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Driver Expectations for System Control Errors, Driver Engagement, and Crash Avoidance in Level 2 Driving Automation Systems

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16. Abstract

Many vehicles available to consumers offer some level of automated lateral and longitudinal driving functionality. The capabilities of these vehicles vary widely among both vehicle makes and models. Drivers may or may not have preconceived expectations about how these driver assistance systems function. This project tested 96 participants in vehicles equipped with SAE Level 2 driving automation systems of different capabilities. To evaluate the effects of driver expectations, participant training was either congruent or incongruent with system capabilities, creating a four-condition between-subjects factor. Testing was conducted on public roads and on the Virginia Smart Road test track. While on the test track, participants were asked to complete non-driving tasks while driving, and mid-way through the driving session experienced a surprise event (crash-imminent scenario). Analyses focused on summary measures of driver engagement behaviors such as driver hands on steering wheel behavior and subjective measures of automation acceptance and engagement. Response times to surprise events were also compared between expectation levels. Results indicate that driver training can have an effect on driver engagement on public roads that is independent from vehicle capabilities.

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Acronyms

ACC	adaptive cruise control
DAS	data acquisition system
HMI	human-machine interface
L2 NDS	Naturalistic Driving Studies of Level 2 Vehicles (project)
LCA	lane centering assist
LKA	lane keep assist
NDS	naturalistic driving study
RQ	research question
SE	standard error
VTTI	Virginia Tech Transportation Institute

Table of Contents

FIGURES

TABLES

EXECUTIVE SUMMARY

Many vehicles available to consumers today offer some level of automated lateral and longitudinal driving functionality that could fit the classification of SAE Level 2 driving automation (lane centering plus adaptive cruise control or ACC) or Level 1 (lane keeping plus adaptive cruise control). At the time of this report, there were 39 models available with lateral features described as "lane centering." An additional 147 models were available with lane keeping, a Level 0 crash avoidance system. Within each distinction, capabilities vary widely among both vehicle makes and models, and exact functionality will vary due to both feature settings and environmental factors. Drivers may or may not have preconceived expectations about how these driver support features function, depending on various sources of information encountered before experiencing first hand (e.g., dealership training, reading an owner's manual, or watching YouTube videos of similar vehicles).

The goal of the Driver Expectations project was to determine if expectations about driver support features would change the way drivers interacted with Level 2 driving automation systems compared to a system with a Level 1 system (ACC) plus an active safety system (lane keeping). The study manipulated driver expectations independently from the lateral feature capability using information provided at training. After receiving the training information, participants then drove the study vehicle on public roads to experience the technology before driving onto the test track. While driving on the Virginia Smart Road, participants performed non-driving tasks, and experienced a surprise event — either a lane departure or a potential forward crash. After experiencing the event, participants resumed driving and performing non-driving tasks.

Research Questions

The approach described in this report was designed to address the following research questions. The research questions were formulated to address the impact of both driver expectations and feature capability on driver engagement in the driving task and driver performance.

- **RQ1 (Driver Response and Expectation)**: Does driver response to avoid an imminent crash differ based on expectations for encountering safety critical system errors in automated lateral and longitudinal (mixed function) control?
- **RQ2 (Non-Driving Task Engagement)**: What are the effects of engaging in non-driving (secondary) tasks when responding to an imminent crash or lane departure scenario that is caused by lateral and longitudinal system control errors?
- **RQ3 (Driver Response I)**: How do driver responses compare across different performance and reliability levels of driver support features?
- **RQ4 (Driver Engagement)**: How is engagement in driving mediated by driver expectations for system errors/failures, type of secondary task, and imminent crash scenario?
- **RQ5 (Driver Acceptance and Trust)**: What are the effects on user acceptance and trust when drivers encounter critical system errors/failures? How resilient or enduring are the effects of expectations on acceptance and trust?

- **RQ6 (Crash Potential)**: Are crashes more likely with increased system performance and reliability?
- **RQ7 (Driver Response II)**: Do drivers respond faster to crash imminent events when they have a higher expectation for system performance and reliability?
- **RQ8 (Acceptable Driver Engagement Threshold)**: Can an acceptable driver engagement threshold that is relative to driver expectations be established from this study?

Approach

Participants

Data from a total of 96 participants are included in the final data set. All participants were recruited from the Blacksburg, Virginia, area. Participation time was approximately 4 hours per participant. All participants were compensated at the rate of $120 for full participation. An equal number of males and females were recruited from two age groups: 24 to 39 (average age of 30) and 40 to 54 (average age of 46).

Vehicle

The vehicle used for this study was a 2015 Infiniti Q50 with longitudinal (factory-equipped adaptive cruise control) and lateral feature capabilities customized and modified by the Virginia Tech Transportation Institute. The study vehicle lateral feature was configured to operate at different capability levels (low and high). The two capability levels were designed to mimic commercially available lateral features. Capabilities were reviewed with both NHTSA and the stakeholder group prior to implementation. The stakeholder group included representatives from OEMs (General Motors, Nissan, Volkswagen North America), Tier 1 suppliers (Bosch, Continental), as well as other regulatory agencies (Transport Canada). The vehicle included a factory-equipped longitudinal control feature (implemented as adaptive cruise control in the present study).

Design and Procedure

The study employed a 4×2×6×3 mixed design. Training, which was used to set participant expectations (see Participants section in this chapter), and capability (see Vehicle section in this chapter) were combined into a four-condition between-subject factor. The between-subject factors included two congruent conditions, where the training matched the capabilities of the lateral feature and two incongruent conditions, where the training set expectations above or below the capabilities of the lateral feature. In addition, there were two different crash imminent scenarios as a between-subject factor. Three different non-driving tasks were administered, with six different non-driving task orders as the remaining between-subject factor.

Participants first drove the vehicle on public roads, followed by driving on a closed test track. Participants were asked to repeat a series of three non-driving related tasks: (1) texting (visual-manual distraction); (2) watching video (visual distraction alone); and (3) baseline (no non-driving task) in one of six orders. The six orders included all possible combinations of the three task types. Midway through the test track portion of the study (trial 7), participants experienced one of two crash-imminent scenarios: lateral feature failure leading to a lane departure or longitudinal feature limitation leading to an imminent forward crash. In total, participants performed each type of non-driving task four times across 12 trials.

Results and Key Findings

The results showed that drivers' pre-conceived, training-based expectations did influence their interaction with technology in a potentially negative way. In particular, on the public road, drivers were more likely to have their hands off the steering wheel in the high-expectation training condition, regardless of the lateral feature capability. This behavior was also present immediately prior to experiencing a surprise event.

Overall, there were no effects of either capability or training on response times to surprise events observed in the current experiment. However, experiencing the surprise event did change the way participants were engaged in the driving task. After the surprise event, participants in all conditions were more likely to have their hands on the steering wheel and eyes on the road compared to trials before the surprise event. There was a significant difference in eye glance behavior while performing non-driving tasks before and after the surprise event. Specifically, drivers were less likely to focus on the video task and texting tasks after the surprise event. Self-reported trust measures were high and increased throughout the experiment, but did not show a statistically significant change before and after the surprise event.

In the present study, multiple drivers across all training/capability conditions did not brake during the reveal event, where a slow-moving vehicle ahead was suddenly exposed, and instead relied on the adaptive cruise control (ACC) system to slow the study vehicle. Given the performance envelope of the factory system (and design of the event itself) the behavior could be described as anticipatory; the drivers were looking forward and attentive but did not respond immediately to the event. Rather, they reported that they wanted to "see what the car would do." Similar behaviors were observed in a naturalistic study of Level 2 driving automation, albeit with responses to request to intervene alerts (e.g., Russell et al., 2018).

With Level 2 driving automation, any level of driver disengagement is potentially detrimental. Although the system may perform control of the longitudinal path, hands on the steering wheel and eyes on the road are still required for adequate engagement. Drivers' pre-conceived expectations about the system's capabilities and effectiveness can change engagement patterns throughout the study in complex ways. This suggests that to keep drivers properly engaged, the capabilities and limitations of driver support technology should be described to a driver as accurately as possible; if drivers expect less from the feature than it is capable of, their driving may, at least initially, reflect their expectations of capabilities rather than the actual system capabilities.

1. INTRODUCTION

In the broadest sense, expectations shape the way we see, interpret, and act within the world. The influence of our expectations can be both positive (e.g., a beneficial placebo) and negative (e.g., an expectancy bias). Expectations are formed in a variety of ways and via many sources, but are generally the result of either direct (conditioning, learning, immediate exposure, etc.), or indirect (verbal instruction, reading, observing others, watching a video, etc.) experience. As driving automation technology emerges, current road users' expectations will shape their willingness to adopt this new technology, and affect the speed at which they learn to use the technology. As Level 2 technology is just beginning to become available to consumers, most drivers have had no direct experience with, and may or may not have had indirect exposure to these commercially available systems. The goal of the Driver Expectations for System Control Errors, Driver Engagement, and Crash Avoidance in Level 2 Driving Automation Systems (Driver Expectations for short) project is to better understand how expectations influence driver behaviors when using Level 2 driving automation technology.

Many vehicles available to consumers today offer combined lateral (lane centering) and longitudinal (ACC) support features that could fit the classification of SAE Level 2 driving automation (see **Figure 1** for SAE levels and definitions). Appendix A includes a review of currently available models with lateral and longitudinal features; at the time of this report, 39 models were available with lateral automation described as "lane centering" with an additional 147 having lateral features described as "lane keeping." Even within each distinction, these vehicle capabilities vary widely among both vehicle makes and models, and exact functionality will vary due to both vehicle settings and environmental factors.

Drivers may or may not have preconceived expectations about how these support features function. These expectations may depend on various sources of information, including personal experience (e.g., dealership training, reading an owner's manual, or watching online videos of similar vehicles). At present, it is not clear how driver expectations will affect the use and adoption of automated technology.

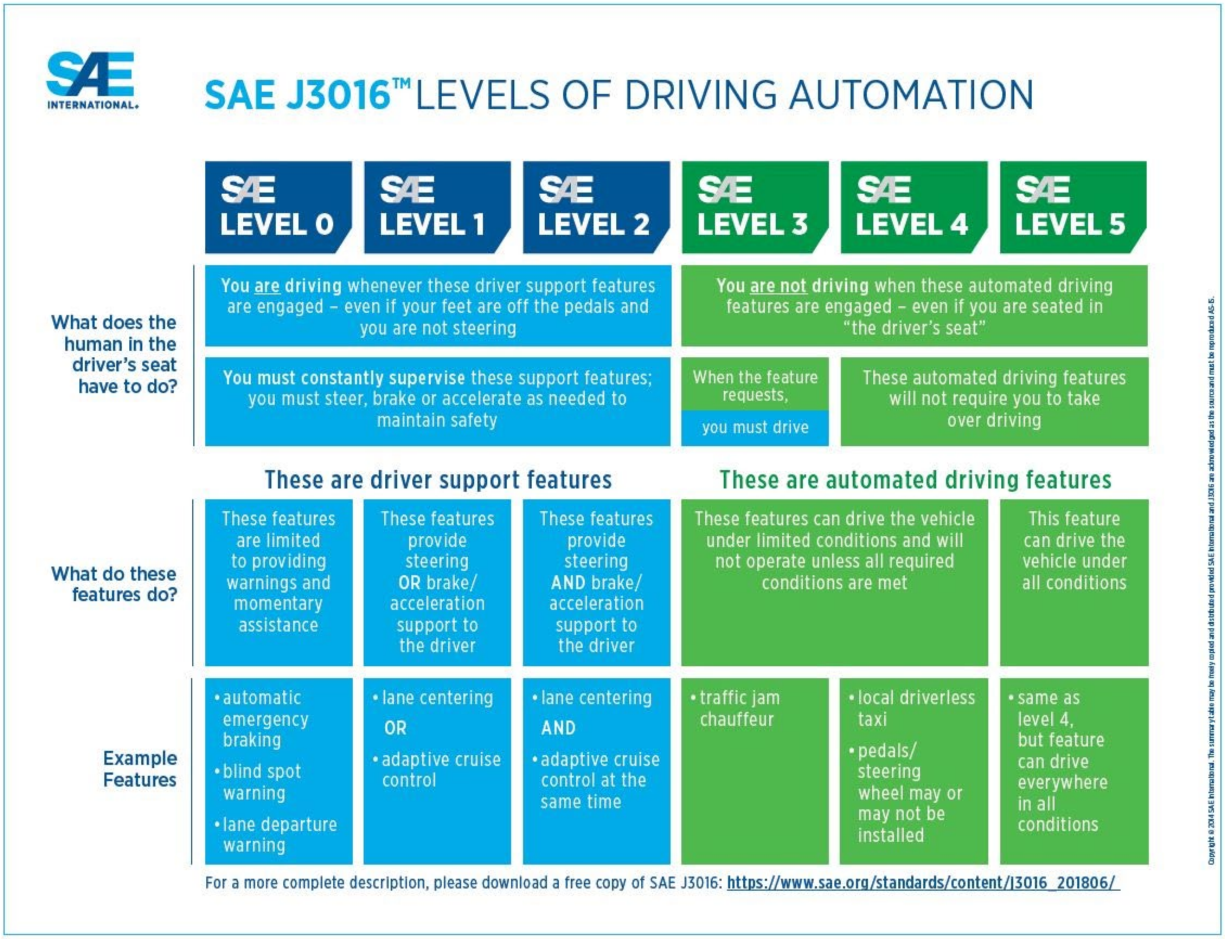

Figure 1. SAE Levels of Automation (Shuttleworth, 2019).

Commercially Available Vehicle Capabilities and Limitations

At present, several commercially available vehicles are equipped with driver support systems that include lateral and longitudinal control features. A table of makes and models that feature some type of lateral and longitudinal automation is included as Appendix A. The list includes annotations for vehicles that have the option to come factory equipped with the capability of automating portions of lateral control and/or longitudinal control (lateral: lane centering or lane keeping; longitudinal: ACC). Either ACC or lane centering alone would classify a vehicle as SAE Level 1 based on the taxonomy defined in **Figure 1**.

Among vehicle information surveyed, 39 vehicles included the option for both sustained lateral support (lane centering) and ACC capabilities. When both of these features are activated at the same time, these 39 vehicle models can be considered to operate at SAE Level 2 (**Figure 1**). This level of automation is considered partial driving automation, and still requires the user to be receptive to objects and events in the driving environment and to act as the fallback-ready user. At present, no commercially available vehicles would be considered to operate at SAE Level 3 or above.

As noted, the feature capabilities (especially of lateral features) vary widely among both vehicle makes and models. Thirty-nine of the driver support features describe their lateral assistance as "lane centering assist (LCA)," as opposed to "lane keeping assist (LKA)." Generally, vehicles that are equipped with LCA have higher functional capabilities. LCA automated systems operate continuously; they are typically able to steer around curves in the roadway, actively center the vehicle in the lane of travel, and are generally able to operate in a wider set of conditions and speed ranges. LKA systems, by contrast, often cannot handle road curves (or at least not to the level of LCA systems), and LKA systems only provide a corrective action if the vehicle is about to depart the lane, rather than make continuous corrections to keep it centered within the lane of travel.

Indirect Sources of Driver Understanding and Expectation

Although more and more vehicles with driver support are becoming available, the technology is still emerging. Unless employed in fields related to vehicle research, manufacture, or design, most individuals are likely unfamiliar with some of the levels of automation shown in **Figure 1**, and may only be aware of the presence of driver support in a vehicle once they drive it. A driver's primary source of information about these limitations should be the vehicle owner's manual. However, it is not known how often drivers read their owner's manuals. A *New York Times* article (Taub, 2016) indicates that OEMs are distributing some or all of the information in the owner's manual using electronic means, such as putting owner's manuals on the internet, providing them via smartphone or tablet applications, or even via video displays within the vehicle.

Manufacturers may be moving toward electronic dissemination of owner's manuals, but there are many sources of information already on the internet that are not provided by OEMs, and some of this information is directly contrary to limitations that are described in owner manuals. More than one internet article refers to the Tesla Autopilot system as "self-driving" (Boudette, 2017; Greenemeier, 2017; Stewart, 2017), a term which alludes to driver disengagement and does not readily align with the definition of Level 2 capable systems. Additionally, a search of YouTube with the keywords "Tesla Autopilot" returns about 204,000 results. Many of these videos are vehicle reviews or other demonstrations of the Autopilot feature that likely fit within the limitations described by Tesla (it should be noted that the vast majority of published videos are not provided by Tesla). However, within the first page of results there are also a number of videos showing drivers who may have unrealistic expectations of the capabilities of automated systems and who are clearly not following the warnings about the systems' limitations. In some cases, the behaviors are particularly egregious; one video in particular shows the driver playing cards while the system is engaged (Jukin Media, 2016).

Although the Jukin Media video was produced for entertainment purposes and not intended as a training or review video, it provides a clear depiction of a driver disengaging from the driving task while the driver support features are active. It is entirely possible that this video and others like it may lead viewers to have similar unrealistic expectations about vehicle capabilities. Furthermore, although Tesla's automated features may be among the most publicized, other manufacturers also offer vehicles equipped with driver support features for purchase. It is possible that drivers may assume that all driver support features have similar features and capabilities, when, in fact, the capabilities of features can vary widely.

Literature Review

The first part of the introduction provided an overview of indirect sources of information that may influence how a driver expects an automated system to operate before actually experiencing it. Expectations will change again after direct experience with the system. More specifically, once drivers use a system, their indirect expectations may be exceeded, met, or not met, and this experience will change the way they learn about and then use the system. Once the driver has established a relatively stable set of expectations with a system, the driver's overall level of expectation could be described as trust or reliance on the system. There is a broad body of literature about trust in automation (e.g., Parasuraman & Riley, 1997), which will not be reviewed here. The general conclusion from research on trust in automation from domains other than vehicle automation is that systems should be designed for "appropriate reliance" (e.g., Lee & See, 2004), meaning that a system's capabilities and limitations are clear and apparent to the user such that they can form congruent expectations about how the system operates.

The topic of trust in regard to surface vehicle automation is an active area of research. Trimble, Bishop, Morgan, and Blanco (2014) conducted a broad literature review of research and policy critical to Level 2 and Level 3 driving automation development as part of a previous National Highway Traffic Safety Administration study. The present review is intended to supplement previous work by focusing on research that studied expectations in the domain of highway transportation, either through instruction, or by varying the capabilities or reliability of an automated system.

Driver Expectations for Advanced Driver Assistance Systems

Control System Performance and Limitations

This section is a review of the published literature examining drivers' expectations and trust of advanced driver assistance systems and their subsequent behavior or performance related to system control errors, limitations, or imperfections. The findings are categorized by system capabilities, with research testing driver support features (both longitudinal and lateral control features) presented separately from work that studied individual control features (lateral or longitudinal control separately).

Research on Driver Support Features

In a review, Stanton and Young (1998) summarized findings from three early simulator studies of ACC and active steering systems and generalized three major findings. First, in a driving simulator, automated longitudinal and latitudinal systems demonstrated higher consistency in control of the simulated vehicle (lower variability in speed, lane position, etc.) compared to manual control. Second, drivers reported decreases in overall workload when lateral and longitudinal support were active. Third, when failures were implemented in studies with ACC, 40 percent of drivers were unable to intervene in time to avoid crashes with the simulated vehicle. This suggests that there may be a tendency for overreliance when drivers experience a system that is generally reliable but can exceed capabilities in rare circumstances.

Gold, Körber, Hohenberger, Lechner, and Bengler (2015) used a driving simulator to study how drivers operated an ADAS system that was capable of longitudinal and lateral control, including maneuvers such as lane changes, when operated at highway speeds (under 120 km/h). This study assessed drivers' attitudes, such as trust, and intention toward the system in the course of the experiment and the variance in their eye gaze. Participants were provided instructions about the system's limits, including that the vehicle was unable to operate in specific situations, and that the simulated vehicle would emit a warning signal and a request to intervene 7 seconds prior to an imminent crash scenario. The results showed that participants over 60 years old exhibited more positive overall ratings and higher levels of trust compared to younger participants under 30. Older drivers had higher gains in safety, higher intention to use the system, and were more willing to activate it. For all drivers in the study, driver discharge and safety gain decreased, while the self-reported trust rating increased. The experience of a crash following a request to intervene showed an effect on driver trust, as measured by a post-experiment questionnaire. Finally, although horizontal gaze deviations decreased over the experiment, which is a possible indication of an increase in reliance upon the system, the study did not find a statistically significant correlation between horizontal gaze behavior and self-reported ratings of trust (Gold et al., 2015).

Research on Individual Features

Itoh (2012) conducted a driving simulator experiment and observed two types of driver overreliance on an ACC system: (1) drivers who relied on the ACC system beyond its deceleration limit and (2) drivers who expected that the ACC system could decelerate against a stopped vehicle. The results suggest the existence of a "ripple effect" in which experience of an ACC system in previous conditions led to greater trust in higher complexity driving scenarios that were outside the system's defined performance capabilities. Itoh suggested that drivers' repeated observations of successful system control against stopping leading vehicles may be closely associated with the false expectation that ACC could decelerate against stopped leading vehicles.

Seppelt and Lee (2015) used modeling and simulation to assess driver interaction with ACC. The analysis indicated that ACC failures occurring during normal use in common driving scenarios may lead to crashes. The results of this study yielded multiple conclusions relating to driver expectations for vehicle automation. First, due to the limited time available to respond to ACC failures, drivers need to properly understand ACC and intervene prior to its failure. Experience and training with ACC allows drivers to anticipate ACC error situations based on correct expectations of how ACC changes the driving. Finally, peripheral and easily understood feedback about ACC behavior in different situations can help drivers develop accurate expectations.

A driving simulator study showed that a collision warning system that produces false or unnecessary alarms in non-critical events may limit the effectiveness of the system (Lees & Lee, 2007). The findings indicated that driving context and experience with false and/or unnecessary warnings could affect a driver's response to in-vehicle alerts and imminent crash scenarios. First, driving context can influence driver compliance with alarms. Drivers complied more with unnecessary alarms, which occurred in response to roadway events, than false alarms, which had no discernible potential threat. Second, drivers receiving unnecessary alarms more often in non-critical events braked more often and exhibited larger reductions in vehicle speed in response to unnecessary alarms compared to drivers who experienced false alarms. Therefore, the authors suggested that expectations about crash warning systems can influence how drivers respond to accurate warnings. Drivers complied more if they had experienced unnecessary alarms under a non-critical scenario compared to the experience with false alarms. Results also showed that drivers trusted a system with a lot of unnecessary alarms as much as they trusted a system consisting only of true alerts. False alarms, however, diminished drivers' trust. The study did not find an interaction between distracting tasks and types of crash warning systems (Lees & Lee, 2007).

Bliss and Acton (2003) conducted a simulator study examining the effectiveness of a collision avoidance warning system based on the rate of accurate alarms (50, 75, and 100%) and alarm location, either from the center console or from various locations about the cabin corresponding to the direction of the threat. Prior to the experiment, researchers provided participants with reliability information to establish appropriate and stable trust levels. The first experiment confirmed the association between lower reliability alarms and lower alarm reaction frequency and driving reaction appropriateness. The rate of collision with approaching vehicles of the 50 percent reliability group was significantly lower than that of the 100 percent reliability group. Drivers in the 50 percent group checked their rearview mirrors more deliberately before swerving to avoid a collision than those in 100 percent group. Moreover, participants in the 100 percent group seemed to swerve more carelessly as time progressed. In the second experiment, a spatially generated warning corresponding to threat direction replaced the console-located warning. The results of the second sessions also showed that there was a performance deficit in the 50 and 75 percent reliability groups, as those drivers responded to alarms less frequently and performed driving tasks less appropriately compared to the 100 percent group. Yet the rate of collision for the 50 percent group was lower than that of the 75 percent and 100 percent reliability groups. The findings regarding driver performance, including appropriateness of reaction and collision frequency, between alarms from the center console and spatial alarms were inconsistent.

Driver Expectation and Performance for System Specifications

This section is a review of research on driver expectations of and trust in driving automation systems, and consequent behavior or performance associated with system specifications (e.g., alarm timing), specific driving environments (e.g., traffic conditions), or specific instructions about system behavior. Again, the review is separated by capabilities.

Research on Driver Support Features

In a recent study, Banks and Stanton (2016) examined driver mental workload and trust in driver-initiated automation (automation that a driver can either accept or ignore) that would provide a combination of lateral and longitudinal control. A head-up display was used to present a request to intervene consisting of a visual warning and auditory warning. Participants were given instructions regarding the request specifying that a request to intervene did not represent an automation failure, but rather that the system was "struggling to maintain full functionality" (p. 2). The tests were conducted on a simulated highway at a steady speed of 70 mph. The results showed that drivers relied on the human-machine interface to determine if the system was operating under manual or automated driving, and the HMI itself led to driver confusion over the state of system. The authors found that the overall ratings of the drivers' mental workload were significantly higher in automated driving compared to manual driving, potentially related to confusion caused by the design of the HMI. Nearly one-quarter of drivers failed to regain control of the vehicle following the request to intervene, indicating that HMI design (including requests to intervene) can negatively impact driver performance.

Merat and Jamson (2009) used a driving simulator to compare driver response between manual driving and a driver support system (lateral and longitudinal automated). During the experiment, drivers were required to be receptive to objects and events on the road and respond to crash scenarios as they unfolded while traveling at 40 mph with a headway of 2 seconds to a leading vehicle. In imminent crash situations, drivers received an auditory alarm. The results showed that drivers' responses to critical events were slower with driver support features engaged. The majority of drivers braked after the auditory alarm during critical events in automated driving scenarios; however, researchers did not specifically examine whether the drivers deliberately avoided braking until they heard the alarm, relying on the automation, or if they reduced their receptivity to the driving scenario and therefore had reduced situational awareness. Overall, the study reported that drivers' subjective evaluation of the system was positive.

Merat, Jamson, Lai, Daly, and Carsten (2014) conducted a driving simulator study to examine automated driving system user performance following a request to intervene using a limited driving automation system intended to be a simulation of Level 3 automation. Two types of request were used. The first switched off automation and responding to the request required manual control at a regular interval. The second was based on the length of time users were not receptive to road conditions. Results indicated that overall better driver performance was associated with a request to intervene after a fixed automated duration of 6 minutes compared to when automation disengaged as a result of drivers' eyes being off the center of the road.

Carsten, Lai, Barnard, Jamson, and Merat (2012) examined drivers' engagement during driving and willingness to engage in non-driving tasks under manual driving, with either longitudinal or lateral automation present, or with both longitudinal and lateral automation using a driving simulator. The systems used in the experiment were designed to be reliable (e.g., surprise failures were not tested) and were designed to maintain lane position. First, the study found that drivers responded differently to longitudinal and lateral automation. Lateral automation alone was more likely to be relied on than longitudinal support alone. Drivers were less attentive to the road and traffic with lateral control compared to longitudinal control. Second, there was a tendency for drivers to shift glances away from the center to the left region of the roadway as the level of automation increased. Drivers in the lateral control group appeared to make this shift earlier than drivers in the longitudinal control group. Drivers were more willing to engage in non-driving tasks as the automation capability increased, but the effects of automation level and secondary task on driver performance (such as response times to alerts or crash scenarios) were not a primary focus of this study.

Research on Individual Features

Beggiato and Krems (2013) used a driving simulator to investigate the effect of preliminary ACC reliability on participant trust, acceptance, and mental model evolvement. Three descriptions of an ACC system were presented to participants: a correct description, an incomplete and idealized explanation without potential system failures, and an incorrect characterization including problems that would not happen. The results showed a clear distinction between groups that read different descriptions. Participants reported differences in initial expectations, with their incorrect mental models converging with the actual functionality of the system with experience. The results also showed that drivers monitored the ACC system less after they used the system for a long period, and that initial information had an enduring effect on participants' trust and acceptance of the system. Although the results showed that participants who received incorrect information about the system performance eventually formed a realistic understanding of the system, more cognitive effort was required, and drivers also reported lower trust and acceptance compared to drivers who had received correct information.

In a driving simulator study, Abe and Richardson (2005) investigated the effect of three alarm timings — early alarms, late alarms, and no alarms — for a forward collision warning system in low-speed driving scenarios (30 mph) under two imminent collision situations consisting of high (0.8 g) and low (0.4 g) decelerations of a leading vehicle. The study concluded that, in the low-deceleration situation, the difference in alarm presentations did not affect driver braking reaction time. In the high deceleration situation, early alarms were shown to reduce braking reaction time and its variation. Trust in early alarms was higher than trust in the late timing, although braking reaction time did not change. Drivers who experienced late alarms tended to begin braking before the alarm was presented. In a follow-up driving simulator study conducted by Abe and Richardson (2006), relatively early and late alarm timings were tested with three speed variables (40, 60, and 70 mph) and time headways ranging from 1.7 to 2.2 seconds. The authors concluded that driver performance was dependent on time headways. Particularly under long time headways scenarios, drivers' reactions to late alarms were associated with a delayed braking response compared to the "no alarm" condition. Driver trust in late alarms was lower than trust in early alarms, and a positive correlation between alarm promptness and driver's trust was found, although trust interacted with different headway conditions.

Summary

The literature review was intentionally focused on previous work related to expectation formation that would be relevant for the current project. Furthermore, although there is a long history of research on automation and trust, the body of work investigating expectations and trust development for driver support systems is still relatively limited. The majority of studies reviewed studied longitudinal support (i.e., ACC) systems alone, and did not include lateral support. Within the reviewed literature, there were multiple studies that collected self-reported measures to understand driver trust; however, this was often not the focus of the research. Nevertheless, insights applicable to the current project were gained, including evidence supporting the expected manipulation of driver expectations using instructions about vehicle capabilities.

Many specific characteristics of Level 2 driving automation systems were not included in the design or research questions of the current study (alarm/alert timings, ACC reliability, and forward collision warning alerts/capabilities). Alarm timings would fall under vehicle HMI design, which was outside the scope of the project. Given the existing body of work on longitudinal capabilities, the overall reliability of the ACC system was fixed in this work. Vehicle capabilities were only varied in the lateral automation system.

Overall, it appears that there is a ripe environment for overreliance on driver support systems. There is a wide selection of vehicles with different capabilities, an abundance of potential misinformation, and a trend seen in the research for drivers to over-rely on support features when present (as measured by both trust ratings and driving performance). While the present study administered a subjective trust rating to drivers, the primary dependent measures used to assess driver acceptance and trust were those associated with driver reliance on the automated features, such as drivers removing their hands from the steering wheel when lateral control features were active, and driver engagement variables, such as eyes on road time while lateral features were active.

Understanding the interactions among driver engagement, driver expectations, and vehicle capabilities is a critically needed contribution to the safe deployment of vehicles equipped with L2 driving automation systems. During the experiment described herein, participants operated a vehicle equipped with both lateral and longitudinal driver support features on both real public roadways and on a test track (the Virginia Smart Road). This combination of real road and test track experimentation allowed for the opportunity to examine use in a real-world setting as well as during specific, controlled tests. Driving the vehicle on real roadways provided realistic data on driver expectations, as drivers experienced the real-world limitations of the automated systems (e.g., how the conditions of lane markings affected system function), improving the generalizability of the study results.

The study vehicle was a 2015 Infiniti Q50 with customized capabilities developed at VTTI. This vehicle was configured to operate with low and high lateral capabilities to evaluate how drivers responded to and engaged with each. Drivers received training that was either congruent or incongruent with the vehicle’s capabilities. This latter manipulation created situations where the vehicle capabilities did not match drivers’ expectations. **Figure 2** shows a sample testing procedure for one participant who received training for a low capability vehicle, but then experienced a vehicle with higher capabilities.

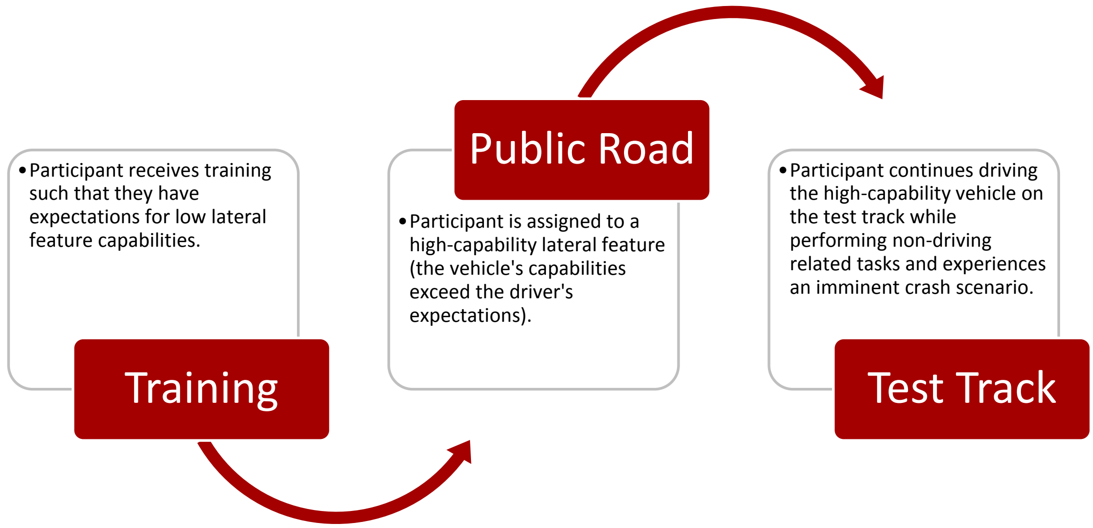

Figure 2. Example Testing Procedure for One Participant Assigned to the Low-Training/High-Capability Condition.

Research Questions

The approach described in the following chapter was designed to address the following research questions. The research questions were formulated to address the impact of both driver expectations and support capability on driver engagement and driver performance.

- **RQ1 (Driver Response and Expectation)**: Does driver response to avoid an imminent crash differ based on expectations for encountering safety critical system errors in automated lateral and longitudinal (mixed function) control?
- **RQ2 (Non-Driving Task Engagement)**: What are the effects of engaging in non-driving (secondary) tasks when responding to an imminent crash scenario that is caused by lateral and longitudinal system control errors?
- **RQ3 (Driver Response I)**: How do driver responses compare across different performance and reliability levels of driver support features?
- **RQ4 (Driver Engagement)**: How is engagement mediated by driver expectations for system errors/failures, type of secondary task, and imminent crash scenario?
- **RQ5 (Driver Acceptance and Trust)**: What are the effects on user acceptance and trust when drivers encounter critical system errors/failures? How resilient or enduring are the effects of expectations on acceptance and trust?
- **RQ6 (Crash Potential)**: Are crashes more likely with increased system performance and reliability?
- **RQ7 (Driver Response II)**: Do drivers respond faster to crash imminent events when they have a higher expectation for system performance and reliability?
- **RQ8 (Acceptable Driver Engagement Threshold)**: Can an acceptable driver engagement threshold that is relative to driver expectations be established from this study?

2. RESEARCH METHODS

Design

The design was a 4×2×6×3 mixed design. Training, which was used to set participant expectations (see Participants section in this chapter), and capability (see Vehicle section in this chapter) were combined into a four-condition between-subject factor. As shown in Table 1, the between-subject factors included two congruent conditions, where the training matched the capabilities of the vehicle, and two incongruent conditions, where the training set expectations above or below the capabilities of the vehicle.

Table 1. Training and Capability Levels

Training	Capability	
	High	**Low**
High	High-High (Congruent)	High-Low (Incongruent)
Low	Low-High (Incongruent)	Low-Low (Congruent)

Additionally, there were two types of crash-imminent scenarios: lateral failure and longitudinal failure. Participants were asked to repeat a series of three non-driving related tasks as a within-subject factor: (1) texting, visual-manual; (2) watching video, visual alone; and (3) baseline, no non-driving task in one of six counterbalanced orders. The six orders, varied between subjects, and included all possible combinations of the three task types. In total, participants were asked to perform each type of non-driving task 4 times across 12 trials. The design and method of training used to set participant expectations were tested as part of study development (Phase I of the project). The green cells in Table 2 show the conditions that were collected as part of Phase I. All conditions, including those shown in green, were collected as part of the Phase II effort.

The instructions issued to participants were to complete the tasks as they felt comfortable. (See Appendix B for task instructions). For example, during the texting task, an experimenter sent a text message to the participant with instructions to respond when they felt comfortable doing so; this exchange was repeated one additional time during the trial as time permitted. The purpose of administering non-driving tasks was to measure participants' willingness to engage in non-driving tasks, their types of engagement behaviors while performing these tasks, and to further explore potential instances of primary task reversal, where drivers focus on a non-driving task as the primary task at the expense of driving (Blanco et al., 2015). This approach allowed participants to engage as they felt comfortable rather than "forcing" drivers to become distracted by instructing them to complete tasks under the specific cue from the experimenter. Table 2 shows the distribution of participants across expectation-capability combinations, crash-imminent scenarios, task orders, and age groups for Phase I (dark grey cells) and Phase II.

Again, training and feature capability were crossed to create a four-condition, between-subjects factor. This manipulation was necessary to determine the overall relationship between driver expectations and vehicle capabilities, and how both potentially affect automated system use, driver responses to error events, subjective questionnaire responses, and non-driving-related task engagement. This design also allowed for between-subjects comparisons when expectations of feature capability were aligned with the feature's actual capabilities, as well as when expectations differed from feature capabilities (i.e., when they were incongruent).

Table 2. Overview of the Experimental Design and Participant Allocation for the Study

Task Orders	Crash Imminent Scenario	Expectation-Capability Combinations								Participants Per Combination
		Low-Low		Low-High		High-Low		High-High		
		Age Group		Age Group		Age Group		Age Group		
		Younger	Older	Younger	Older	Younger	Older	Younger	Older	
TO-1	Depart	1	1	1	1	1	1	1	1	8
TO-1	Reveal	1	1	1	1	1	1	1	1	8
TO-2	Depart	1	1	1	1	1	1	1	1	8
TO-2	Reveal	1	1	1	1	1	1	1	1	8
TO-3	Depart	1	1	1	1	1	1	1	1	8
TO-3	Reveal	1	1	1	1	1	1	1	1	8
TO-4	Depart	1	1	1	1	1	1	1	1	8
TO-4	Reveal	1	1	1	1	1	1	1	1	8
TO-5	Depart	1	1	1	1	1	1	1	1	8
TO-5	Reveal	1	1	1	1	1	1	1	1	8
TO-6	Depart	1	1	1	1	1	1	1	1	8
TO-6	Reveal	1	1	1	1	1	1	1	1	8
								Total Phase 1		**16**
								Total Phase 2		**96**
								Grand Total		**112**

Vehicle

The vehicle used for this study was a 2015 Infiniti Q50 with customizable lateral control capabilities. The Q50 was configured by VTTI to operate at different capability levels (low and high). The two capability levels were designed to mimic commercially available lateral and longitudinal control features, respectively lane keeping and ACC. Capabilities were reviewed with both NHTSA and the stakeholder group prior to implementation. The stakeholder group included representatives from OEMs (General Motors, Nissan, Volkswagen North America), Tier 1 suppliers (Bosch, Continental), as well as other regulatory agencies (Transport Canada). This review was conducted as part of Phase I of the research project to ensure that the method for mimicking commercially available lateral control was effective, as well as to further refine the overall experimental design and approach.

The vehicle included a factory-equipped longitudinal control feature (implemented as ACC in the present study). Although the vehicle was capable of both lateral and longitudinal control, only the lateral support systems were modified for the study. Longitudinal capabilities remained unchanged between feature capability conditions. There were multiple reasons for this decision. First, the type of longitudinal capabilities implemented in this study (i.e., ACC) have been studied in previous work. Furthermore, capabilities are quite similar across all commercially available ACC implementations.

The vehicle lateral capability levels were combined into two categories: high and low. In the high condition, the centerline sensing was provided directly to the control system similar to production lateral driving support features that center within the lane of travel. In the low condition, the machine vision roadway centerline output was modified with a sine wave disturbance, which was then input into the VTTI-developed vehicle control system. The control system then steered to adjust to this modified signal (it should be noted that production systems do not operate in this fashion). Both levels had the same torque authority. General descriptions of the lateral system capability levels are as follows:

- <u>Low-Capability Lateral Control Assistance Feature</u>: The automated feature is not a Level 1 feature because it needs intervention from the driver often. The automated system can track straight sections of road with little problem; however, the automated system will steer back and forth between the left and right lane marking (i.e., “ping pong”) in the lane periodically. The system is unable to navigate curves without assistance from the driver.

- <u>High-Capability Lateral Control Assistance Feature</u>: In limited cases the system may need intervention from the driver. The vehicle continuously centers in the lane during straight sections of road, but may exhibit a lane departure in rare cases (e.g., lane markings obscured/degraded). The system can navigate most curves without assistance from the driver.

Activation of the automated features was under the control of the in-vehicle experimenter, with an in-vehicle display to notify the driver that features were active. Taking into account that the vehicle interface and displays may play a significant role in how participants respond to alerts or system errors, the study vehicle interface was designed to be a simplified representation of driver support feature interfaces currently available on the market. As shown in **Figure 3**, the study vehicle was equipped with a multi-modal automated state display that appeared in the center console. **Figure 4** shows a view of the automated state display. An “A” in a circle was displayed when the driver support system was active, and the system also included both a voice instruction (“automated systems activating”) and an additional auditory cue when the systems activated and deactivated. This multimodal display was constant across all conditions in the experiment.

Figure 3. Center Console of the Test Vehicle, With the Automated State Display Circled in Red.

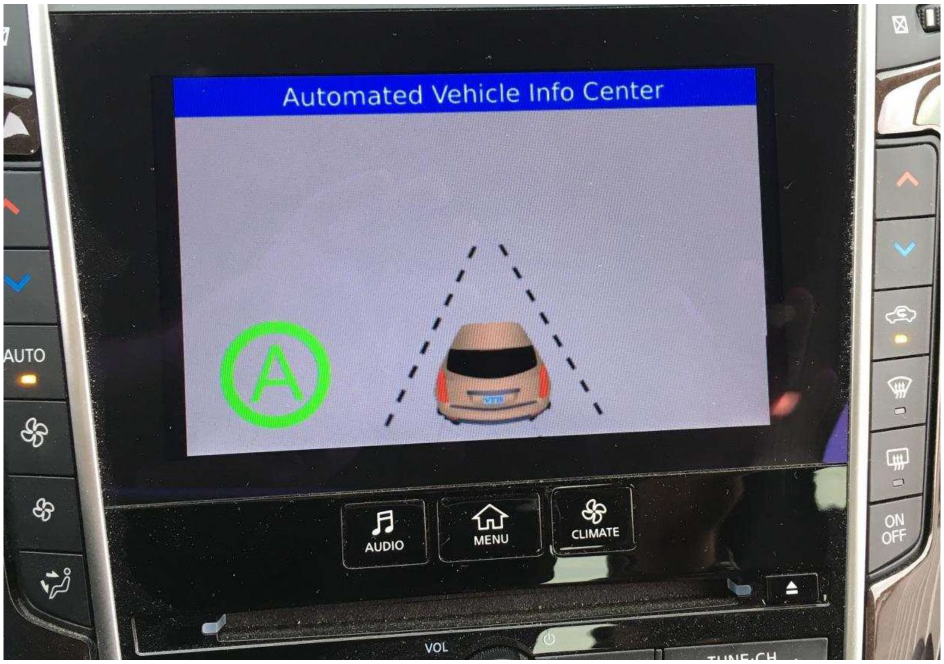

Figure 4. Automated State Display; the Green "A" Symbol Indicated That Automation Was Active.

The lateral support system functioned as shared control with the driver. When engaged, the driver was able to steer "with" the system and override as they saw fit to make corrections within the lane; these corrections did not cancel the feature. Activating the turn signal suspended the feature so that a lane change or passing maneuver could be conducted. Both features could also be disengaged and/or overridden by the participant after they had been activated. Pressing the brake pedal disengaged both features. The longitudinal feature could be temporarily overridden with the accelerator pedal. The steering wheel included a capacitive sensor to detect when the driver's hands were on the steering wheel (i.e., "hands-on-wheel behavior"). As long as one hand was on the steering wheel, the data acquisition system (DAS) recorded that hands were on the wheel (see DAS section below). Hands on the steering wheel was not a requirement for the lateral control system to remain active nor was there any request to intervene alert associated with a driver's hands off the steering wheel for any length of time.

Steps were taken to ensure that the study vehicle was operated safely, even if a participant chose to remove their hands from the steering wheel. **Figure 5** shows an example image of the "safety driver." The safety driver was present at all times during the experiment, and had access to a set of redundant mechanical controls (steering wheel and hand brake) that he or she operated from the rear seat. The safety driver would have been able to take over control of the study vehicle in the event of an unanticipated system action, the failure of a participant to respond to the surprise event, or in response to any similar event that may have occurred. A shroud was installed (not pictured) over the rear seat steering wheel such that the secondary controls were not visible to the participant from the driver's seat, nor was the specific purpose of the safety driver known to participants prior to the surprise event scenario. No unexpected events requiring safety driver intervention occurred as part of any testing conducted during the project.

Figure 5. Safety Driver Position With Rear Seat Steering Wheel.

DAS

The test vehicle was equipped with a DAS, which recorded high-definition video of the driver's face, the forward roadway, an over-the-shoulder view of the driver's hands and lap area (to verify driver hand position), and a view of the foot well (to identify foot position). **Figure 6** shows an example image captured by the DAS. The DAS also recorded speed, driver hands on steering wheel behavior, accelerator pedal position, brake application, acceleration, lane position, turn signal activation, and GPS coordinates. In addition, the DAS recorded data from the vehicle network indicating the level of control system activation. All video, vehicle, and parametric data were time synchronized by the DAS.

Figure 6. High-definition Snapshots of Videos Recorded by the DAS.

Test Route and Facilities

Data collection included two parts: a public road driving portion and a test track driving portion. During the public road drive, system limitations restricted the use of support features, as some road curves were outside of the capabilities of the system (i.e., the curve exceeded the torque authority of the system). During these instances, the experimenter disengaged the lateral feature temporarily, and re-engaged it at the next opportunity. Note that this limitation is similar to commercially available lateral support systems. The test route is included in **Figure 7**. This route was designed to include system use on closed access highways, and divided multi-lane roadways (representative of OEM guidance for feature use). Automation was not engaged on entrance ramps, or in the limited town/urban areas where stoplights were present. The total route was 36 miles (18 miles each way) and was a total drive time of approximately 45 minutes.

The test track portion was conducted on the Virginia Smart Road (**Figure 8**). The Smart Road is a 2.2-mile closed test course where safely controlled crash imminent scenarios can be studied.

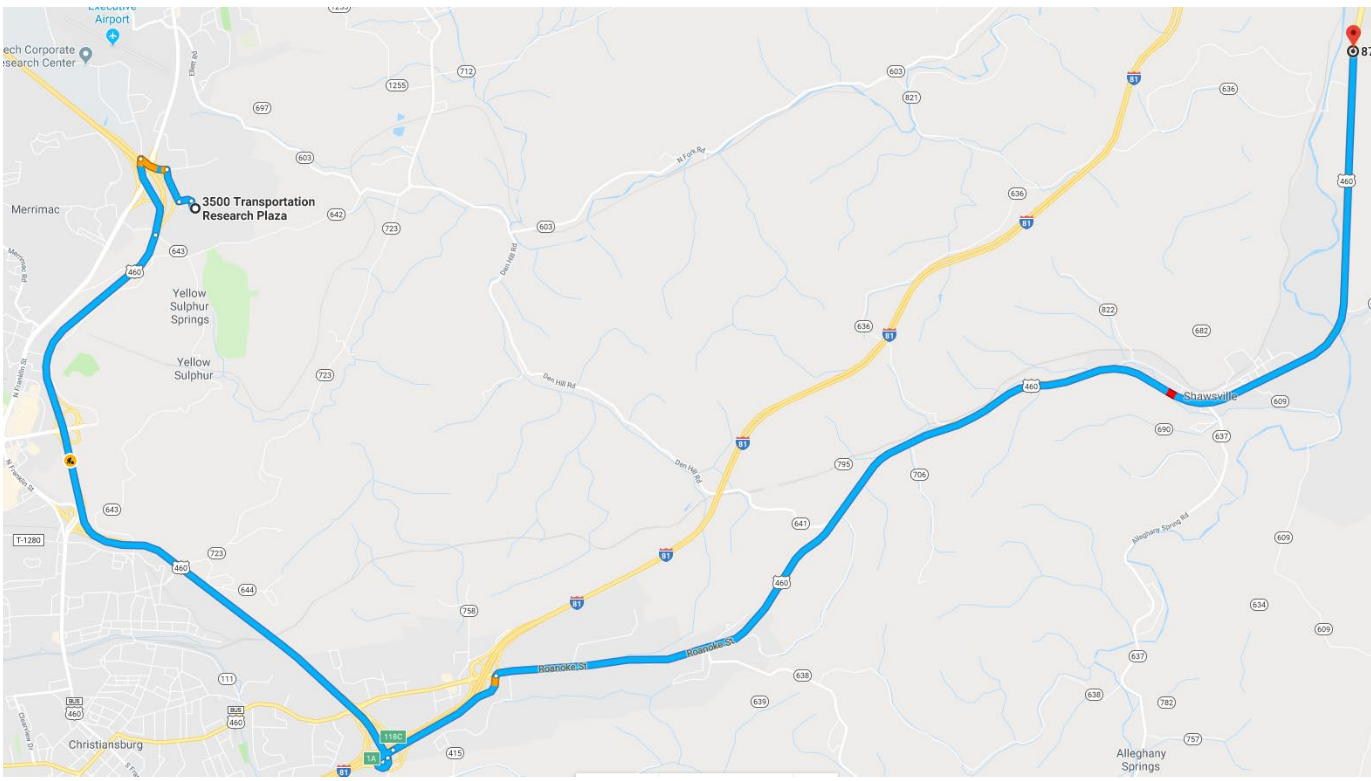

Figure 7. Test Route Including Highway, Rural, and Town/Urban Driving.

Figure 8. Virginia Smart Road.

Participants

All data collection procedures described in the report were approved by the Internal Review Board at Virginia Polytechnic and State University (Virginia Tech). As such, all participants underwent an informed consent process, including debrief and re-consent after experiencing the surprise event. A total of 96 participants are included in the final data set. All participants were recruited from the Blacksburg, Virginia, area. Participation time was approximately 4 hours per participant. All participants were compensated at the rate of $120 for full participation. An equal number of males and females were recruited from two age groups: 24 to 39 (48 participants with an average age of 30) and 40 to 54 (48 participants with an average age of 46).

Participants were asked to complete a general demographic questionnaire (included in Appendix D). All participants had been daily smartphone users for 3 years or more, reporting performance of a variety of daily smartphone tasks (photos, texting, gaming, etc.). As part of this questionnaire, participants were asked to self-report whether or not they performed non-driving tasks while driving—47 of 48 younger and 40 of 48 older drivers reported doing at least some type of non-driving task while driving at least monthly.

Participants were asked whether or not they had any experience with driver assistance features. Slightly less than half of drivers (24 older and 21 younger) reported some experience with crash warning systems. Fourteen younger drivers and 19 older drivers had driven vehicles with ACC. Finally, 14 younger and 14 older drivers reported driving vehicles with some type of lateral driver support feature.

Participant Training

Participant training was manipulated in order to provide a source of information to set participant expectations prior to driving the study vehicle for the first time. This manipulation was necessary because it was critical that participant expectations were not confounded with the vehicle capabilities. Training was conducted in two parts: computer-based training and vehicle orientation.

Computer-based training consisted of a video-based presentation outlining the overall vehicle features, including descriptions of the driver support systems. The presentation consisted of a narrative explanation about vehicle functions, including climate control, seat adjustment, and so on. The computer-based training also included an overview of the lateral and longitudinal feature capabilities. Two different training packages were used (i.e., one for high- and one for low capability), in which the lateral features were described as lane keeping or lane centering. Specific language used in the training is included below, with emphasis added here in sections to note differences between the two training modules.

Low-Capability Training

In this vehicle, the lateral control features are the lane keeping features. This means that when active, the vehicle will perform slight steering corrections to help keep you within the travel lane, although you will likely need to intervene while it is active.

Using a camera located in front of the inside rearview mirror, this system detects the lane markers on the traveling lane, and road curvature information and then provides small steering force and angle adjustments to help the driver maintain the forward path. When this occurs, you may experience a slight movement in the steering wheel.

Activating the turn signal will temporarily suspend the automation so that a turn or lane change can be conducted. If at any point you wish to cancel the features, you can press the brake pedal to de-activate both the lateral and longitudinal features.

Based on our testing and experience, the feature may encounter difficulties while navigating curves that we encounter during highway driving, and may experience problems with lane keeping if we travel through an area where lane markings are degraded.

High Capability Training

In this vehicle, the lateral control features are the lane centering features. This means that when active, the vehicle will perform steering corrections to help keep you centered within the travel lane, although you may need to intervene in rare circumstances.

Using a camera located in front of the inside rearview mirror, this system detects the lane markers on the traveling lane and road curvature information and then provides small steering force and angle adjustments to help the driver maintain a straight path and reduce fatigue. When this occurs, you may experience a slight movement in the steering wheel.

Activating the turn signal will temporarily suspend the automation so that a turn or lane change can be conducted. If at any point you wish to cancel the features, you can press the brake pedal to de-activate both the lateral and longitudinal control features.

Based on our testing and experience, the feature will handle most curves that we encounter during highway driving, and should only experience problems with lane centering if we travel through an area where lane markings are degraded.

In addition to the computer-based training, a vehicle orientation was conducted. This orientation was intended to approximate what a participant might experience at a dealership if they were to purchase a vehicle. The vehicle orientation included a review of basic vehicle controls (mirror adjustment, seat adjustment, climate controls, etc.). The orientation also included a verbal description of the driver support systems to reinforce the computer-based training.

After completing the vehicle orientation, participants then began an initial test drive without any features active so that they could become familiar with the vehicle prior to the beginning of testing. A short test drive with both driver support features active was then conducted prior to beginning the public road portion of the study.

Non-Driving Tasks

Table 3 shows the non-driving task types that were used for the study, along with the distraction type and expected level of engagement. Care was taken in selecting appropriate non-driving tasks during the study. Of interest was how participant willingness to engage in non-driving tasks varied based on both expectation and feature capability, and how this compared to baseline driving (no tasks) under the same conditions. The handheld used was a Samsung Galaxy S5 smartphone cradled in a dashboard mount. Participants were free to leave the phone in the cradle or remove it as they saw fit (including placing it in the cup holder if desired).

For the texting task, an experimenter sent a text message to participants while they were driving on the test track with driver support systems engaged. The participant then used the phone to respond to the message. For the video task, once driver support systems were active, participants used the phone to select a video of their choice from the video library. Appendix C includes instructions for each task, including the specific text messages initially sent to participants.

Table 3. Non-Driving Tasks With Anticipated Driver Engagement Levels

Task Type	Description	Distraction Type
Texting	Respond to a text message sent by experimenter	Visual and manual
Watching video	Select and watch a video on handheld device	Visual; limited manual
Baseline	Driving without other tasks	N/A

Procedures

Upon arrival at the research facility, participants were greeted by the experimenter, underwent voluntary consent procedures, and then underwent basic vision and hearing tests. Participants then completed a short demographic questionnaire, as well as a questionnaire to assess their anticipated trust with assistive features in vehicles. Participants reviewed training materials that described the vehicle features, including how the support features worked, their overall capability level, and expected limitations. As part of the experimental design (discussed above), the training materials were either congruent or incongruent with the vehicle features.

Participants were then escorted to the vehicle to begin vehicle orientation. Basic features of the vehicle (mirrors, climate controls, seat adjustment, etc.) were explained to each participant. Verbal instructions consistent with previously reviewed training materials were administered. The safety driver was present in the study vehicle, as was the experimenter. A shroud covered the safety driver's rear steering wheel, and the presence of the redundant these controls was not explained to the participant until after the surprise event (see below). Two other confederate vehicles were present, driven by trained personnel, to act as leading and following vehicles while on public roads and to set up the surprise event on the test track (see below).

After completing the vehicle orientation, participants went for a short test drive, following the lead confederate vehicle. The first section of the test drive included manual driving only, so that participants could become familiar with the vehicle. During the second half of the test drive, participants experienced the automated features, which were activated by the experimenter. After completing training, including the test drive, participants completed subjective questionnaires to estimate their perceived level of trust and expectations for the study vehicle.

Participants then began the public road portion of the study. The public road portion consisted of a set route designed to include conditions present during a typical commute, including both highway and town driving and some rural roads, with a distance of 36 miles (approximately 45 minutes). As mentioned above, confederate drivers were present to ensure that participants experienced surrounding traffic as consistently as possible, and to act as a safety buffer for other road users. The route for the public road drive is shown in **Figure 7**. The public road portion lasted approximately 45 minutes.

Once the public road drive was completed, participants completed another round of subjective questionnaires to estimate their overall level of trust and expectations prior to moving on to the test track portion of the study. Confederate drivers were present in order to carry out the surprise event scenarios safely. The orientation of the subject vehicle and confederate vehicles was adjusted such that each vehicle was in each position (e.g., lead, middle, following) an equal number of times but also so that the subject vehicle was always in the following position at trial 7 so that the surprise event could be executed (**Figure 9**).

The test track portion of the study was completed on the Virginia Smart Road at VTTI. Participants drove laps on the test track at 40 mph using ACC to maintain speed, with the experimenter activating the lateral support feature during each lap. Participants were asked to perform non-driving related tasks, which were administered in counterbalanced orders as a within-subject factor. Participants completed a total of 12 secondary task trials on the test track, one task each time the participant drove a length of the test track. While performing the secondary task on the seventh trial, participants experienced a crash imminent scenario (i.e., surprise event).

There were two imminent crash scenarios, both of which are diagrammed in **Figure 9**. The surprise event was a between-subjects factor, so participants only experienced one of these surprise events. One type of surprise event was a road departure event, (a lateral path error) in which the subject vehicle was maneuvered by the safety driver to straddle the right lane marking using the rear seat steering controls (left side of **Figure 9)**. The other surprise event type was a reveal event (a longitudinal path limitation), in which the lead confederate vehicle braked from 40 mph to 20 mph, with an average deceleration of -.6g, with the center vehicle swerving into the adjacent lane (right side of **Figure 9**). In both cases, these events occurred without any alerts from the vehicle's HMI.

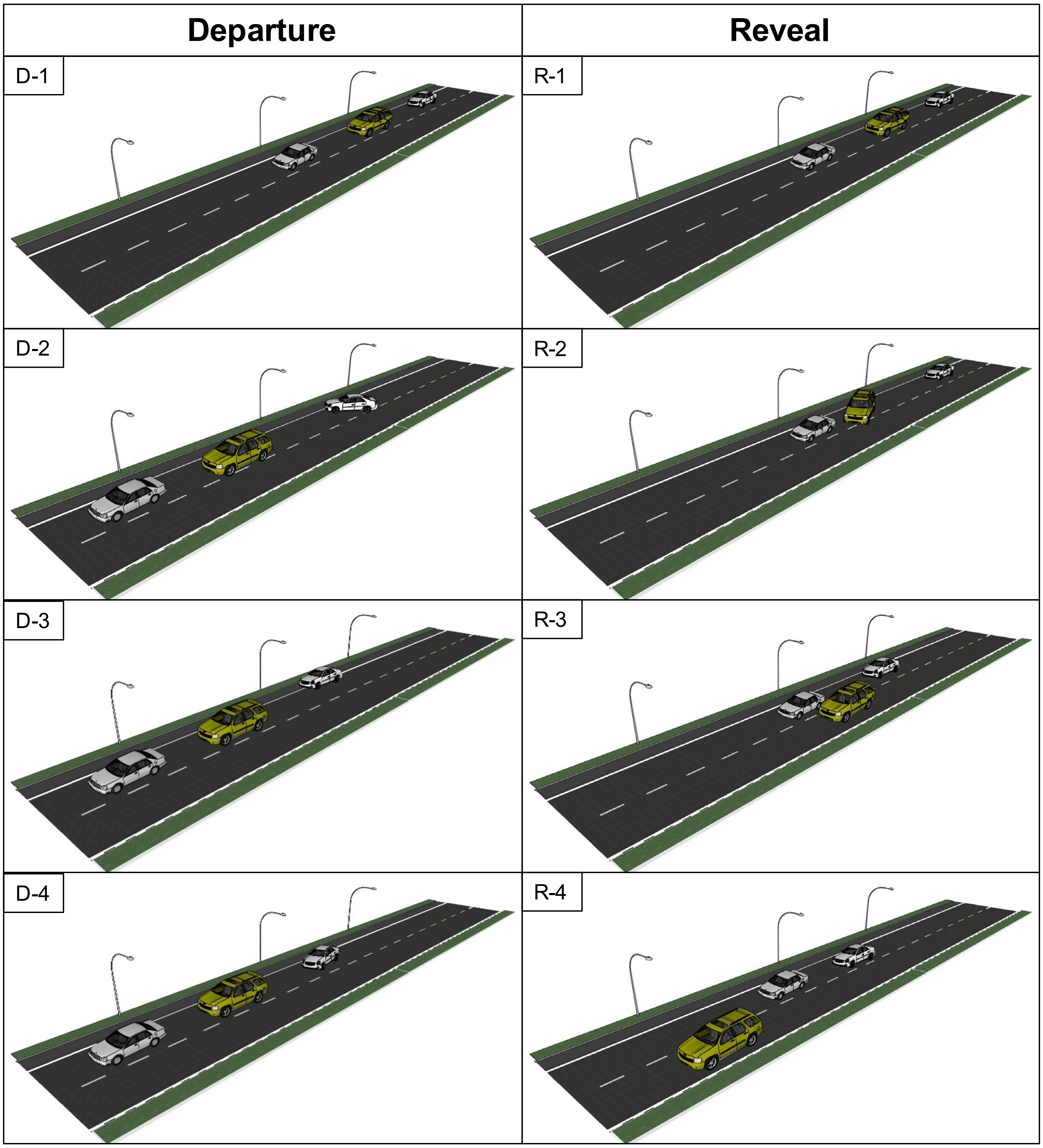

Figure 9. Diagrams for the Road Departure (Left) and Reveal (Right) Surprise Events; the Test Vehicle Is the Trailing Vehicle in Both Events.

After experiencing the surprise event, participants were asked if they consented to continue participation. All participants chose to continue in the study. Participants then completed a third round of subjective questionnaires. Afterwards, participants were asked to resume driving and continue for the remaining 5 trials (to reach the total of 12 trials) with the explicit understanding that the experiment did not include another planned surprise event.

The design of the study accounted for possible effects from the sequence of non-driving tasks before the crash-imminent scenario by ensuring that each task was completed the same number of times before the surprise event occurred, and counterbalancing the order of tasks across participants. Each trial consisted of one half lap of the test track while performing the assigned non-driving task. Participants completed six trials (each non-driving task twice) prior to experiencing the crash imminent scenario. With this method, whichever task was performed during trial one was repeated for the third time on trial seven, when the surprise event occurred.

3. DATA SAMPLING AND REDUCTION

Measures

Table 4 shows the dependent measures that were collected and/or computed. These measures include recordings by the DAS installed in the test vehicle (described above), measures calculated from video reduction, and subjective measures. Also noted in Table 4 are the availability of measures by experimental scenario (public road and test track portions) and applicable research questions.

Table 4. Dependent Measures, Sources, and Applicable Research Questions

Dependent Measure	Source	Type	Public Roads	Test Track	Research Questions
Hands on steering wheel (yes or no and duration)	DAS and video analysis	Binary	Available	Available	1, 3, 4, 6, 7, 8
Brake activity (activation, release, hovering)	DAS and video analysis	Categorical	Available	Available	1, 3, 4, 6, 7, 8
Pedal activity (activation, release, hovering)	DAS and video analysis	Categorical	Available	Available	1, 3, 4, 6, 7, 8
Eye glance (eyes-off-road time, eyes on display time)	Video analysis	Continuous	Available	Available	1, 2, 3, 4, 6, 7, 8
Response time to surprise event	Video analysis	Continuous	N/A	Available	1, 3, 4, 6, 7, 8
Trust and acceptance levels	Subjective	Ordinal	Available	Available	5

Data Sampling

Several of the research questions required the sampling of certain instances of the participants' driving. Samples were taken from both the public road drive and during test track driving. For sampling purposes, an instance was defined as a block of 15 seconds in which the DAS was continuously active (activations). During the public road drive, the research team sampled the data by time; one activation was sampled within the first 15 minutes of driving, one in the second 15 minutes, and one in the last 15 minutes of the drive. During each trial on the test track, one sample was taken during each baseline and video trial. For video trials, the sample was taken after the video had been selected and playback began, such that the task was primarily visual; the only manual part of the task was holding the phone if the participant chose to do so.

Measures were sampled from text message trials based on the length of the task. The start of the task was when the participant was reaching for the phone. The participant then discernibly said "done" when they were finished, signifying the end of the task. All participants responded to at least one text message during texting trials; however, given the time to complete one lap of the

Smart Road, participants could send up to two messages during a lap. Each message was sampled separately.

Measures for the surprise event were sampled 10 seconds prior to the precipitating event for each scenario. For the reveal scenario, this was the first time-stamped video frame in which the slowed lead vehicle was visible in the forward camera. For the road departure, this was the first time-stamped video frame in which the subject vehicle began steering to the right, (as evidenced by vehicle motion or visible view of the steering wheel).

As described, each participant could have up to 19 samples—3 samples were taken during the public road portion, up to 8 samples were taken before the surprise event, 1 was taken during the surprise event trial, and up to 7 samples were taken after the surprise event.

Data Reduction

All analyses of video data took place in a secure data reduction lab at VTTI, and were carried out by trained data reductionists. The data reductionists used the recorded video and parametric data to identify the driver, vehicle, and environmental factors present during sampled events. Eye glance analyses were conducted on all samples taken. **Figure 10** shows the 15-second reduction window for driving samples from the public road portion of the study and for tasks conducted during the test track portion of the study.

Of particular interest for this study was hands on-wheel behavior observed during the samples. Hands on wheel time was computed during each sample, and converted to a percentage of time during each sample. It should be noted that the percentage of time with hands on wheel behavior was not normally distributed. That is, most participants either had their hands on the steering wheel during the entire sample or hands off the wheel during the entire sample. Therefore, hands off wheel data were categorized by dividing up the events into two groups: one with less than 50 percent of the time with hands off the steering wheel, and one with more than 50 percent of the time with hands off the steering wheel (see Chapter 4 for further details).

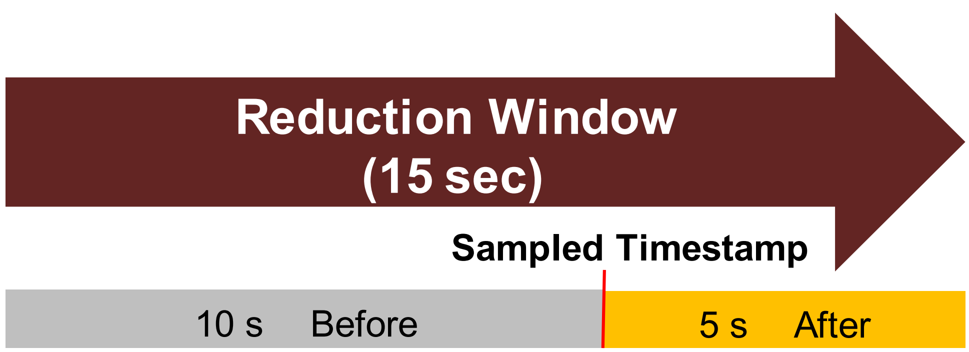

Figure 10. Time Window of Each Reduced Sample.

In addition to sampled tasks, reductionists recorded the series of actions taken by drivers in response to the surprise event. **Figure 11** shows the reduction window for surprise events. The precipitating event for the departure event was the onset of the steering input to the side of the road (tilted steering wheel, as shown in **Figure 12**; this corresponds to D-2 in **Figure 9**). The precipitating event for the reveal event was the first forward video frame in which the slowed vehicle was visible (**Figure 13**; this corresponds to R-2 in **Figure 9**). The following variables were recorded starting from the precipitating event: participant's first reaction and method of reaction (e.g., the driver's foot begins moving towards the brake pedal or hand moves towards the steering wheel), when the action was completed (e.g., braking, steering), and when the event had resolved.

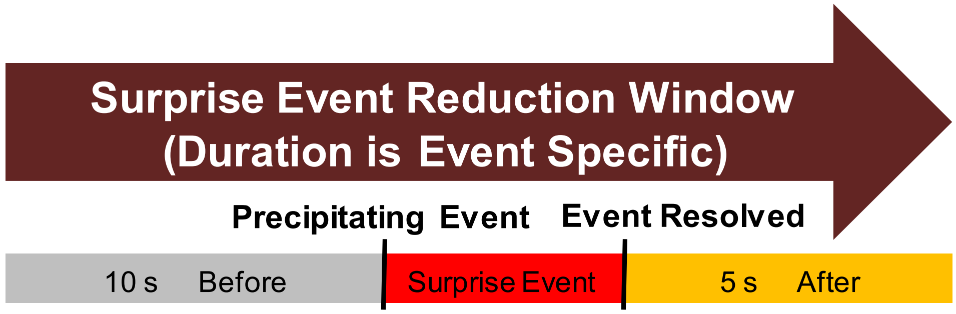

Figure 11. Reduction Window for Surprise Events.

Some participants did not react to the surprise event in typical fashion, (e.g., immediately reaching for the steering wheel or pressing the brake pedal). However, in nearly all of these cases the participant was attentive and monitoring how the systems would respond to the event, and in many cases already had their hands on the steering wheel. Given this variability in reaction types and times, the points of focus of the analyses in this report are the event resolution times. The resolution times for each event are defined separately. The departure event was considered resolved when the test vehicle returned to lane of travel (D-4 in **Figure 9)**. The reveal event was considered resolved when one of two conditions were met: the participant released the brake pedal or the ACC had slowed the system to match the speed of the slowed lead vehicle (both represented in R-4 in **Figure 9**). A third possible resolution for the reveal was included but did not occur: the participant could have steered the test vehicle into the adjacent lane around the slowed vehicle. As this resolution did not occur in any of the events, it is not pictured in Figure 9. These definitions were adapted from existing methods for describing crash and near crash events in naturalistic driving studies (L2 NDS; Russell et al., 2018).

Figure 12. Over-the-Shoulder Camera View Immediately Prior (Left) and at the Onset (Right) of the Departure Event. Note the Steering Wheel Angle Change (Circled in Red).

Figure 13*. Forward Camera View of the Reveal Event, the First Frame With the Slowed Lead Vehicle Visible (Circled in Red).*

4. RESULTS

Results are reported for each research questions. The text of each question is included (in italics) for clarity. For each research question, the specific analytical approach is also included, describing tests for main effects as well as interactions. Note that task order was included in all models, and did not show a significant effect in any analysis. Research questions 6 and 8 are included in the discussion chapter, as they were not associated with specific statistical tests.

For event resolution times, the statistical model implemented was an accelerated failure time model; for eyes-off-road behavior, a longitudinal regression model was used; and for hands on wheel. a mixed logistic regression model was used. All models included age group as a covariate in all analyses, so that any variance due to age group was controlled for, but was not tested for significance.

The specific independent variables used within each model depended on the purpose of each test. As noted for each research question, some models included interaction terms, while others did not. For example, when assessing main effects of training, capability, and the timing (before or after the surprise event) on the percentage of eyes-off-road time, training, capability, and before/after the surprise event were included (along with age group and task order) without interactions. However, when the interaction of training and capability was of interest, this interaction was also included, but without other interactions. The same procedure accompanied the interaction of training and before/after the surprise event, and the interaction of capability and before/after the surprise event.

RQ1 (Driver Response and Expectation)

Does driver response to avoid an imminent crash differ based on expectations for encountering safety critical system errors in automated lateral and longitudinal (mixed function) control?

Overall, driver response did not differ based on expectations for encountering safety critical system errors, or by task.

As noted in Chapter 3, the event resolution times were used for analyses of driver response. When modeling time to resolve the surprise event, we accounted for the fact that in 13 instances participants did not react prior to the experimenter intervening (6 seconds after the event start). These observations were considered to be right-censored, where the theoretical time that the participant would have reacted, given the opportunity, would have been *at least* 6 seconds. An accelerated failure time model was used to account for this censoring in modeling the reaction time as a function of the independent variables.

Two models were fit. The first model assessed the effect of training, capability, and task on time to react. These three factors were included as independent variables, with event type included to adjust for differences between lane departure and reveal, and age group as a covariate. Note that task is confounded with task order (no two tasks share any task orders), and so task order was dropped as a result. The second model assessed the interactions of task, training, and capability. Note that since this was an accelerated failure time model, reaction times were interpreted relatively rather than absolutely.

Neither capability ($\chi = 0.9$, $p > 0.05$), nor training ($\chi = 2.8$, $p > 0.05$) significantly affected resolution time. However, when participants experienced a lane departure, the event was resolved about 0.5 times more quickly than when they experienced a reveal ($p < 0.001$, 95 percent confidence interval of 0.4 to 0.7).

Training and capability did not significantly interact in terms of their effect on resolution time ($\chi = 0.0$, $p > 0.05$)

Training and task did not significantly interact in terms of their effect on resolution time ($\chi = 3.7$, $p > 0.05$)

Capability and task did not significantly interact in terms of their effect on resolution time ($\chi = 0.9$, $p > 0.05$).

RQ2 (Non-Driving Task Engagement)

What are the effects of engaging in non-driving (secondary) tasks when responding to an imminent crash scenario that is caused by lateral and longitudinal system control errors?

The effect of task on resolution time was tested as part of the model described in RQ1. Task type was not related to resolution time ($\chi = 3.7$, $p > 0.05$). However, eye glance analyses were conducted to determine if there were differences in eyes-off-road time across different non-driving tasks. As would be expected, texting had the highest eyes-off-road time, followed by video tasks, and baseline tasks with the lowest eyes-off-road time. Details of the specific analyses are as follows:

Two linear mixed models were built to investigate whether the task type affected percentage of eyes-off-road time.

The first model investigated only the tasks' main effect. This model included before/after the surprise event, training, and capability as other independent variables of interest, as well as age group and task order as pre-determined blocking variables.

The second model investigated whether any change in percentage of eyes-off-road time between tasks varied across different training and capability levels. In this model, two-way interactions between task and training, and task and capability were included in addition to the variables described in the first model.

The model fit here was a linear mixed model with a Kenward Roger adjustment for degrees of freedom. Random terms for intercepts, tasks, and whether the task came before or after the surprise event were included.

The effect of tasks on the percentage of time that participants looked away from the road did not vary significantly across different training levels ($F(3, 273) = 1.13$, $p > 0.05$) or capability levels ($F(3, 273) = 0.47$, $p > 0.05$) for any task. Note that there was a significant interaction of task type for eyes-off-road time before and after the surprise event (see RQ 4 for this analysis)

Task significantly affected the percentage of time that participants kept their eyes-off-road time ($F(3,280) = 691.83$, $p < 0.0001$). Comparisons between tasks are noted below.

Differences Between Baseline and Distraction Tasks

Specifically, participants had less eyes-off-road time during baseline tasks compared to the first texting task (estimated percentage decrease = 63.7, S.E. = 1.6, $p < 0.001$, 95 percent confidence interval = 60.4 percent to 66.9 percent), the second texting task (estimated percentage decrease = 64.6, S.E. = 1.6, $p < 0.001$, 95 percent confidence interval = 61.3 percent to 67.8 percent), and the video task (estimated percentage decrease = 35.3%, S.E. = 1.6, $p < 0.001$, 95 percent confidence interval = 32.1 percent to 38.5 percent).

Differences Between Texting and Video

Additionally, participants had less eyes-off-road time during the video task compared to the first texting task (estimated percentage decrease = 28.4 percent, S.E. = 1.6, $p < 0.001$, 95 percent confidence interval = 25.2 percent to 31.6 percent) and the second texting task (estimated percentage decrease = 29.2 percent, S.E. = 1.6, $p < 0.001$, 95 percent confidence interval = 26.0 percent to 32.5 percent). The two texting tasks did not differ significantly from each other ($p > 0.05$).

RQ3 (Driver Response I) and RQ7 (Driver Response II)

How do driver responses compare across different performance and reliability levels of driver support features?

Do drivers respond faster to crash imminent events when they have a higher expectation for system performance and reliability?

As noted in RQ1 there were no significant differences in response time between feature capability levels. However, hands off wheel behavior was investigated to determine if there were effects of expectation and/or capability levels during the surprise event trials. As described in the following analyses, participants in the high training condition were more likely to have hands off the wheel immediately prior to the surprise event, but again this was not related to response times.

Two logistic regression models were built to investigate whether the percentage of hands off wheel time differed between training or capability levels during trials with the surprise event.

The first model investigated only the main effects of training and capability, and included no interactions. This model included training and capability as independent variables of interest, as well as age group and event type as covariates.

The second model investigated whether there was any interaction between training and capability levels. In this model, the two-way interaction between training and capability was included in addition to the variables described in the first model.

A logistic regression model was fit during this analysis. Since each participant had only one surprise event, no random effects were used.

Training was found to significantly affect the probability that participants took their hands off the wheel most of the time ($F(1,87) = 4.02$, $p = 0.048$) during the reduction window immediately prior to the surprise event. Specifically, participants were more likely to keep their hands off the wheel most of the time with high training compared to low training (odds ratio = 3.1, 95 percent confidence interval = 1.0 to 9.4).

Capability did not have a significant effect ($F(1,87) = 2.34$, $p = > 0.05$).

There was no significant interaction between training and capability ($F(1,90) = 0.00$, $p > 0.05$).

RQ4 (Driver Engagement)

How is engagement mediated by driver expectations for system errors/failures, type of secondary task, and imminent crash scenario?

This question was investigated using eyes-off-road time and hands on wheel behavior during public road driving and all non-surprise event trials from the test track portion of the study. Additional analyses were conducted for trials before and after the surprise event. For eyes-off-road time, there were no differences based on training or capability level while driving on public roads. However, during the test track portion, drivers were more likely to have their eyes off road when capability and training were both high. Texting had the highest eyes-off-road time, followed by Video, with Baseline tasks exhibiting the lowest eyes-off-road time. Eyes-off-road time was also significantly different after experiencing the surprise event. Specific tests are as follows:

Percentage of Eyes-Off-Road Time

Public Road

Linear mixed models were fit with the Kenward Roger adjustment for degrees of freedom. Random intercepts were used.

Neither training ($F(1,86) = 1.04$, $p > 0.05$) nor capability ($F(1, 86) = 2.87$, $p > 0.05$) had a significant effect on the percentage of time participants kept their eyes off the road during public road driving samples.

There was no significant interaction between training and capability ($F(1, 85) = 0.25$, $p > 0.05$).

Test Track Trials

Two linear mixed models were built to investigate whether the percentage of eyes-off-road time differed among training and capability levels.

The first model investigated only the main effects of training and capability, and included no interactions. This model included task, and whether the trial occurred before/after the surprise event as other independent variables of interest, as well as age group and task order as pre-determined blocking variables.

The model fit here was a linear mixed model with a Kenward Roger adjustment for degrees of freedom. Random terms for intercepts, tasks, and whether the task came before or after the surprise event, were included.

There were no main effects associated with training level or feature capability alone. Neither training ($F(1, 84.2) = 0.40$, $p > 0.05$) nor capability ($F(1, 84.2) = 1.74$, $p > 0.05$) significantly affected the percentage of time drivers looked away from the road, on average.

The second model investigated whether any difference in percentage of eyes-off-road time between different training levels differed between capability levels. In this model, the two-way interaction between training and capability was included in addition to the main effects.

The degree to which training affected the percentage of time that drivers looked away from the road depended significantly on the capability level ($F(1, 83.3) = 7.78$, $p = 0.007$).

With a significant interaction between training and capability established, we next investigated which capability levels experienced a significant change in percentage of eyes-off-road time between training levels. To adjust for multiple comparisons (two, in this case), we used a *p* of 0.025 instead of 0.05 as the criterion for statistical significance (Bonferroni correction). Table 5 displays each capability level and the associated estimated changes in percentage eyes-off-road time from low to high training. As shown in **Figure 14**, when training and capability were both high, participants exhibited significantly higher eyes-off-road time (shown in bold font) compared to other training/capability combinations.

Table 5. Differences in Eyes-Off-Road Time Comparing Low to High Training

Capability	Average Change From Low to High Training (%)	SE	P-Value	Lower Confidence Limit (%)	Upper Confidence Limit (%)
High	**6.4**	**2.6**	**0.017**	**1.2**	**11.6**
Low	-4	2.7	0.132	-9.3	1.2

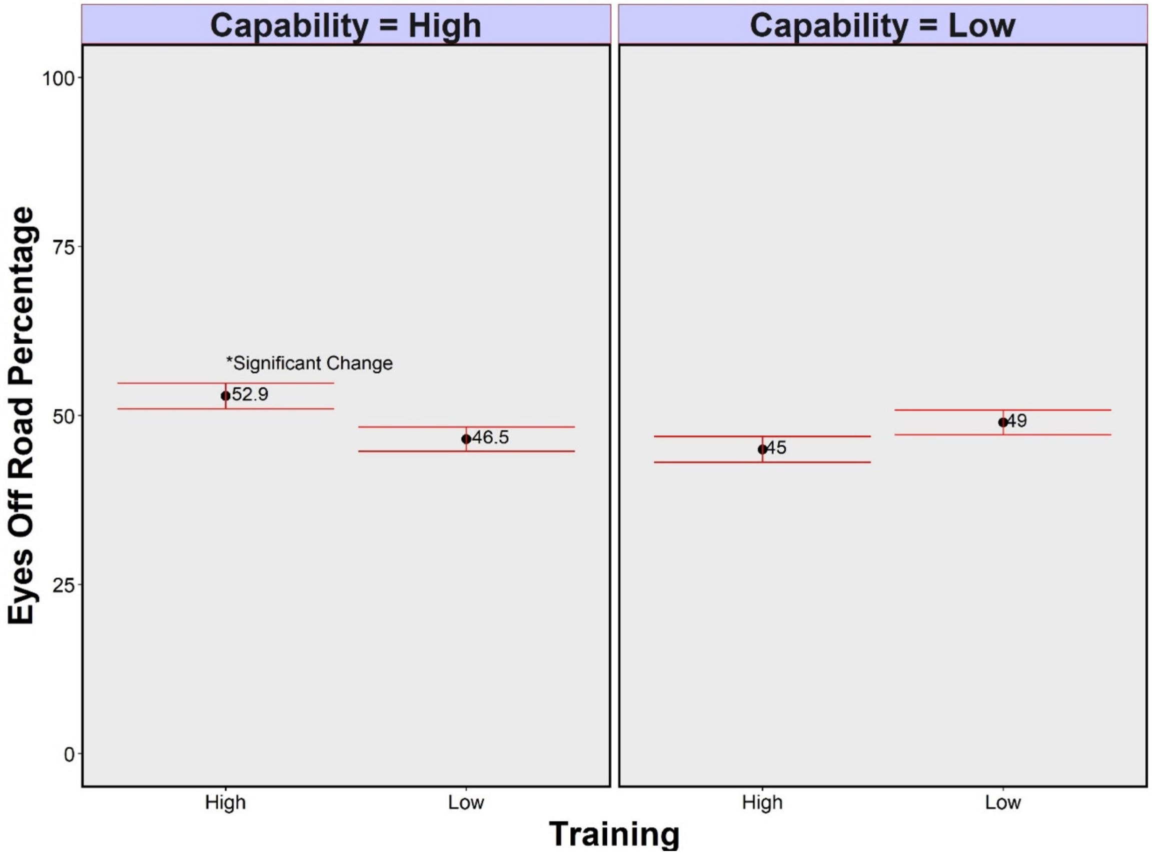

Figure 14. Plot of the Interaction of Eyes-Off-Road Percentage (Y Axis) for Training (X Axis) for High (Left Plot) and Low (Right Plot) Feature Capability.

Before and After the Surprise Event

Two linear mixed models were built to investigate whether percentage of eyes-off-road time changed from trials before the surprise event to after the surprise event. There were 708 trials before the surprise event and 616 trials after the surprise event.

The first model investigated only the main effect of before/after, and included no interactions. This model included task, training, and capability as other independent variables of interest, as well as age group and task order as pre-determined blocking variables.

The model fit here was a linear mixed model with a Kenward Roger adjustment for degrees of freedom. Random terms for intercepts, tasks, and whether the task came before or after the surprise event, were included.

Participants showed a statistically significant decrease in eyes-off-road time during trials after the surprise event compared to trials before the surprise event ($F(1,89.2) = 17.7$, $p < 0.001$). Specifically, participants averaged a 3.2 percent decrease in percentage of eyes-off-road time (S.E. = 0.8, 95 percent confidence interval = 1.7 percent to 4.7 percent).

The second model investigated whether any change in percentage of eyes-off-road time from before to after the surprise event varied across different tasks, training levels, and capability models. In this model, two-way interactions between before/after and task, before/after and training, and before/after and capability were included in addition to the variables described in the first model.

Interaction With Task Type

The change in percentage of time participants kept their eyes off the road during trials from before to after the surprise event depended significantly on the task ($F(3,893) = 8.44$, $p < 0.001$). However, there was no such dependence on training ($F(1,87.1) = 0.15$, $p = 0.6973$) or capability ($F(1,87.2) = 0.18$, $p = 0.6689$).

With a significant interaction between before/after and task established, we next investigated which tasks experienced a significant change in percentage of eyes-off-road time. To adjust for multiple comparisons (four, in this case), we used a *p* of 0.0125 instead of 0.05 as a criterion for statistical significance. The video task registered a significant decrease in percentage of eyes-off-road time from before to after the surprise event. Table 6 displays each task and its estimated change in percentage of eyes-off-road time from before to after the surprise event. **Figure 14** plots the interaction among tasks before and after the surprise event (note that texting tasks are combined in this figure, resulting in a statistically significant effect).

Table 6. Change in Percentage of Eyes-Off-Road Time From Before to After the Surprise Event by Task

Task	Change From Before to After	SE	P-Value	Lower Confidence Limit	Upper Confidence Limit
Baseline	0.8	1	0.559	-1.8	3.4
Text 1	-3.2	1	0.018	-5.9	-0.6
Text 2	-2.1	1	0.119	-4.8	0.5
Video	**-8.0**	**1**	**<0.001**	**-10.6**	**-5.4**

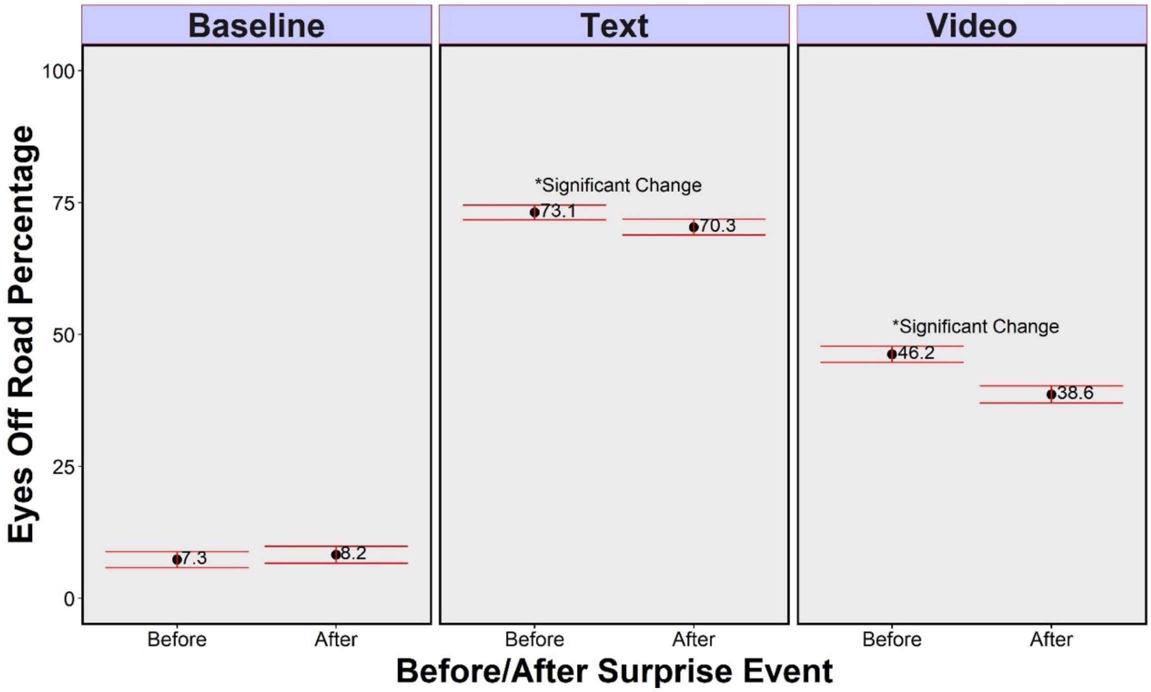

Figure 15. Eyes-Off-Road Percentage (Y Axis) for Each Task Type Before and After (X Axis) the Surprise Event.

Hands-on-Wheel Behavior

As shown in **Figure 16** (and noted in the previous chapter) the distribution of the percentage of time with hands on wheel behavior does not lend itself to standard statistical modeling of a continuous variable. The tallest parts of the distributions lie at either end. That is, most participants either had their hands on the steering wheel during the entire sample or hands off the wheel during the entire sample. Standard linear models come closer to fulfilling assumptions (i.e., the normality of the residuals and constant variance) when the data is more centered. Therefore, hands off wheel data were categorized by dividing up the events into two groups: one with less than 50 percent of the time with hands off the wheel, and one with more than 50 percent of the time with hands off the wheel. A mixed logistic regression was then used to model the odds of keeping hands off the wheel more than 50 percent of the time.

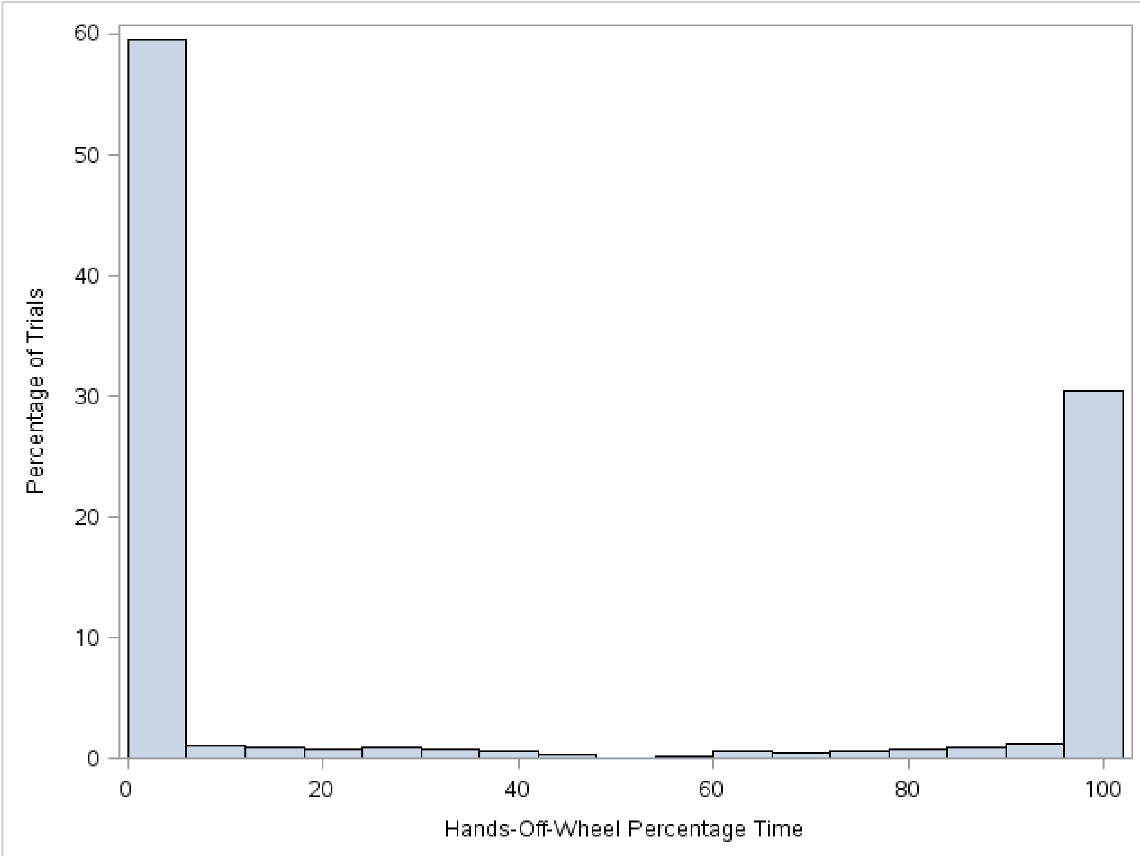

Figure 16. Distribution Hands-Off-Wheel Percentages Observed Across all Samples.

Public Road

Two mixed logistic regression models were built to investigate whether percentage of hands off wheel time changed from training or capability during the public-road trials.

The first model investigated only the main effects of training and capability, and included no interactions. This model included training and capability as independent variables of interest, as well as age group and trial number as covariates.

The second model investigated whether there was any interaction between training and capability levels. In this model, the two-way interaction between training and capability was included in addition to the variables described in the first model.

Training was found to significantly affect the probability that participants had their hands off the wheel during public road samples ($F(1,91) = 4.01$, $p = 0.048$). Specifically, participants were more likely to have their hands off the wheel with high training compared to low training (odds ratio = 3.1, 95 percent confidence interval = 1.0 to 9.3).

Capability did not have a significant effect ($F(1, 91) = 0.00$, $p = > 0.05$) and there was no significant interaction between training and capability ($F(1,90) = 0.83$, $p > 0.05$).

Test Track

Again, two mixed logistic regression models were built to investigate whether percentage of hands off wheel time changed from training, capability, or task levels.

The first model investigated only the main effects of training, capability, and task type, and included no interactions. This model included task, training, and capability as independent variables of interest, as well as age group, task order, and whether the trial occurred before/after the surprise event.

The second model investigated whether there was any interaction between training, capability, and task levels in the change in percentage of hands off wheel time. In this model, the two-way interactions between training, capability, and task were included in addition to the variables described in the first model.

The probability that participants would take their hands off the wheel at least 50 percent of the time changed significantly depending on the task they performed ($F(3,263) = 4.65$, $p = 0.004$). Specifically, participants had less hands-off wheel time during the first texting task compared to baseline (odds ratio = 0.3, $p = 0.002$, 95 percent confidence interval = 0.2 to 0.7) during the second texting task compared to baseline (odds ratio = 0.4, $p = 0.007$, 95 percent confidence interval = 0.2 to 0.8) and during the video task compared to baseline (odds ratio = 0.3, $p = 0.001$, 95 percent confidence interval = 0.2 to 0.6).

Neither training ($F(1,83) = 0.69$, $p > 0.05$) nor capability ($F(1, 83) = 0.15$, $p > 0.05$) significantly changed the probability that participants would keep their hands off the wheel most of the time, on average.

There was no significant interaction between task and training ($F(3,257) = 2.14$, $p > 0.05$), task and capability ($F(3, 257) = 0.47$, $p > 0.05$), or training and capability ($F(1, 82) = 0.68$, $p > 0.05$).

Before and After the Surprise Event

Two mixed logistic regression models were built to investigate whether the probability of a driver keeping their hands off the wheel most of the time changed from trials before the surprise event to after the surprise event.

The first model investigated only the main effect of before/after, and included no interactions. This model included task, training, and capability as other independent variables of interest, as well as age group and task order as pre-determined blocking variables.

The second model investigated whether there was an interaction between before/after the surprise event and task, training, or capability. In this model, two-way interactions between before/after and task, before/after and training, and before/after and capability were included in addition to the variables described in the first model.

There was a change in the probability that participants would take their hands off the wheel most of the time from before to after the surprise event ($F(1, 89) = 5.08$, $p = 0.027$). Specifically, participants were less likely to have their hands of off the wheel after the surprise event compared to before (odds ratio = 0.5, 95 percent confidence interval = 0.3 to 0.9).

There were no statistically significant interactions observed between before/after and training ($F(1, 87) = 0.02$, $p > 0.05$), before/after and capability ($F(1, 87) = 0.04$, $p > 0.05$), or before/after and task ($F(3, 829) = 0.48$, $p > 0.05$).

RQ5 (Driver Acceptance and Trust)

What are the effects on user acceptance and trust when drivers encounter critical system errors/failures? How resilient or enduring are the effects of expectations on acceptance and trust?

Overall, subjective opinions of the lateral automated feature were high, and subsequently increased throughout the study. These opinions were resilient to the experience of the surprise event; there were no statistically significant changes in any measure after experiencing the surprise event. Details of the analyses are as follows:

Subjective opinions were assessed at multiple points throughout the study: After training, test drive, public road drive, trial 3 on the test track, surprise event, and at the end of the study. Two different measures were used (See Appendix D for questionnaires). The first was a general questionnaire that was used to assess trust in the lateral and longitudinal features on a 1 to 7 Likert type scale, adapted from previous work on L2 driving automation (Russell et al., 2018). The second was the van der Laan (van der Laan, Jinke, & deWaard, 1997) scale designed to assess acceptance of technology. The van der Laan Scale asks participants to rate the system on two opposing ends of a 7-point scale, and when scored loads onto two factors: usefulness and satisfaction in using the technology. The van der Laan scale scores from -2 to 2 with higher scores indicating positive acceptance on both scales. Data is presented for the lateral feature in the present report.

Figure 17 shows the responses to the question, "I felt safe using the lateral features," over the course of the study. Overall, scores for this question increased significantly from the beginning of the study to the end of the study (estimate = 1.2, S.E. = 0.2, $p < 0.001$, 95 percent confidence interval = 0.9 to 1.5). Neither training ($F(1, 86) = 3.14$, $p > 0.05$) nor capability ($F(1, 86) = 0.00$, $p > 0.05$) had a significant effect on responses to this question. There was not a significant interaction between training and capability ($F(1, 85) = 0.19$, $p > 0.05$).

The results are nearly identical for the question, "I trust the Lateral Features" (**Figure 18**). Again, scores on this question increased significantly from the beginning of the study to the end of the study (estimate = 0.9, S.E. = 0.2, $p < 0.001$, 95 percent confidence interval = 0.5 to 1.3). Neither training ($F(1, 86) = 1.73$, $p > 0.05$) nor capability ($F(1, 86) = 0.01$, $p > 0.05$) had a significant effect on change in trust of the lateral control feature. There was not a significant interaction between training and capability ($F(1, 85) = 0.19$, $p > 0.05$).

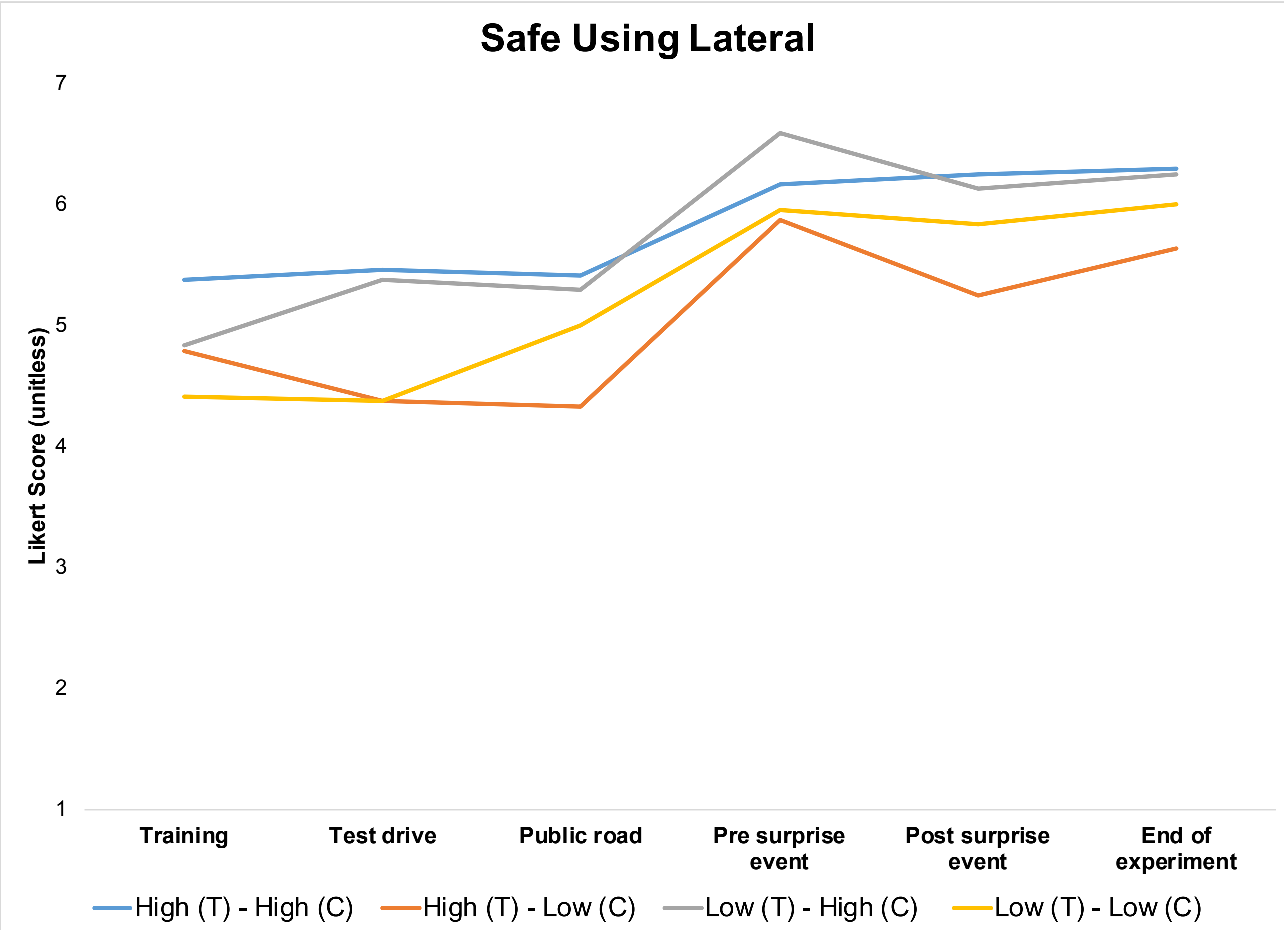

Figure 17. Subjective Safety Ratings for the Lateral Control Feature for Each Training (T) and Capability (C) Condition.

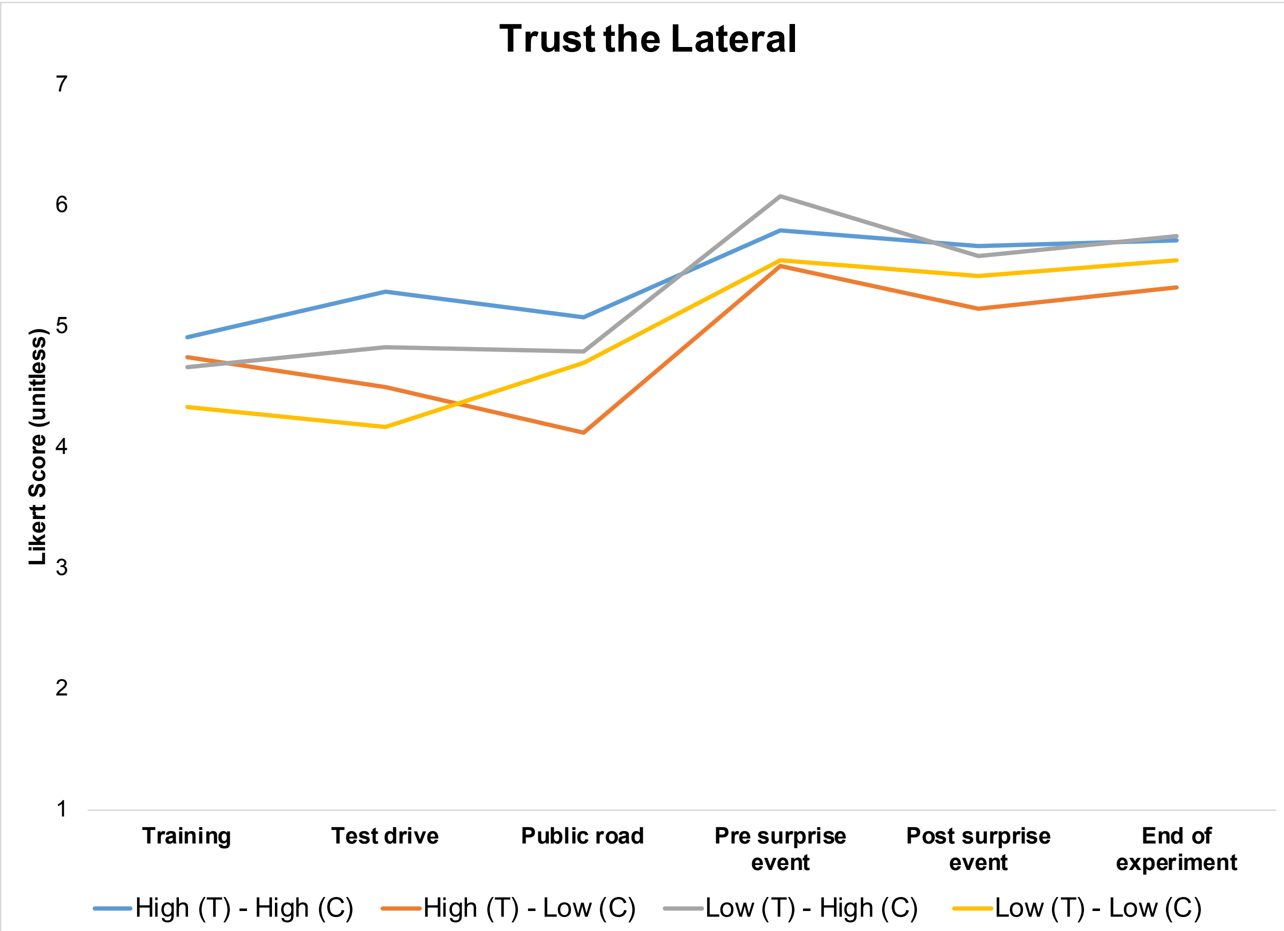

Figure 18. Subjective Trust Ratings in the Lateral Feature for Each Training (T) and Capability (C) Condition.

Scores on the van der Laan scales show a similar trend. **Figure 19** shows the scores for the usefulness subscale. Ratings for usefulness of the system increased significantly from the beginning of the study to the end of the study (estimate = 0.5, S.E. = 0.1, $p < 0.001$, 95 percent confidence interval = 0.3 to 0.6). Neither training ($F(1, 86) = 1.06$, $p > 0.05$) nor capability ($F(1, 86) = 0.02$, $p > 0.05$) had a significant effect on change in usefulness. There was also not a significant interaction between training and capability ($F(1, 85) = 0.47$, $p => 0.05$).

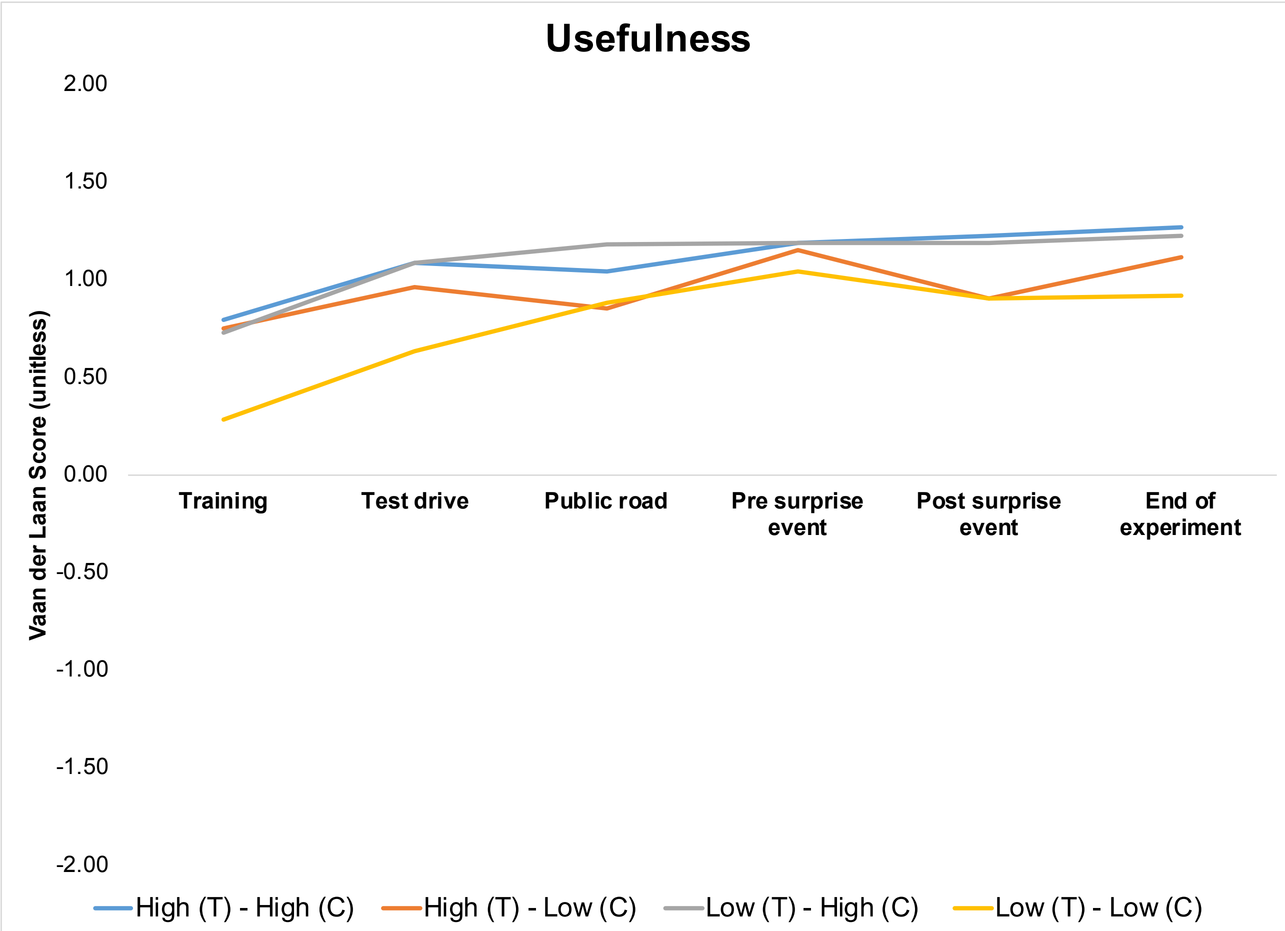

Figure 19. Van der Laan Usefulness Scores for Each Training (T) and Capability (C) Condition.

Figure 20 shows the average ratings for the satisfying subscale. Scores for the satisfying subscale also increased significantly from the beginning of the study to the end of the study (estimate = 0.4, S.E. = 0.1, $p < 0.001$, 95 percent confidence interval = 0.2 to 0.6). Once again, neither training ($F(1, 86) = 0.85$, $p > 0.05$) nor capability ($F(1, 86) = 0.36$, $p > 0.05$) had a significant effect on change in satisfying scores. There was not a significant interaction between training and capability ($F(1, 85) = 0.51$, $p > 0.05$).

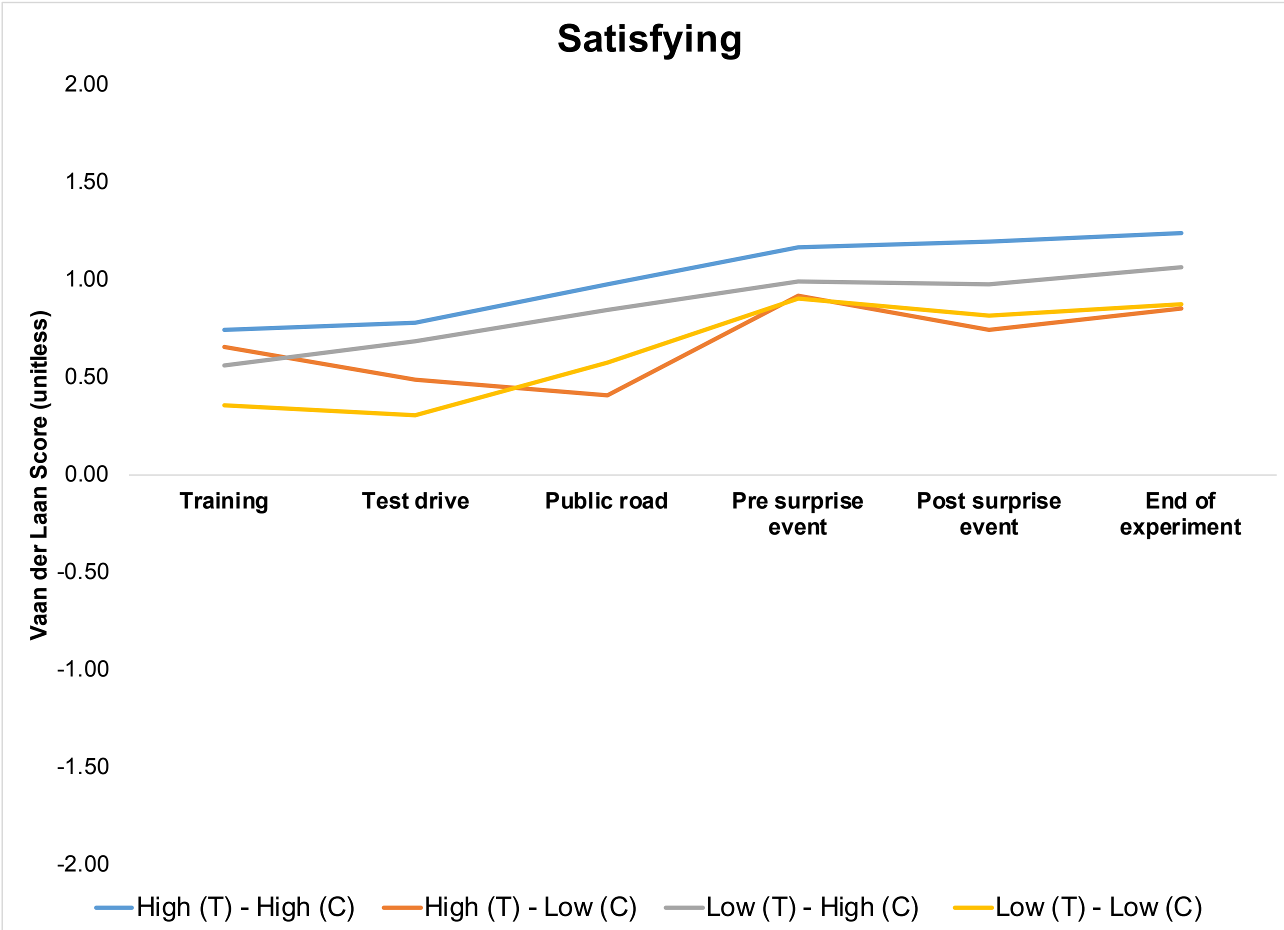

Figure 20. Van der Laan Satisfying Scores for Each Training (T) and Capability (C) Condition.

5. DISCUSSION

The goal of the Driver Expectations project was to determine if expectations about Level 2 driving automation would change the way drivers interacted with these systems. The study adjusted driver expectations without adjusting the capability of driver support systems by adjusting the information provided to the driver at training. After receiving the training information, participants then drove the study vehicle on public roads to experience the technology before driving onto the test track. While on the Smart Road, participants performed non-driving tasks, and experienced a surprise event. After experiencing the event, participants resumed driving and performing non-driving tasks.

Table 7 summarizes the results of the statistical tests. The results showed that a driver's pre-conceived training-based expectations did influence their interaction with technology in a potentially negative way. In particular, during the public road samples, drivers were more likely to have their hands off the wheel in the high training condition, which induced expectations for reliable lateral control, regardless of the feature capability. Not shown in this table, expectations also produced a main effect on taking hands off the wheel on the test track just prior to the surprise event.

Table 7. Summary: Table of Results

Dependent Measure	Capability	Training	Interaction	Pre-Post Surprise Event
Hands on wheel yes or no	Not Significant	Main Effect (Public Road)	Not Significant	Main Effect
Eye glance (eyes-off-road time)	Not Significant	Not Significant	Capability x Training	Main Effect
Response time to surprise event	Not Significant	Not Significant	Not Significant	N/A
Trust and acceptance levels	Not Significant	Not Significant	Not Significant	Not Significant

Additional implications of these results are summarized as part of the remaining research questions (RQs 6 and 8). Again, each question is repeated for clarity. Additional conclusions follow.

RQ6 (Crash Potential)

Are crashes more likely with increased system performance and reliability? A commonly accepted risk factor for crashes is eyes-off-road time. In the current experiment, eye glance patterns were related to both training and feature capability. Specifically, in the high training/ high capability condition, where one would expect the most reliance, participants were more likely to have eyes off the road than in the low training high capability condition. The results for eyes-off-road time were presented as percentages observed during each sample. Given that the sample duration was 15 seconds, the difference between conditions was approximately 1 second more (6.5%) eyes-off-road time in the high training high capability condition than in the high capability low training condition.

Additional concerns about crash potential are related to driver hands on wheel behaviors. The main effects showed drivers were more likely to have hands off the wheel in the high training capability condition, regardless of the actual capability of the vehicle during samples taken from the public road portion of the study. During the test track portion of the study, drivers were more likely to have at least one hand on the wheel during the texting and video tasks. That means that baseline tasks showed an increase in hands off wheel behavior; however, drivers were more likely to have eyes on the forward road during these samples. After experiencing the surprise event, drivers were more likely to have eyes on the road and hands on the wheel.

There were no effects of either capability or training on the time participants took to resolve (recover lane position or avoid the revealed vehicle) the surprise events. In the present study, multiple drivers across all training/capability conditions did not brake during the reveal event, instead relying on the ACC system to slow the study vehicle. Given the performance envelope of the factory system (and design of the event itself) the behavior could be described as anticipatory; the drivers were looking forward and attentive but did not respond immediately to the event. Rather, they reported that they wanted to "see what the car would do." Similar behaviors were observed in a naturalistic study of Level 2 driving automation, albeit with responses to request to intervene alerts (L2 NDS; Russell et al., 2018). These types of behaviors may be related to the novelty of L2 systems.

RQ8 (Acceptable Driver Engagement Threshold)

Can an acceptable driver engagement threshold that is relative to driver expectations be established from this study?

Per the SAE definition, while operating a Level 2 driving automation system, adequate driver engagement requires the driver to be fully engaged in the driving task to supervise system operation and intervene as necessary. Although the system may afford control of the longitudinal path, hands on wheel and eyes on road are still required for adequate engagement. In the absolute sense, any level of disengagement is potentially detrimental. However, the level of control provided by Level 2 driving automation may afford a driver some level of disengagement, at least in the form of hands off the steering wheel, whether it is the design intent of the system or not. A challenge to defining a threshold for engagement (other than the absolute above) is the variance in capabilities afforded by different systems.

The results of this study indicate that drivers' pre-conceived expectations about the system's capabilities and effectiveness can change their patterns of engagement (both visual and manual). Over-reliance may not be completely avoided, but may be reduced if the capabilities and limitations of driver support features are described to a driver as accurately as possible. If drivers expect more from the feature (from advertisement or other media) than it is capable of, there may be a critical period where they rely on their expectations of capabilities, until they experience a system limitation that corrects their expectation of the system capability.

Early on, during the drive on public roads, drivers were more likely to manually disengage from the driving task (i.e., hands off the steering wheel) when they were told that the vehicle capabilities were high (e.g., high training), whether or not the capabilities were actually high. During the test track portion of the study, when capabilities and training were both high, drivers in this condition were more likely have hands off the steering wheel prior to the surprise event. After experiencing the surprise event, however, hands were more likely to be on the wheel and eyes were more likely to be on the road for all capability and training levels, even when performing non-driving tasks.

Comparisons to L2 NDS Study

The results for the present study are generally in agreement with those observed in the naturalistic driving studies of Level 2 ADAS-equipped Vehicles (L2 NDS; Russell et al., 2018). In that sample, drivers were generally observed to use L2 driving automation features in their intended fashion, and the use of driver support features was not shown to increase non-driving task prevalence or eyes-off-road time. The study did show drivers disengaging from the primary task of driving, but these types of behaviors (e.g., cell phone use) were observed at all levels of feature activation (e.g., no features, one feature, and both lateral and longitudinal features active).

Similar previous work (Russell, et al, 2018), drivers reported high scores on each trust scale, with scores increasing across the duration of the experiment. Trust ratings were not statistically different between conditions, and did not show a statistically significant drop after the surprise event. This suggests that drivers were trusting and comfortable with the systems, but their subjective responses were not as sensitive as objective measures of engagement (hands on wheel and eyes-off-road).

Limitations

Limitations to generalizing the current results include the method for setting expectations via training materials. The training manipulation was designed to be similar to a tutorial video in which the features are explained, followed by a dealership test drive. This may have made the information seem more “official” than would be expected if the content had been made for entertainment purposes (a primary source of indirect expectations).

Furthermore, the exposure to L2 driving automation systems in the study was a single, 4-hour exposure. It is likely that the overall effects of expectation will diminish over time. However, the overall patterns observed on public roads in this study, as well as the “anticipatory” responses to surprise events resembled the behaviors observed from drivers in the L2NDS project. During L2NDS, participants drove vehicles with similar lateral and longitudinal capabilities for a period of four weeks.

Finally, the focus of the experiment was on driver expectations for lateral driver assistance. Testing did not vary the longitudinal feature. Furthermore, the test did not include condition without driver support features to determine if driver engagement patterns observed in the present study differ from driving without driver support features.

Conclusions

The focus of the results thus far has been on instances of driver disengagement. However, the global average of hands on wheel for all 15-second samples was 10.8 seconds. A total of 65 percent of participants (62 of 96) already had their hands on the wheel at the onset of the surprise event. Of all 288 samples taken during the drive on public roads (three samples from each of 96 drivers), 129 (45%) had no recorded hands-off-wheel time. These figures are essentially split evenly between low training (66 samples) and high training (63 samples). Still, with Level 2 driving automation systems, any amount of manual disengagement can have serious consequences.

The results observed here do not indicate that high functioning Level 2 driving automation creates disengagement; rather the results give an indication of conditions in which driver disengagement is most likely to occur. Specifically, when a driver expects higher capability they are three times as likely to have their hands off the steering wheel, as observed in the sampling window on the test track than when they expect low capability. Drivers in the high training high capability conditions were also more likely to have higher eyes-off-road time in these samples. Although we found that most drivers took their hands off the steering wheel, we believe that it is likely that an overall minority of drivers would be most likely to disengage (e.g., the riskiest drivers), and as with previous test track studies (Blanco et al., 2015) the experiment was intended to show a potential "worst case scenario" for disengagement with Level 2 driving automation.

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APPENDIX A: Commercially Available Driving Automation System Features

Table 8 includes a list of the reviewed makes and models for model years 2017 to 2019. Optional lateral and longitudinal driver support features are noted if available, and highlighted in green. If the lateral feature was described as providing corrections to keep the vehicle centered within the lane, it is noted to include "lane centering." Where available, the first entry in the make column is a hyperlink to the website where the information was gathered. A combination of lane centering and adaptive cruise control fit the definition of Level 2.

Table 8. Make and Models of Vehicles That Are Available With Lateral and Longitudinal Control Assistance Features – Green-Shaded Cells Denote Availability

Vehicles		**Lateral Features**		**Longitudinal Features**	
Make	**Model**	**Lane Centering**	**Lane Keeping**	**Adaptive Cruise Control**	**Automated Emergency Braking**
Acura	ILX	Green	Green	Green	Green
Acura	MDX	Green	Green	Green	Green
Acura	RDX	Gray	Gray	Green	Green
Acura	RLX	Green	Green	Green	Green
Acura	TLX	Gray	Gray	Gray	Gray
Audi	A3 Cabriolet	Gray	Green	Green	Green
Audi	A3 Sedan	Gray	Green	Green	Green
Audi	A3 Sportback e-tron	Gray	Green	Green	Green
Audi	A4	Gray	Green	Green	Green
Audi	A4 allroad	Gray	Green	Green	Green
Audi	A5 Sport	Gray	Gray	Gray	Green
Audi	A5 Sport Cabriolet	Gray	Gray	Gray	Green
Audi	A6	Gray	Green	Green	Green
Audi	A7	Gray	Gray	Green	Green
Audi	A8 L	Gray	Green	Green	Green
Audi	Q5	Gray	Gray	Gray	Green
Audi	Q7	Gray	Green	Green	Green
Audi	S3	Gray	Green	Green	Green
Audi	SQ5	Gray	Gray	Gray	Gray
Audi	RS 3	Gray	Gray	Gray	Gray
Audi	S4	Gray	Green	Green	Green
Audi	S5 Sport	Gray	Gray	Gray	Gray

Vehicles		Lateral Features		Longitudinal Features	
Make	**Model**	**Lane Centering**	**Lane Keeping**	**Adaptive Cruise Control**	**Automated Emergency Braking**
Audi	S6	n/a	Available	Available	Available
Audi	RS 7	n/a	Available	Available	Available
Audi	Q3	n/a	n/a	n/a	n/a
Audi	A5 coupe	n/a	Available	Available	Available
Audi	S5 coupe	n/a	Available	Available	Available
Audi	RS 5 coupe	n/a	n/a	Available	Available
Audi	S5 cabriolet	n/a	n/a	n/a	n/a
Audi	TTS coupe	n/a	n/a	n/a	n/a
Audi	TT RS coupe	n/a	n/a	n/a	n/a
Audi	TT Roadster	n/a	n/a	n/a	n/a
Audi	S7	n/a	Available	Available	Available
Audi	TT Coupe	n/a	n/a	n/a	n/a
BMW	2 Series	n/a	Available	n/a	Available
BMW	3 Series	n/a	Available	Available	Available
BMW	4 Series	n/a	Available	Available	Available
BMW	5 Series	Available	Available	Available	Available
BMW	6 Series	n/a	Available	Available	Available
BMW	7 Series	Available	Available	Available	Available
BMW	i3	n/a	n/a	Available	Available
BMW	i8	n/a	Available	Available	Available
BMW	M Series	n/a	Available	Available	Available
BMW	X1	n/a	Available	Available	Available
BMW	X2	n/a	Available	Available	Available
BMW	X3	n/a	Available	Available	Available
BMW	X4	n/a	Available	Available	Available
BMW	X5	n/a	Available	Available	Available
BMW	X6	n/a	Available	Available	Available
Buick	Envision	n/a	Available	n/a	Available
Buick	Regal SportBack	n/a	Available	Available	Available
Buick	Cascada	n/a	Available	n/a	Available
Buick	Encore	n/a	Available	n/a	Available
Buick	Regal TourX	n/a	Available	n/a	Available

Vehicles		Lateral Features		Longitudinal Features	
Make	Model	Lane Centering	Lane Keeping	Adaptive Cruise Control	Automated Emergency Braking
Buick	Enclave	n/a	Available	Available	Available
Buick	Regal GS	n/a	Available	Available	Available
Buick	Lacrosse	n/a	Available	n/a	Available
Cadillac	ATS	n/a	Available	Available	Available
Cadillac	CT6	Available	Available	Available	Available
Cadillac	CTS	n/a	Available	Available	Available
Cadillac	CTS-V	n/a	Available	n/a	Available
Cadillac	Escalade / ESV	n/a	Available	Available	Available
Cadillac	XT5 Crossover	n/a	Available	Available	Available
Cadillac	XTS	n/a	Available	Available	Available
Chevrolet	Cruze	n/a	Available		Available
Chevrolet	Equinox	n/a	Available		Available
Chevrolet	Express Passenger	n/a			
Chevrolet	Spark	n/a			
Chevrolet	Sonic	n/a			
Chevrolet	Bolt EV	n/a			
Chevrolet	Camaro	n/a			
Chevrolet	Traverse	n/a	Available	Available	Available
Chevrolet	Colorado	n/a	Available	n/a	n/a
Chevrolet	Trax	n/a	Available	n/a	Available
Chevrolet	Impala	n/a	Available	Available	Available
Chevrolet	Malibu	n/a	Available	Available	Available
Chevrolet	Silverado 1500	n/a	Available	n/a	Available
Chevrolet	Suburban	n/a	Available	Available	Available
Chevrolet	Tahoe	n/a	Available	Available	Available
Chevrolet	Volt	n/a	Available	Available	Available
Chrysler	200	n/a	Available	Available	Available
Chrysler	300	n/a	Available	Available	Available
Chrysler	Pacifica Hybrid	n/a	Available	Available	Available
Chrysler	Pacifica	n/a	Available	Available	Available

Vehicles		Lateral Features		Longitudinal Features	
Make	Model	Lane Centering	Lane Keeping	Adaptive Cruise Control	Automated Emergency Braking
Dodge	Charger	n/a	Available	Available	Available
Dodge	Challenger	n/a	n/a	Available	Available
Dodge	Journey	n/a	n/a	n/a	n/a
Dodge	Durango	n/a	Available	Available	Available
Fiat	124 Spider	n/a	n/a	n/a	n/a
Fiat	500L	n/a	n/a	n/a	n/a
Fiat	500X	n/a	Available	n/a	Available
Ford	C-MAX	n/a	n/a	n/a	n/a
Ford	Edge	Available	Available	Available	n/a
Ford	Escape	n/a	Available	Available	Available
Ford	Fiesta	n/a	n/a	n/a	n/a
Ford	Mustang	n/a	Available	Available	Available
Ford	ECO- sport	n/a	n/a	n/a	n/a
Ford	Transit	n/a	n/a	n/a	n/a
Ford	Super Duty	n/a	n/a	n/a	n/a
Ford	Expedition	n/a	Available	Available	Available
Ford	Explorer	n/a	Available	Available	Available
Ford	F-150	n/a	Available	Available	Available
Ford	Flex	n/a	n/a	Available	n/a
Ford	Focus	n/a	n/a	n/a	n/a
Ford	Fusion	n/a	Available	Available	Available
Ford	Taurus	n/a	Available	Available	Available
Genesis	G80	n/a	Available	Available	Available
Genesis	G90	n/a	Available	Available	Available
GMC	Acadia	n/a	Available	n/a	Available
GMC	Sierra 1500	n/a	Available	n/a	Available
GMC	Canyon	n/a	Available	n/a	Available
GMC	Terrain	n/a	Available	n/a	Available
GMC	Yukon	n/a	Available	Available	Available
GMC	Yukon XL	n/a	Available	Available	Available
Honda	Accord Hybrid	Available	Available	Available	Available
Honda	Accord Sedan	Available	Available	Available	Available

Vehicles		**Lateral Features**		**Longitudinal Features**	
Make	**Model**	**Lane Centering**	**Lane Keeping**	**Adaptive Cruise Control**	**Automated Emergency Braking**
Honda	Civic Sedan	Available	Available	Available	Available
Honda	Clarity Fuel Cell	Available	Available	Available	Available
Honda	Clarity Electric	n/a	Available	Available	Available
Honda	CR-V	Available	Available	Available	Available
Honda	Fit	Available	Available	Available	Available
Honda	HR-V	n/a	n/a	n/a	n/a
Honda	Odyssey	Available	Available	Available	Available
Honda	Pilot	Available	Available	Available	Available
Honda	Ridgeline	Available	Available	Available	Available
Hyundai	Accent	n/a	n/a	n/a	Available
Hyundai	Elantra	n/a	Available	Available	Available
Hyundai	Santa Fe	n/a	Available	Available	Available
Hyundai	Kona	Available	Available	Available	Available
Hyundai	Veloster	n/a	Available	n/a	
Hyundai	Ioniq	n/a	Available	n/a	n/a
Hyundai	Sonata	n/a	Available	Available	Available
Hyundai	Tucson	n/a	Available	n/a	Available
Infiniti	Q50	Available	Available	n/a	Available
Infiniti	Q60	Available	Available	n/a	Available
Infiniti	Q70	n/a	n/a	n/a	Available
Infiniti	QX30	n/a	Available	Available	Available
Infiniti	QX50	Available	Available	Available	Available
Infiniti	QX60	n/a	Available	n/a	Available
Infiniti	QX70	n/a	Available	Available	Available
Infiniti	QX80	n/a	Available	Available	Available
Jaguar	F-PACE	n/a	Available	Available	Available
Jaguar	E-PACE	n/a	Available	Available	Available
Jaguar	I-PACE	n/a	Available	Available	Available
Jaguar	F-TYPE	n/a	Available	Available	Available
Jaguar	XJ	n/a	Available	Available	Available
Jaguar	XE	n/a	Available	Available	Available

Vehicles		Lateral Features		Longitudinal Features	
Make	Model	Lane Centering	Lane Keeping	Adaptive Cruise Control	Automated Emergency Braking
Jaguar	XF	n/a	Available	n/a	Available
Jeep	Cherokee	n/a	Available	n/a	Available
Jeep	Wrangler	n/a	n/a	n/a	n/a
Jeep	Compass	n/a	Available	n/a	Available
Jeep	Grand Cherokee	n/a	Available	n/a	Available
Jeep	Renegade	n/a	Available	n/a	Available
Kia	Cadenza	n/a	n/a	n/a	Available
Kia	Forte	n/a	Available	n/a	Available
Kia	K900	n/a	n/a	Available	Available
Kia	Rio	n/a	n/a	n/a	n/a
Kia	Stinger	n/a	n/a	n/a	n/a
Kia	Soul	n/a	n/a	n/a	n/a
Kia	Niro	n/a	n/a	n/a	n/a
Kia	Optima	n/a	n/a	Available	Available
Kia	Sedona	n/a	Available	Available	Available
Kia	Sorento	n/a	Available	Available	Available
Kia	Sportage	n/a	Available	n/a	
Land Rover	Discovery Sport	n/a	Available	Available	Available
Land Rover	Velar	n/a	Available	Available	Available
Land Rover	Evoque	n/a	Available	Available	Available
Land Rover	Range Rover	n/a	Available	Available	Available
Lexus	ES	n/a	Available	Available	Available
Lexus	GS F	n/a	Available	Available	Available
Lexus	ES Hybrid	n/a	Available	Available	Available
Lexus	GS Hybrid	n/a	Available	Available	Available
Lexus	GS	n/a	Available	Available	Available
Lexus	GX	n/a	Available	Available	Available
Lexus	IS	n/a	Available	Available	Available
Lexus	LS Hybrid	n/a	Available	Available	Available
Lexus	RC F	n/a	Available	Available	Available
Lexus	LC	n/a	Available	Available	Available

Vehicles		Lateral Features		Longitudinal Features	
Make	Model	Lane Centering	Lane Keeping	Adaptive Cruise Control	Automated Emergency Braking
Lexus	LC Hybrid	n/a	Available	Available	Available
Lexus	LS	n/a	Available	Available	Available
Lexus	LX	n/a	Available	Available	Available
Lexus	NX	n/a	Available	Available	Available
Lexus	NX Hybrid	n/a	Available	Available	Available
Lexus	RC	n/a	Available	Available	Available
Lexus	RX	n/a	Available	Available	Available
Lexus	RX Hybrid	n/a	Available	Available	Available
Lincoln	Continental	n/a	n/a	Available	Available
Lincoln	Navigator	n/a	Available	Available	Available
Lincoln	MKC	n/a	Available	Available	Available
Lincoln	MKT	n/a	Available	Available	Available
Lincoln	MKX	n/a	Available	n/a	Available
Lincoln	MKZ	n/a	Available	Available	Available
Mazda	CX-3	n/a	Available	n/a	Available
Mazda	CX-5	n/a	Available	Available	Available
Mazda	CX-9	n/a	Available	Available	Available
Mazda	Mazda3	n/a	Available	Available	Available
Mazda	Mazda6	n/a	Available	Available	Available
Mercedes-Benz	A-Class	n/a	Available	n/a	Available
Mercedes-Benz	B-Class	n/a	Available	Available	Available
Mercedes-Benz	C-Class	Available	Available	n/a	Available
Mercedes-Benz	CLA	Available	Available	Available	Available
Mercedes-Benz	CLS	Available	Available	Available	Available
Mercedes-Benz	E-Class	Available	Available	Available	Available
Mercedes-Benz	G-Class	n/a	n/a	Available	Available
Mercedes-Benz	GLA	n/a	Available	Available	Available
Mercedes-Benz	GLC	Available	Available	Available	Available
Mercedes-Benz	GLE	Available	Available	Available	Available
Mercedes-Benz	GLS	Available	Available	Available	Available
Mercedes-Benz	S-Class	Available	Available	Available	Available
Mercedes-Benz	SL	n/a	Available	Available	Available
Mercedes-Benz	SLC	n/a	Available	Available	Available

Vehicles		Lateral Features		Longitudinal Features	
Make	Model	Lane Centering	Lane Keeping	Adaptive Cruise Control	Automated Emergency Braking
Mini	Clubman	n/a	n/a	Available	Available
Mini	Convertible	n/a	n/a	n/a	Available
Mini	Countryman	n/a	n/a	Available	Available
Mini	Hardtop	n/a	n/a	n/a	Available
Mitsubishi	Outlander	n/a	n/a	Available	Available
Mitsubishi	Outlander Phev	n/a	n/a	Available	Available
Mitsubishi	Eclipse Cross	n/a	Available	Available	Available
Nissan	Altima	Available	n/a	Available	Available
Nissan	Armada	n/a	Available	Available	Available
Nissan	Maxima	n/a	n/a	Available	Available
Nissan	Versa	n/a	n/a	n/a	n/a
Nissan	LEAF	Available	Available	Available	Available
Nissan	Kicks	n/a	n/a	n/a	n/a
Nissan	Murano	n/a	n/a	Available	Available
Nissan	Pathfinder	n/a	n/a	Available	Available
Nissan	Rogue	Available	Available	Available	Available
Nissan	Sentra	n/a	n/a	Available	Available
Porsche	718	n/a	Available	Available	Available
Porsche	911	n/a	Available	Available	Available
Porsche	Cayenne	n/a	Available	Available	Available
Porsche	Macan	n/a	Available	Available	Available
Porsche	Panamera	n/a	Available	Available	Available
Subaru	Crosstek	n/a	Available	Available	Available
Subaru	Ascent	n/a	Available	Available	Available
Subaru	Forester	n/a	Available	Available	Available
Subaru	Impreza	n/a	Available	Available	Available
Subaru	Legacy	n/a	Available	Available	Available
Subaru	Outback	n/a	Available	Available	Available
Subaru	WRX	n/a	Available	Available	Available
Tesla	Model S	Available	Available	Available	Available
Tesla	Model 3	Available	Available	Available	Available
Tesla	Model X	Available	Available	Available	Available

Vehicles		Lateral Features		Longitudinal Features	
Make	**Model**	**Lane Centering**	**Lane Keeping**	**Adaptive Cruise Control**	**Automated Emergency Braking**
Toyota	Avalon	n/a	Available	Available	Available
Toyota	Camry	n/a	Available	Available	Available
Toyota	Corolla	n/a	Available	Available	Available
Toyota	Corolla iM	n/a	n/a	n/a	Available
Toyota	Highlander	n/a	Available	Available	Available
Toyota	Land Cruiser	n/a	Available	Available	Available
Toyota	Mirai	n/a	Available	Available	Available
Toyota	Prius	n/a	Available	Available	Available
Toyota	Prius v	n/a	Available	Available	Available
Toyota	Corolla Hatchback	Available	Available	Available	Available
Toyota	Sequoia	n/a	Available	Available	Available
Toyota	Tacoma	n/a	Available	Available	Available
Toyota	Tundra	n/a	Available	Available	Available
Toyota	4Runner	n/a	n/a	n/a	Available
Toyota	C-HR	n/a	Available	Available	Available
Toyota	RAV4	n/a	Available	Available	Available
Toyota	Sienna	n/a	Available	Available	Available
Toyota	Yaris iA	n/a	n/a	n/a	Available
Volkswagen	Golf	n/a	Available	Available	Available
Volkswagen	Golf GTI	n/a	Available	Available	Available
Volkswagen	Golf SportWagen	n/a	n/a	Available	Available
Volkswagen	e-Golf	n/a	Available	Available	Available
Volkswagen	Beetle	n/a	n/a	n/a	Available
Volkswagen	Tiguan	n/a	Available	Available	Available
Volkswagen	Atlas	n/a	Available	Available	Available
Volkswagen	Jetta	n/a	Available	Available	Available
Volkswagen	Passat	n/a	Available	Available	Available
Volkswagen	Touraeg	n/a	Available	Available	Available
Volvo	S60	Available	Available	Available	Available
Volvo	S90	Available	Available	Available	Available
Volvo	V60	n/a	Available	Available	Available

Vehicles		**Lateral Features**		**Longitudinal Features**	
Make	**Model**	**Lane Centering**	**Lane Keeping**	**Adaptive Cruise Control**	**Automated Emergency Braking**
Volvo	V90	n/a	Available	Available	Available
Volvo	XC60	Available	Available	Available	Available
Volvo	XC40	n/a	Available	Available	
Volvo	XC90	Available	Available	Available	Available

APPENDIX B: Draft of Vehicle Orientation and Training Script – High-Capability Condition

Module 1: Study Vehicle Basic Features

Introduction

Now, we are going to spend a few minutes reviewing the basics of the vehicle so that you can begin to familiarize yourself with its features.

Learning Objectives

At the end of this process, you will be able to:

1. *Turn the vehicle on and off,*
2. *Turn the wipers on and off, and*
3. *Identify the gauges on the dash.*

I will also be pointing out other basic features such as the dual display, the heating, ventilation, and air conditioning, and the drive mode selector (including the automatic transmission gear selector and manual shift mode).

Key Fob and Start/Stop

This car features a push button start, which allows you to start the vehicle by pushing the Start/Stop button as long as the key fob is inside the vehicle. To start the vehicle, you must first depress the brake pedal, then press the Start/Stop button. If you would like only the auxiliary features on, you may push the Start/Stop button without depressing the brake pedal. To turn the vehicle off, simply hit the Start/Stop button while the vehicle is in Park. If you accidentally hit the Start/Stop button while it is in Drive or Reverse, nothing will happen. In an emergency, by pressing and holding the Start/Stop button for more than 2 seconds or rapidly pressing the Start/Stop button three times the engine will shut off.

Windshield Wipers

We should not need to use the windshield wipers today, but just in case I would like to show you the windshield wiper controls. The windshield wipers are controlled by the stalk on the right side of the steering wheel.

- **Note the adjustment features of the windshield wipers.**

HVAC

Your heating, ventilation, and air conditioning controls are located here. Note, you can control the HVAC through the buttons or through the touch screen display.

- **Point out all features: dual zone, mode, fan speed, temperature settings, and heated seats.**

Gauges

Now I would like to point out the gauges. You have a typical array of gauges including speed, fuel level, and engine temperature. This vehicle also has a Vehicle Information Display located between the speedometer and tachometer. Operation information is shown on the display for various warnings and indicators as well as the advanced features I am going to show you later.

- **Point out all the gauges on the dash. Point out steering wheel buttons to change the display.**

Gear Shift Selector

This is your gear shift selector.

- **Point out operation of the gear shift selector (including the automatic transmission gear selector and manual shift mode).**

Drive Mode

Point out the Drive Mode Selector switch and indicate how to select drive mode.

- **Drive Mode Selector (including the automatic transmission gear selector and manual shift mode)**

- **Answer any questions before proceeding to Module 2.**

Module 2: Review of Assistance Features

Introduction

We're now going to review the advanced features of the study vehicle.

There are two parts to this training:

1. *First, we will review the advanced features of the study vehicle.*
2. *Second, we will go on a short test drive. During that drive you will experience these features. During the test drive I will answer any questions you have.*
3. *After completing the test drive, we will begin the next portion of the study.*

Learning Objectives

By the end of this training session you should be able to:

1. *Name the advanced features of the study vehicle and the purpose of each feature.*
2. *Identify the alerts and/or prompts associated with each feature.*

Do you have any questions before we get started?

Part One: Review of Driver Assistance Features

The study vehicle has several advanced driver assistance features that we will be reviewing today.

Driver Assistance Description

When we are driving, there will be times that we ask you to use the lateral and longitudinal automation features. I will activate these features for you. We ask that you keep these systems active as long as you feel safe doing so.

Let's review how the features work, beginning with the longitudinal system control.

This is an adaptive cruise control system that aids you based on vehicles detected with the use of the radar sensor system in the front of the vehicle. This feature regulates the speed of the vehicle while active and automatically helps you maintain the distance to the vehicle detected in front. The system will brake automatically so that the set speed is not exceeded. You can also control the distance at which this vehicle will follow a vehicle directly in front of you. This system provides limited braking power, so the system may require the driver to apply the brakes in certain hard braking situations.

Now that we have discussed longitudinal control we will move onto lateral control. In this vehicle, the lateral control features are the lane Centering features. This means that when active, *the vehicle will perform steering corrections to help keep you centered within the travel lane. These features read lane markings and road curvature information using a camera system. Based on our testing and experience, the feature will handle most curves that we encounter during highway driving, and should only experience problems with lane centering if we travel through an area where lane markings are degraded.*

If at any point you wish to cancel the features, you can press the brake pedal to de-activate both features.

Do you have any questions before we head out on our drive?

- ***Answer any questions.***

Part Two: Test Drive

Now that we've reviewed basics associated with each feature, let's review how they work while you are driving on a short section of 460 before we begin driving the full test route. The first half of the drive will be manual driving so that you can become familiar with the study vehicle. About half way through the drive, I will activate the features for you via my laptop. At any time, if you feel unsafe to operate the vehicle with the automated features enabled, you can cancel their activation by pressing the brake pedal and resuming full manual control of the vehicle. However, when we get to the next area that the features are to be activated, I will re-activate them. Again, feel free to cancel if you feel unsafe using them.

- ***Once you have switched seats, ensure that the participant has fastened his/her seat belt. If seat belt is not fastened ask the participant to fasten it.***
    - *Before we begin driving, please fasten your seat belt.*
- ***Instruct the participant on the route, at the designated point, activate the features for the participant.***

When you reach the end of the first test route, i**nstruct the participant to park in the parking area.**

Now that you've seen how these features work, I'd like to get your initial impressions about them.

- ***Administer questionnaires.***
- ***Ensure that the participant has fastened her/his seat belt.***
- ***Answer any questions the participant might have,***

Instruct participant to continue on the test route.

APPENDIX C: Non-Driving Task Instructions

Task #1 – Reply to a Text Message

For this test trial, you will be replying to a text message while driving. Keep in mind we are not on a public road so it is okay to perform and complete this task. As before, when you reach the green traffic cone located in front of us you should be at 40 mph and maintaining about a 2-second following distance to the vehicle in front of you. Once we have passed the cone I will activate the vehicle automation which will maintain the set speed, following distance, and lane position. The task you will perform will be to reply to text messages that you receive. During the test trial, we will ask you to reply to multiple text messages. When you receive a text, you will then reply to the text message when comfortable and then say "done" when the task is complete. An experimenter will then send another text message for you to respond to. Let's go ahead and practice a task similar to what you will be performing while driving.

When you receive the text message use the smartphone to read the text message and reply to it. Once you have competed this task say "done." Do you have any questions?

Experimenter Task Preparation: Reply to a Text Message
1. Ensure the all text messages are deleted from the smartphone. 2. Place smartphone in the cup holder or on the mount 3. Make sure text message is previously entered into experimenter phone. 4. Perform practice task.

Task No.: 1.0 Practice	
Goal: Reply to a text message	
1	Experimenter sends text message "How tall are you?"
2	Participant retrieves smartphone
3	Participant presses home button
4	Participant presses home button
5	Participant opens text message application
6	Participant selects text message
7	Participant types reply to text message
8	Participant presses the send button
9	Participant says "done" when they have completed the task

Do you have any questions about the task you just performed?

The task you will be performing for this test trial will be to reply to text messages that you receive. Remember, you will reply to the text message you receive when comfortable in doing so and you will say "done" each time you respond. When I say begin you may begin driving. We will continue the length of the test track through the turn-around. You can park at the orange traffic cones as we exit the turn-around. Do you have any questions?

You can begin driving as the vehicle in front of you begins to move.

<u>Task #1.1 – Reply to a Text Message</u>

For this test trial, you will again be replying to a text message.

- *As before, when you reach the green traffic cone located in front of us you should be at 40 mph*
- *Maintaining a 2-second following distance to the vehicle in front of you*
- *Automation will then maintain your headway and lane position*

The task you will perform will be to reply to a text message that you receive using the smartphone. During the test trial, when you receive the text message and are comfortable you will reply to the text message and then say "done" when the task is complete. Please continue to respond to messages throughout the trial until we reach the stopping point.

When I say begin you may begin driving. We will continue the length of the test track through the turn-around. You can park at the orange traffic cones as we exit the turn-around. Do you have any questions?

Experimenter Task Preparation: Reply to a Text Message
1. Place smartphone in the cup holder or on the mount. 2. Make sure first text message is previously entered into experimenter phone. 3. Repeat with any of the approved text messages once the participant has replied.

Task No.: 1.1	
Goal: Reply to a text message	
Remember to reach a speed of 40 mph, and I will activate the automation. Once you reply to this first text message, please continue to respond to each message until we reach the stopping point.	
1	Experimenter sends text message "What time do you get off work today?"
2	Participant retrieves smartphone
3	Participant presses home button
4	Participant presses home button
5	Participant opens text message application
6	Participant selects text message
7	Participant types reply to text message
8	Participant presses the send button
9	Participant says "done" when they have completed the task

Do you have any comments about this task?

☐ **See Video**
☐ **No Comments**

Task #1.2 – Reply to a Text Message

For this test trial, you will again be replying to a text message.

- *As before, when you reach the green traffic cone located in front of us you should be at 40 mph.*
- *Maintaining a 2-second following distance to the vehicle in front of you*
- *Automation will then maintain your headway and lane position*

The task you will perform will be to reply to a text message that you receive using the smartphone. During the test trial, when you receive the text message and are comfortable you will reply to the text message and then say "done" when the task is complete. Please continue to respond to messages throughout the trial until we reach the stopping point.

When I say begin you may begin driving. We will continue the length of the test track through the turn-around. You can park at the orange traffic cones as we exit the turn-around. Do you have any questions?

Experimenter Task Preparation: Reply to a Text Message
4. Place smartphone in the cup holder or on the mount. 5. Make sure first text message is previously entered into experimenter phone. 6. Repeat with any of the approved text messages once the participant has replied.

Task No.: 1.2	
Goal: Reply to a text message	
Remember to reach a speed of 40 mph, and I will activate the automation. Once you reply to this first text message, please continue to respond to each message until we reach the stopping point.	
1	Experimenter sends text message "How do you like your coffee?"
2	Participant retrieves smartphone
3	Participant presses home button
4	Participant presses home button
5	Participant opens text message application
6	Participant selects text message
7	Participant types reply to text message
8	Participant presses the send button
9	Participant says "done" when they have completed the task

Do you have any comments about this task?

☐ **See Video**
☐ **No Comments**

<u>Task #1.3 – Reply to a Text Message</u>

For this test trial, you will again be replying to a text message.

- *As before, when you reach the green traffic cone located in front of us you should be at 40 mph.*
- *Maintaining a 2-second following distance to the vehicle in front of you*
- *Automation will then maintain your headway and lane position*

The task you will perform will be to reply to a text message that you receive using the smartphone. During the test trial, when you receive the text message and are comfortable you will reply to the text message and then say "done" when the task is complete. Please continue to respond to messages throughout the trial until we reach the stopping point.

When I say begin you may begin driving. We will continue the length of the test track through the turn-around. You can park at the orange traffic cones as we exit the turn-around. Do you have any questions?

Experimenter Task Preparation: Reply to a Text Message
1. Place smartphone in the cup holder or mount (participant preference). 2. Make sure first text message is previously entered into experimenter phone. 3. Repeat with any of the approved text messages once the participant has replied.

Task No.: 1.3	
Goal: Reply to a text message	
Remember to reach a speed of 40 mph, and I will activate the automation. Once you reply to this first text message, please continue to respond to each message until we reach the stopping point.	
1	Experimenter sends text message "I'm getting paint, what's your favorite color?"
2	Participant retrieves smartphone from cup holder
3	Participant presses home button
4	Participant presses home button
5	Participant opens text message application
6	Participant selects text message
7	Participant types reply to text message
8	Participant presses the send button
9	Participant says "done" when they have completed the task

Do you have any comments about this task?

☐ **See Video**
☐ **No Comments**

<u>Task #1.4 – Reply to a Text Message</u>

For this test trial, you will again be replying to a text message.

- *As before, when you reach the green traffic cone located in front of us you should be at 40 mph*
- *Maintaining a 2-second following distance to the vehicle in front of you*
- *Automation will then maintain your headway and lane position*

The task you will perform will be to reply to a text message that you receive using the smartphone. During the test trial, when you receive the text message and are comfortable you will reply to the text message and then say "done" when the task is complete. Please continue to respond to messages throughout the trial until we reach the stopping point.

When I say begin you may begin driving. We will continue the length of the test track through the turn-around. You can park at the orange traffic cones as we exit the turn-around. Do you have any questions?

Experimenter Task Preparation: Reply to a Text Message
1. Place smartphone in the cup holder or mount (participant preference). 2. Make sure first text message is previously entered into experimenter phone. 3. Repeat with any of the approved text messages once the participant has replied

Task No.: 1.4	
Goal: Reply to a text message	
Remember to reach a speed of 40 mph, and I will activate the automation. Once you reply to this first text message, please continue to respond to each message until we reach the stopping point.	
1	Experimenter sends text message "I'm renting a movie, what type of movie do you like?"
2	Participant retrieves smartphone from cup holder
3	Participant presses home button
4	Participant presses home button
5	Participant opens text message application
6	Participant selects text message
7	Participant types reply to text message
8	Participant presses the send button
9	Participant says "done" when they have completed the task

Do you have any comments about this task?

☐ **See Video**
☐ **No Comments**

Task #2 – Handheld Video

For this test trial, you will be watching video on a smartphone while driving. Keep in mind we are not on a public road so it is okay to perform and complete this task. As before, when you reach the green traffic cone located in front of us you should be at 40 mph and maintaining about a 2-second following distance to the vehicle in front of you. Once we have passed the cone I will activate the vehicle automation which will maintain the set speed, following distance, and lane position. Once the automation has activated please activate the video. Let's go ahead and practice a task similar to what you will be performing while driving.

When I tell you to begin, please unlock the phone, select the video application, choose a video, and begin watching. Once you have competed this task say "done." Do you have any questions?

Experimenter Task Preparation: Reply to a Text Message
1. Place smartphone in the cup holder or mount (participant preference). 2. Make sure first text message is previously entered into experimenter phone. 3. Repeat with any of the approved text messages once the participant has replied

Task No.: 2.0 Practice	
Goal: Select a video and begin watching	
1	Vehicle automation activates
2	Participant retrieves smartphone
3	Participant presses home button
5	Participant opens video application
6	Participant selects video of their choice
7	Participant begins watching video
9	Participant says "done" when they have completed the task

Do you have any questions about the task you just performed?

The task you will be performing for this test trial will be to watch a video of your choice. Remember, you begin when you are comfortable in doing so and you will say "done" when you begin watching the video. When I say begin you may begin driving. We will continue the length of the test track through the turn-around. You can park at the orange traffic cones as we exit the turn-around. Do you have any questions?

You can begin driving as the vehicle in front of you begins to move.

Task #2.1 – Handheld Video

For this test trial, you will again watch a video on the smartphone.

- *As before, when you reach the green traffic cone located in front of us you should be at 40 mph*
- *Maintaining a 2-second following distance to the vehicle in front of you*
- *Automation will then maintain your headway and lane position*

When I say begin you may begin driving. We will continue the length of the test track through the turn-around. You can park at the orange traffic cones as we exit the turn-around. Do you have any questions?

The task you will be performing for this test trial will be to watch a video of your choice. You can continue watching a video you started previously or select a new video. Remember, once the automation activates you may begin when you are comfortable in doing so and say "done" when you have selected and begin watching the video. When I say begin you may begin driving. We will continue the length of the test track through the turn-around. You can park at the orange traffic cones as we exit the turn-around. Do you have any questions?

Once the automation activates, please unlock the phone, select the video application, choose a video, and begin watching. Once you have competed this task say "done." Do you have any questions?

Experimenter Task Preparation: Reply to a Text Message
1. Have participant place smartphone in the cup holder or on the mount.

Task No.: 2.1 Handheld Video	
Goal: Select a video and begin watching	
1	Vehicle automation activates
2	Participant retrieves smartphone
3	Participant presses home button
5	Participant opens video application
6	Participant selects video of their choice
7	Participant begins watching video
9	Participant says "done" when they have completed the task

Do you have any comments about this task?

☐ **See Video**
☐ **No Comments**

Task #2.2 – Handheld Video

For this test trial, you will again watch a video on the smartphone.

- *As before, when you reach the green traffic cone located in front of us you should be at 40 mph*
- *Maintaining a 2-second following distance to the vehicle in front of you*
- *Automation will then maintain your headway and lane position*

When I say begin you may begin driving. We will continue the length of the test track through the turn-around. You can park at the orange traffic cones as we exit the turn-around. Do you have any questions?

The task you will be performing for this test trial will be to watch a video of your choice. You can continue watching a video you started previously or select a new video. Remember, once the automation activates you may begin when you are comfortable in doing so and say "done" when you have selected and begin watching the video. When I say begin you may begin driving. We will continue the length of the test track through the turn-around. You can park at the orange traffic cones as we exit the turn-around. Do you have any questions?

Once the automation activates, please unlock the phone, select the video application, choose a video, and begin watching. Once you have competed this task say "done." Do you have any questions?

Experimenter Task Preparation: Reply to a Text Message
1. Have participant place smartphone in the cup holder or on the mount.

Task No.: 2.2 Handheld Video	
Goal: Select a video and begin watching	
1	Vehicle automation activates
2	Participant retrieves smartphone
3	Participant presses home button
5	Participant opens video application
6	Participant selects video of their choice
7	Participant begins watching video
9	Participant says "done" when they have completed the task

Do you have any comments about this task?

☐ **See Video**
☐ **No Comments**

Task #2.3 – Handheld Video

For this test trial, you will again watch a video on the smartphone.

- *As before, when you reach the green traffic cone located in front of us you should be at 40 mph*
- *Maintaining a 2-second following distance to the vehicle in front of you*
- *Automation will then maintain your headway and lane position*

When I say begin you may begin driving. We will continue the length of the test track through the turn-around. You can park at the orange traffic cones as we exit the turn-around. Do you have any questions?

The task you will be performing for this test trial will be to watch a video of your choice. You can continue watching a video you started previously or select a new video. Remember, once the automation activates you may begin when you are comfortable in doing so and say "done" when you have selected and begin watching the video. When I say begin you may begin driving. We will continue the length of the test track through the turn-around. You can park at the orange traffic cones as we exit the turn-around. Do you have any questions?

Once the automation activates, please unlock the phone, select the video application, choose a video, and begin watching. Once you have competed this task say "done." Do you have any questions?

Experimenter Task Preparation: Reply to a Text Message
1. Have participant place smartphone in the cup holder or on the mount.

Task No.: 2.3 Handheld Video	
Goal: Select a video and begin watching	
1	Vehicle automation activates
2	Participant retrieves smartphone
3	Participant presses home button
5	Participant opens video application
6	Participant selects video of their choice
7	Participant begins watching video
9	Participant says "done" when they have completed the task

Do you have any comments about this task?

☐ **See Video**
☐ **No Comments**

Task #2.4 – Handheld Video

For this test trial, you will again watch a video on the smartphone.

- *As before, when you reach the green traffic cone located in front of us you should be at 40 mph*
- *Maintaining a 2-second following distance to the vehicle in front of you*
- *Automation will then maintain your headway and lane position*

When I say begin you may begin driving. We will continue the length of the test track through the turn-around. You can park at the orange traffic cones as we exit the turn-around. Do you have any questions?

The task you will be performing for this test trial will be to watch a video of your choice. You can continue watching a video you started previously or select a new video. Remember, once the automation activates you may begin when you are comfortable in doing so and say "done" when you have selected and begin watching the video. When I say begin you may begin driving. We will continue the length of the test track through the turn-around. You can park at the orange traffic cones as we exit the turn-around. Do you have any questions?

Once the automation activates, please unlock the phone, select the video application, choose a video, and begin watching. Once you have competed this task say "done." Do you have any questions?

Experimenter Task Preparation: Reply to a Text Message
1. Have participant place smartphone in the cup holder or on the mount.

Task No.: 2.4 Handheld Video	
Goal: Select a video and begin watching	
1	Vehicle automation activates
2	Participant retrieves smartphone
3	Participant presses home button
5	Participant opens video application
6	Participant selects video of their choice
7	Participant begins watching video
9	Participant says "done" when they have completed the task

Do you have any comments about this task?

☐ **See Video**
☐ **No Comments**

Task #3 – Baseline Driving

For this test trial, you will not be performing any tasks besides driving. As before, when you reach the green traffic cone located in front of us you should be at 40 mph and maintaining about a 2-second following distance to the vehicle in front of you. Once we have passed the cone I will activate the vehicle automation which will maintain the set speed, following distance, and lane position. During the test trial, we will not ask you to perform any tasks other than driving.

Experimenter Task Preparation: Baseline
1. Ensure the smartphone is in the cup holder or on the mount. 2. Provide instructions for each baseline trial

When I say begin you may begin driving. We will continue the length of the test track through the turn-around. You can park at the orange traffic cones as we exit the turn-around. Do you have any questions before we begin?

You can begin driving as the vehicle in front of you begins to move.

APPENDIX D: Questionnaires

Demographic Questionnaire

Participant Number:
Date:
Time:

Results of Color Vision Test
Color Vision: Passed Did Not Pass

Basic Information

1. What is your age in years?

2. What is your gender? Circle one
a. Male
b. Female

3. Are you left- or right-handed?
a. Right
b. Left
c. Ambidextrous

4. Is English your primary language? Circle one.
a. Yes
b. No

5. What is the highest level of education you have completed? Circle one.
a. Elementary school
b. High school or equivalent
c. Vocational/technical school (2-year)
d. Some college
e. Bachelor's degree
f. Master's degree
g. Doctoral (Ph.D.) or professional (M.D., J.D., Psy.D.) degree

Technology Experience

6. What smartphone do you own? Please list.

7. How long have you used a smartphone? Circle one.
a. Under 2 years
b. More than 2 years, but less than 4 years
c. Over 4 years

8. Do you use your smartphone on a daily basis? Circle one.
a. Yes
b. No

9. What tasks do you typically perform on your smartphone? Check all that apply.
o E-mail
o Gaming
o Navigation
o Taking pictures
o Scheduling and calendar tasks
o Social networking
o Text messaging
o Web browsing
o Other (please list):

10. Do you do typically perform any of the above tasks while driving? If so, please list the tasks, estimate how often (daily, weekly, etc.), and the situations you might perform them (e.g., stopped at a light).

Task Frequency Situation

11. When your smartphone is paired with your vehicle, do you use any functions such as music, navigation, hands-free calling, etc.? If so please list the functions you typically use.

Driving Related Questions

12. At what age, in years, did you receive your full/unrestricted driver's license?

13. How many people of driving age live in your household? How many are licensed drivers?

__________ people of driving age

__________ are licensed drivers

14. Please estimate your average annual miles driven over the last year. Round to the nearest thousand miles.
__________,000 miles

15. Please list and briefly describe any moving violations you have received in the past 3 years.

16. Please list the year, make, and model of all vehicles you currently own or operate on a regular basis, and any driver assistance systems, such as cruise control, back-up camera, or collision warnings that you have on your current vehicle.

	Vehicle 1	Vehicle 2	Vehicle 3
Year			
Make			
Model			
Driver Assistance Features			

17. Are you planning to purchase a vehicle in the coming year? If so can you describe the type of vehicle you're looking for?

18. Have you driven a vehicle with any crash warning systems, such as those that warn you of a head-on crash or of a lane departure while you are driving? These types of systems provide a warning if you are approaching too quickly or are about to crash into a car in front of you, or if you start to drift out of your lane, while you are driving on roads. If so, please describe the vehicle.

19. Have you driven a vehicle with adaptive cruise control? This is not cruise control. Instead, adaptive cruise control automatically slows down to make space for cars in front of you, without the driver having to press the brake. If so, please describe the vehicle.

20. Have you driven a vehicle with a system that helps you maintain your lane position? Note that this is not referring to power steering on a car. Instead, this is a system that warns if you leave your lane without a turn signal and automatically steer your vehicle back into the lane. If so, please describe the vehicle.

General Opinion Questionnaire

Date: __________
Participant Number: __________

Circle the number that best describes your feeling or impression.

Lateral Control Features

1.) I can rely on the lateral control features to function properly while I am doing something else.

1	2	3	4	5	6	7
Strongly Disagree	Moderately Disagree	Slightly Disagree	Neither Agree Nor Disagree	Slightly Agree	Moderately Agree	Strongly Agree

2.) The lateral control features are dependable.

1	2	3	4	5	6	7
Strongly Disagree	Moderately Disagree	Slightly Disagree	Neither Agree Nor Disagree	Slightly Agree	Moderately Agree	Strongly Agree

3.) I am familiar with the lateral control features.

1	2	3	4	5	6	7
Strongly Disagree	Moderately Disagree	Slightly Disagree	Neither Agree Nor Disagree	Slightly Agree	Moderately Agree	Strongly Agree

4.) I felt safe using the lateral control features.

1	2	3	4	5	6	7
Strongly Disagree	Moderately Disagree	Slightly Disagree	Neither Agree Nor Disagree	Slightly Agree	Moderately Agree	Strongly Agree

5.) I trust the lateral control features.

1	2	3	4	5	6	7
Strongly Disagree	Moderately Disagree	Slightly Disagree	Neither Agree Nor Disagree	Slightly Agree	Moderately Agree	Strongly Agree

Longitudinal Control Features

6.) I can rely on the longitudinal control features to function properly while I am doing something else.

1	2	3	4	5	6	7
Strongly Disagree	Moderately Disagree	Slightly Disagree	Neither Agree Nor Disagree	Slightly Agree	Moderately Agree	Strongly Agree

7.) The longitudinal control features are dependable.

1	2	3	4	5	6	7
Strongly Disagree	Moderately Disagree	Slightly Disagree	Neither Agree Nor Disagree	Slightly Agree	Moderately Agree	Strongly Agree

8.) I am familiar with the longitudinal control features

1	2	3	4	5	6	7
Strongly Disagree	Moderately Disagree	Slightly Disagree	Neither Agree Nor Disagree	Slightly Agree	Moderately Agree	Strongly Agree

9.) I felt safe using the longitudinal control features.

1	2	3	4	5	6	7
Strongly Disagree	Moderately Disagree	Slightly Disagree	Neither Agree Nor Disagree	Slightly Agree	Moderately Agree	Strongly Agree

10.) I trust the longitudinal control features.

1	2	3	4	5	6	7
Strongly Disagree	Moderately Disagree	Slightly Disagree	Neither Agree Nor Disagree	Slightly Agree	Moderately Agree	Strongly Agree

11.) Considering both lateral and longitudinal control features available in the vehicle, please rate your overall level of trust the vehicle.

1	2	3	4	5	6	7
Strongly Disagree	Moderately Disagree	Slightly Disagree	Neither Agree Nor Disagree	Slightly Agree	Moderately Agree	Strongly Agree

Modified van der Laan Questionnaire

Date: __________
Participant Number: __________

Each item contains a description of each end of the scale. For each item, circle the number that best describes your feeling or impression.

I find the System:

Useless 1 2 3 4 5 6 7 Useful

I find the System:

Unpleasant 1 2 3 4 5 6 7 Pleasant

I find the System:

Bad 1 2 3 4 5 6 7 Good

I find the System:

Annoying 1 2 3 4 5 6 7 Nice

I find the System:

Superfluous 1 2 3 4 5 6 7 Effective

I find the System:

Irritating 1 2 3 4 5 6 7 Likeable

I find the System:

Worthless 1 2 3 4 5 6 7 Assistive

I find the System:

Undesirable 1 2 3 4 5 6 7 Desirable

I find the System:

Sleep Inducing 1 2 3 4 5 6 7 Raises Alertness

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