants and annotated to report foot and hand location just prior to the event.

Analytical Methods Our analysis only considered participants who truly experienced the event. (E.g. if a participant preemptively braked or steered before the alarm sounded, he was excluded from the analysis.) The event characteristics were the alarm itself, a movement of the steering wheel, and the crossing of the driving line by the ego vehicle.

Reaction Point and Time

We define the driver's reaction point as the instant the driver disengaged the automated mode. Since the self-driving mode is disengaged when the driver brakes or steers, this point identifies when the vehicle no longer follows the programmed failure trajectory, indicating that the driver had taken over in manual mode. The reaction time is defined as the difference in time between the event point and the reaction point. The reaction point was identified through analysis of simulator log files. In addition, an indicator "auto off" was displayed on video files to help reviewers with visual analysis of the simulator recordings.

Results and Discussion

Perspectives on Vehicle Automation

The semi-structured interview helped us understand drivers' perception and anticipated use of vehicle automation. We found that among drivers who owned Cruise Control, only 34% of them used the feature. Men were more likely to use the feature (44%) than women (25%). When asked if training for using a self-driving vehicle should be required, all groups (males, females, teens, adults and seniors) answered positively (85%) or more. All 19 older participants (100%) wished for training in automated driving technology.

Hands and Feet Placement While on Autonomous Mode

The introduction of vehicles with level 2 automation to the market in 2016 quickly caused concern among the NHTSA and Safety community since no safeguard was in place to ensure that the driver kept hands on the steering wheel at all times, even when the automation was engaged. Shortly after the first crash involving level 2 automation, the NTSB released a report highlighting the need for drivers to monitor the road but also to keep their hands on the steering wheel [18]. Manufacturers quickly modified the HMIs so that present day automated systems will detect if the driver has removed his hands from the steering wheel. While our scenario mimics the real-life event presented in the YouTube video ([15]) when drivers were not required to keep their hands on steering wheel, it provides a case study for vehicles of level 3 of automation, yet to be introduced, when manufacturers will again provide this ability to drivers. At level 3 of automation, the driver can safely turn their attention away from the driving tasks, (e.g. text or watch a movie). The vehicle will handle situations that call for an immediate response, like emergency braking. The driver must still be prepared to intervene within some limited time, specified by the manufacturer, when called upon by the vehicle to do so.

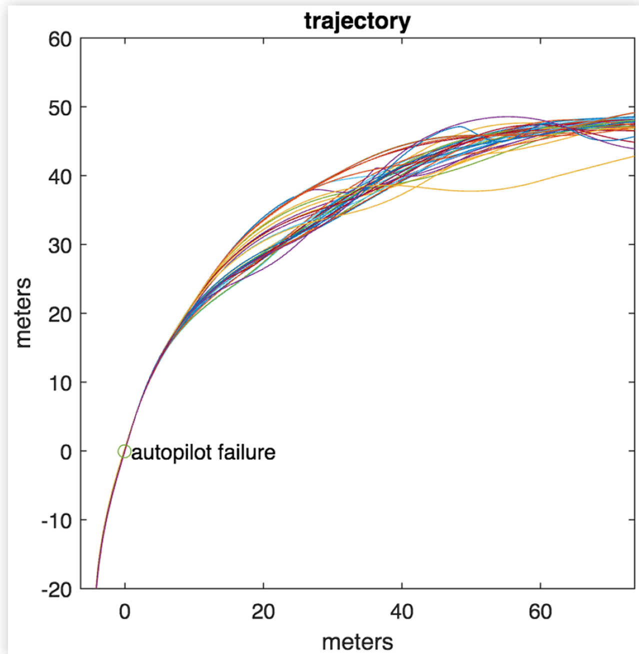
Our driving simulator allowed us to precisely study positions of hands and feet while autopilot was engaged. No specific instructions were given to participants other than to pay attention to the road and monitor safe driving. The "Hands on Wheel" status was detected through the steering wheel via a capacitive sensor. We manually confirmed this by reviewing the video footage of participants' hands. Additionally, position of feet was also recorded (through video analysis). While much attention has been focused on hand position in the safety community, position of feet while in autonomous driving has more rarely been studied. Our results are presented in Table 1.

We observe that as a global result, only 12% of participants kept a hand on the steering wheel while in autopilot mode. When studying foot placement, we used video and noted whether the foot was present on video. As a global result, we found that about 64% had their foot located near the pedal at time of event. Of note, 3 participants (teen male, adult male and senior male) had their foot UNDER the pedal at time of event (Figure 3).

TABLE 1 Hands and feet placement while on autonomous mode

		Hands on wheel	Foot near pedal
Age	Teen	1/18	13/18
	Adults	3/16	11/16
	Older	0/9	4/9
Gender	Female	0/20	12/20
	Male	5/23	16/23

FIGURE 3 Hands and feet placement at time of event



Crash Rate

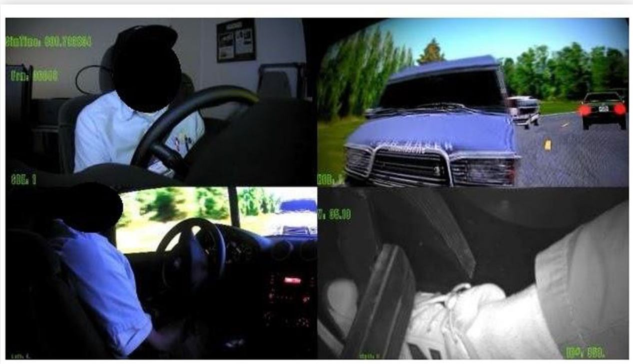
Our initial cohort of 60 participants (all of whom had taken the initial survey) was reduced to an experimental cohort of 46 participants because of simulator sickness. These participants dropped out at the very beginning of the familiarization drive. All other participants became comfortable after the 15 minutes exploration drive, leading us to believe that their driving behavior was not impacted by possible discomfort. In addition, 3 participants were excluded from final results as they did not have the autopilot activated at the time of event. Our final cohort for this autopilot failure experiment consisted of n = 18 teens (ages 16 to 19), n = 16 adults (ages 35 to 54), n = 9 older adults (ages 65+). Gender breakout was as follows: n = 23 males, n = 20 females.

Our event was programmed with a TTC of 2.2 seconds which translated in a global crash rate of 53% (43 participants. To avoid a crash with an incoming vehicle, participants needed to react quickly and perform a solid evasive maneuver (braking and/or swerving). This meant that (1) the driver properly

TABLE 2 Crash rate

		Crash Rate
Age	Teens	9/18
	Adults	6/16
	Older	8/9
Gender	Female	12/20
	Male	10/23

FIGURE 4 Trajectory after autopilot failure



monitored the road (gaze), (2) the driver reacted quickly to the event (position of hands and feet), and (3) the driver reacted adequately to the event (no understeer or oversteer).

Departure from the roadway was not considered a crash in our analysis. A crash was defined as a collision with an incoming vehicle. While classic literature (SHRP2 naturalistic driving database as an example) considers any road departure to be a crash, we chose to limit ourselves to any direct collision with other vehicle in our analysis. The rationale is that with a TTC of 2.2 seconds, this event was quite difficult to handle by drivers, so all of them departed from the road, as seen in the trajectory figure. While road departure is a serious crash, a head-on collision is even more serious. We chose to limit ourselves to this case when tabulating crashes. Crash rate is summarized in Table 2.

The typical evasive reaction to the event was to steer to avoid the head-on collision. The trajectories of all 43 participants are represented in Figure 4. While all participants experienced the same velocity (33 mph) and circumstances leading to the crash, their lack of reaction, understeering or oversteering can be visualized through their trajectory.

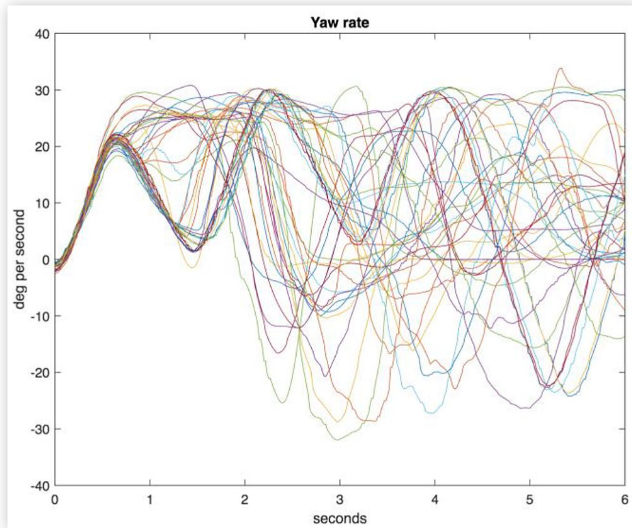
Reaction Time

Because crash vs. no crash is a binary variable, it allows for little interpretation about why and how the crash happened. More refined metrics are the reaction time and type of reaction (swerving vs braking). Yaw rate (e.g. derivative of heading) is represented in Figure 5. As indicated in the figure, there is an identical yaw rate at time of event and for about a second after event. Yaw rate fluctuates tremendously as participants regain control of the steering wheel to avoid the crash. This graph shows various oscillations of period centered around 2 seconds

TABLE 3 Reaction times

Reaction Time	Male	Female	Teen	Adult	Senior	Total
No reaction	9%	20%	6%	6%	44%	14%
Mean Reaction Time (sec)	1.28	0.94	1.31	0.85	1.38	1.01
Deviation Reaction Time (sec)	1.47	1	1.5	0.95	1.4	1.17

FIGURE 5 Yaw rate following the autopilot failure



which represent the actions of drivers on the steering wheel to avoid the crash. We observed the following results:

- 6 drivers had no reaction at all (14% participants)
- 44% seniors did not react to the event compared to 6% of teens and 6% adults.
- The shortest reaction time was 0.37 seconds.
- All participants who reacted within 0.65 seconds were able to avoid the crash.
- All participants who reacted after 0.9 seconds crashed.

Discussion

As more vehicles with level 2 of autonomy get introduced on our roads, it becomes important to study the Human Factors involved in self-driving. It is necessary to address questions about drivers' ability to focus on the road when using self-driving, placement of hands and feet, and capacity to quickly and adequately react to emergencies and take over in manual driving mode. Our driving simulator and emergency scenario allowed us to precisely study the effects of gender and age. While some results are given as indications (e.g. the small cohort when dividing by age group and gender), other results were statistically significant. For example, we observed that females crashed less often than their male peers (45% against 61%). This result was not statistically significant when using an Exact Fisher Test. While the crash rate for seniors appeared to be significant when using a binomial test (P=0.03), it is not the focus of this paper.

We believe that the major takeaway from this study is the low engagement of drivers in the driving task when level 2 autonomy is engaged. At the event time, only 12% of participants had at least one hand on the steering wheel and only 64% had their foot close to pedal at the event time. (Note that for the other 36%, feet could not be seen on video.) This last result is a valuable contribution to our understanding of driver behavior because no work substantial has focused on foot placement while operating vehicles of level 2 autonomy. Of note, our study of 43 people found 3 participants (7%) who kept their foot UNDER the pedal while driving. As vehicles of level 2 of autonomy and above make their way onto our roads, essential practices such as eyes on the road and placement of hands and feet should be emphasized and studied since they play a major role in road safety. We urge manufacturers to develop more research - both on-road and using a simulator - to better understand the human-machine interface when drivers operate vehicles with automation.

Limitations

One strength of this study is its accessibility. Using a driving simulator, participants of all ages and diverse walks of life were able to witness and react to an adverse automation event which was inspired by real-life: a documented real-world scenario that can still be viewed on YouTube. Being able to replicate such an event and replay it for a cohort of participants enables us to tackle the Human Factors at play when studying vehicle automation.

Like many other studies, we would have wished for more participants to amplify the statistical power of the analysis, but we were of course limited by the number of participants. As self-driving technology begins to be deployed *en masse*, we need tools to capture edge cases that should not be experienced on-road. Driving simulators empower us to script situations with small TTCs so we can optimize HMIs for the benefits of all drivers. Safety is about making rare events even more rare. As crash data becomes available, either from naturalistic driving studies or from events documented by users, replication of these events in the controlled environment of a driving simulator should become the norm.

Another limitation of our study was the ability to retain older drivers because of simulation sickness. Ironically, senior drivers who have the most to gain from automated vehicles and are eager to be taught (all 19 older drivers were eager to try our driving simulator to get exposed to automated vehicles) had the largest dropout. More research will be needed to develop tools to safely introduce seniors to self-driving technology.

Another limitation of this study is that it lacked a sense of practical danger. All participants knew that they were safe at all times. The validity of the experiment relies on the sense of immediacy and sense of panic documented in videos during the virtual crash. Previous research has also documented inconsistencies in results provided by simulation research when compared to on-road research [19]. This could possibly explain the lack of involvement in the driving task that our studied observed just prior to the crash event.

Yet despite their limitations, driving simulators are, at the moment, the best proxy for studying focus and reaction time in the case of an autopilot failure. As manufacturers press for higher levels of automation, examples of emergency situations with request for takeover are multiplying [20] and providing solid case studies for simulation. Furthermore, a large portion of the population does not trust automated vehicles [21, 22]. Driving simulators can therefore help bridge the gap such that drivers know what to expect when they are on the road, learn how to responsibly use automation features, so that the benefits of automation can be reaped.

Conclusion

Vehicles of level 2 of autonomy are already on the road. While this paradigm shift in transportation is taking place, little has been done to introduce drivers young and old to the advantages and inevitable risks of self-driving technology. To maximize the benefits of this technology both in comfort and safety, it is essential to accompany the development of ADAS algorithms and levels of self-driving with sound studies of their adoption by the larger population. Our study leveraged a driving simulator to introduce drivers - males and females, young and old - to the concept of "letting go" of the steering wheel. We found that various age and gender groups react differently. While older drivers seemed the most eager to see this technology, they were more at risk when a request to intervene was issued by the system. We anticipate the need to further expand these studies and to develop programs introducing drivers to advanced ADAS systems and various levels of autonomy. As vehicles will level 5 of autonomy emerge, the safety benefits of the technology will be best unlocked through massive yet educated adoption.

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