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Effects of Training Content and Approach on Drivers' Understanding of and Performance with Advanced Driver Assistance Systems

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Title

Effects of Training Content and Approach on Drivers' Understanding of and Performance with Advanced Driver Assistance Systems

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Foreword

Technology that partially automates some components of the task of driving, such as keeping the vehicle in its lane, controlling its speed, and maintaining a gap to the vehicle ahead, is becoming increasingly common in vehicles available to consumers. Research by the AAA Foundation for Traffic Safety has shown the importance of ensuring that drivers have a proper understanding of these systems. Our research has also shown that proper understanding of these technologies can be improved through training. However, little is known about how features of training influence its effectiveness.

This report presents research that investigated how several aspects of training influence drivers' understanding of and driving performance with advanced driver assistance systems and partial driving automation technologies. The report should be of interest to automobile manufacturers, driver education professionals, human factors researchers, and other stakeholders interested in promoting safe mobility.

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About the Sponsor

AAA Foundation for Traffic Safety
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Founded in 1947, the AAA Foundation for Traffic Safety in Washington, D.C., is a nonprofit, publicly supported charitable research and educational organization dedicated to saving lives by preventing traffic crashes and reducing injuries when crashes occur. Funding for this report was provided by voluntary contributions from AAA/CAA and their affiliated motor clubs, individual members, AAA-affiliated insurance companies, and other organizations or sources.

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Abbreviations

ACC	Adaptive Cruise Control
ADAS	Advanced Driver Assistance Systems
BSM	Blind Spot Monitoring
FCW	Forward Collision Warning
HMI	Human-Machine Interface
LC	Lane Centering
LDW	Lane Departure Warning
LKA	Lane Keeping Assistance
PA	Partial Automation
SAE	Society of Automotive Engineers
SDLP	Standard Deviation of Lane Position

Executive Summary

Advanced Driver Assistance Systems (ADAS), designed to assist drivers with various aspects of driving, are becoming increasingly common. Lane Keeping Assistance (LKA) is designed to prevent drivers from departing their lane unintentionally. Adaptive Cruise Control (ACC) is designed to maintain a driver-specified speed and gap to the vehicle ahead. Partial automation (PA) systems combine ACC with technology designed to keep the vehicle centered in its lane. These technologies have the potential to make driving safer and more comfortable; however, it is important for drivers to understand their capabilities as well as their limitations. Although previous research has shown that drivers' understanding of ADAS can be improved through training, not much is known about what features of training influence its effectiveness. The purpose of this research was to investigate how training content, style, and mode of delivery influence drivers' understanding of and performance with ADAS. This research consisted of two experiments. Experiment 1 investigated the impact of training content. Experiment 2 examined the impact of training mode and style.

Methodology

In Experiment 1, 60 participants were divided into three training groups. All participants received baseline training that explained what each ADAS feature was intended to do, how to activate and deactivate it, as well as information about its limitations (e.g., not working reliably in inclement weather). One group received only the baseline training, one group received the baseline training plus interactive question-and-answer style feedback, and one group received the baseline training plus additional training about driver-related issues (e.g., importance of avoiding distractions, maintaining situational awareness, not trusting the technology to do things it cannot do).

In Experiment 2, a separate group of 60 participants were divided into four training groups. Half of the participants received video-based training, and the other half received training inside of an actual vehicle. Within each of those two groups, half received a passive demonstration and half received interactive practice. Interactive video practice involved responding to periodic questions for the participant to apply what they had learned; interactive in-vehicle practice involved driving the vehicle on a closed course and operating the ADAS.

In both experiments, all participants completed questionnaires prior to training that measured their general driving experience and their knowledge of and experience with ADAS. Then they completed the training assigned to their group. After training, they completed another questionnaire to investigate whether their knowledge of ADAS had changed. They also drove in a driving simulator that simulated the functions of LKA, ACC, and PA features. Various measures of their decision-making and performance were

examined when they encountered situations in which the ADAS was not designed to work reliably and driver intervention was required.

Key Findings

Results confirmed that all types of training examined in both experiments, regardless of content, style, or mode, generally increased the accuracy of drivers' knowledge about ADAS. More specifically, results showed:

- Training that included feedback produced the greatest increases in knowledge.
- In-vehicle training resulted in greater knowledge gains than video-based training.
- Video-based practice led to marginally greater knowledge gains than video-based demonstration, but knowledge gains associated with in-vehicle training did not differ between demonstration versus practice.

Results related to driving performance measures were mixed.

- There was no evidence that any type of training led to significantly better decision-making in terms of deactivating the vehicle systems in situations where they would not work reliably.
- Some findings suggested that in-vehicle training might lead to better decision-making in situations most similar to situations in the training, and that video-based training might produce better decision-making across a wider range of scenarios, but those findings were inconclusive.
- Some training types led to faster response times or better steering control in some specific comparisons, but those results were inconsistent and were tempered by the lack of evidence that they led to better decision-making.

Overall, results confirm that drivers' understanding of the capabilities and limitations of ADAS can be improved through training, and provide valuable insights into the features of training that lead to greater gains in knowledge. More research is needed to understand the relationship between training drivers about ADAS and real-world safe driving performance.

Introduction

Advanced Driver Assistance Systems (ADAS), designed to provide assistance to drivers in challenging driving scenarios, has showed its potential to prevent crashes and improve driving safety (Wang, 2019). According to projections from the Highway Loss Data Institute (2022), it is anticipated that approximately 50% of vehicles will be equipped with specific ADAS technologies by 2026. Adaptive Cruise Control (ACC), which automatically adjusts a vehicle's speed to maintain a user-specified following distance from the vehicle ahead, is one of the key control assistance features of ADAS. Lane Keeping Assistance (LKA), which helps to prevent unintentional lane departures by detecting the lane markings and making necessary steering adjustments if the vehicle starts to cross the lane marking without the turn signal activated, is another key feature. In accordance with the Society of Automotive Engineers (SAE) definition of driving automation (SAE, 2016), Level 2 (L2) partial driving automation integrates ACC and Lane Centering (LC), which involves the automatic execution of both longitudinal and lateral control in specific driving conditions. However, L2 systems still require the human driver to act as a failsafe, paying attention to the driving environment and being prepared to respond to any hazards that may materialize. Many vehicles sold in the United States today already include L2 partial driving automation systems as optional or standard equipment.

This growing deployment of ADAS in vehicles signals a transformative change in how human drivers interact with their vehicles. While ADAS offers the promise of enhanced safety, it is crucial to recognize its inherent limitations. It is imperative for drivers to maintain awareness of changes in traffic conditions and utilize ADAS as a supportive system rather than a complete replacement for active driving. In a recent study conducted by AAA (2022), road tests involving five ADAS systems with L2 automation revealed a concerning frequency of adverse events, such as lane departures, erratic lane positioning, and failures to decelerate or stop, occurring approximately once every 8 miles. The majority (73%) of these incidents were linked to the lane-keeping feature of ADAS. Furthermore, the study reported that drivers tended to become more distracted when ADAS was active, suggesting a potential over-reliance on the system. Empirical studies suggested that ADAS may introduce new human factors issues that arise during driving (Saffarian et al., 2012). Significant concerns regarding potential adverse impacts of ADAS in general and L2 partial driving automation in particular include drivers' overtrust on ADAS (Victor et al., 2018), diminished situation awareness (Stanton & Young, 2005), and misperceptions regarding the functioning of automation (McDonald et al., 2018).

In order to fully achieve the potential benefits offered by ADAS, it is crucial to provide drivers with effective education about both the capabilities and limitations of these systems. Much research to date has consistently shown that drivers without adequate training can easily misinterpret the capabilities and constraints of ADAS, leading to potentially hazardous misuse that jeopardizes their safety and that of other road users (Gaspar et al., 2000). The majority of these studies primarily focus on key ADAS features, such as LKA, ACC, and collision prevention functions; however, few studies have examined training effectiveness for L2 partial driving automation. For a comprehensive overview of these research efforts, Table 1 offers a concise summary of studies dedicated to ADAS training and their corresponding characteristics.

Among the reviewed studies, most training initiatives consistently incorporate crucial content, encompassing information about automation functions (e.g., general ADAS knowledge, human-machine interface (HMI) design, ADAS activation/deactivation and the transition between driving modes, and capabilities and limitations). It is worth noting that in their study of training for conditionally automated driving, Ebnali et al. (2021) included driver-related issues in their training content, including considerations related to situational awareness and overtrust concerns. However, this work specifically investigated training for Level 3 (L3) conditional automation systems, which are not yet available on the U.S. market as of the date of this report, rather than L2 partial driving automation systems such as those currently available to U.S. consumers.

The effectiveness of these training programs has been primarily assessed through three key dimensions, including drivers' comprehension of ADAS, their practical performance in utilizing these systems, and subjective evaluations. To evaluate drivers' understanding of ADAS, prior studies commonly used knowledge questionnaires that probe various ADAS functions and transition tasks (Forster et al., 2019a; Forster et al., 2019b; Ebnali et al., 2021; Zahabi et al., 2021; Beggiato et al., 2015). Driver performance while using ADAS was measured with metrics such as reaction time, time headway, speed, and lateral control stability. Additionally, researchers have also evaluated the effectiveness of training with the measures of attention allocation (Zahabi et al., 2020) and the frequency with which drivers use ADAS (Singer & Jenness, 2020).

Despite previous research efforts, there remains a notable gap in our understanding of the crucial information that should be included in ADAS training programs and the extent of knowledge necessary for drivers to safely and effectively utilize these systems. While many studies have explored the effectiveness of various ADAS training approaches, fewer have focused on the specific content of these training programs. There is a general lack of research identifying the essential content that enhances drivers' understanding of ADAS, improves overall performance, and influences their subjective evaluation of these systems. Additionally, existing investigations have often confounded training modes with training styles, making it unclear whether these factors influence drivers' interaction with ADAS in different ways.

Table 1. Review of Studies on Training Content and Approaches for L2 ADAS

	Training Approach	Training Content	Measurements	Main Findings	Systems
Forster et al 2019a	• Manual instruction • Interactive tutorial demo	Generic information, activate/deactivate, capabilities and limitations, HMI	• Knowledge • Subjective rating of the usage performance	Both modes improve knowledge and performance. Interactive tutorial is better for transitions from L2 to L3.	L2 & L3
Koustanaï et al., 2012	• Manual instruction • Simulator practice with manual instruction	Activate/deactivate, capabilities and limitations	• Knowledge • Usage performance • Trust • Acceptance • Workload • Confidence	Simulator training promoted a better understanding and safer behavior, increased trust, lower workload than training with manuals.	FCW
Singer & Jenness, 2020	• Manual instruction • Video demo • In-person instruction	• Activate/deactivate, HMI, general info of the system, • capabilities and limitations	• Usage performance • Knowledge • Usefulness	In-vehicle practice leads to better usage performance compared to other two trainings.	L2 (ACC)
Abraham et al., 2017	In-vehicle instruction	• Activate/deactivate of ACC • General info of the system (LDW, BSM, and FCW)	• Subjective rating of the system • Interview questions regarding their driving experience	In-vehicle training was reported to help reduce feelings of confusion and boost driver confidence	ACC, LDW, BSM, FCW
Zahabi et al., 2020; Zahabi et al., 2021	• Video demo • Simulator practice with in-person demo	System purpose, levels of ADAS and limitations, activate/ deactivate, HMI	• Driving performance • Attention allocation • Mental workload • Knowledge • Trust	Video training is more effective in improving driver performance, reducing off-road attention allocation and mental workload for females, whereas the simulator training is more beneficial for males.	ACC, LKA
Mueller et al., 2020	Video demo	General introduction of ACC and LC, with and without the information on HMI	• Knowledge • Usability	Training improves detection of L2 notifications for LC but not for ACC.	L2 (ACC & LC)
Boelhouwer et al., 2019	Manual instruction	Generic information, capabilities and limitations,	• Knowledge • Takeover decisions	The training of system information based on owner manuals did not support drivers in their take-over decisions.	L2

Notes: HMI (Human-Machine Interface); FCW (Forward Collision Warning); LDW (Lane Departure Warning); BSM (Blind Spot Monitoring)

The goal of this project was to investigate the impact of training content and training approaches on drivers' usage of three key ADAS features, including ACC, LKA, and an L2 partial driving automation system. More specifically, the study evaluates the effectiveness of training in enhancing drivers' comprehension of ADAS capabilities and limitations, their ability to make informed decisions about when to use ADAS, their overall driving performance, and their subjective assessments of ADAS. The research comprised two experiments. Experiment 1 focused on training content. It compared training that only contained general information about ADAS capabilities and limitations, training that also addressed driver issues (e.g., overtrust, situation awareness), and training with feedback provided. Experiment 2 focused on training approaches. It compared two different modes of training (computer-based versus in-vehicle) and two styles of training (passive versus interactive).

Through this investigation, the research aims to provide useful insights into the efficacy and impact of different training content on enhancing drivers' understanding of ADAS, potentially shaping future training protocols in the realm of driver-assistance technologies.

EXPERIMENT 1: TRAINING CONTENT

In this experiment, a between-subject design was used to compare driver knowledge, decision-making, driving performance, and subjective evaluations of ADAS in relation to the content of training provided. Study participants were recruited to complete training about ACC, LKA, and an L2 partial driving automation system (PA) that combined ACC and LC. Before receiving training, participants completed a questionnaire about their demographic characteristics, driving experience, and baseline knowledge of ADAS. Participants were then randomly assigned to complete one of three versions of the ADAS training: baseline training, baseline training enhanced with discussion of driver-related issues, or baseline training with feedback. After completing the training, participants completed another questionnaire measuring their knowledge and subjective evaluations of ADAS. Various measures of their driving performance were measured in a driving simulator in which they drove with ACC, LKA, and PA and encountered limitations of the systems. Statistical analyses compared measures of knowledge, driving performance, and subjective evaluations of ADAS in relation to the type of training completed.

Method

Participants

Sixty participants (40 females and 20 males) were recruited for this experiment. Inclusion criteria required participants to hold a valid U.S. driver's license and have proficiency in English. Recruitment efforts were conducted through the StudyFinder website, email lists, and flyers distributed in the State College, Pennsylvania, region. StudyFinder is a public participant recruitment website hosted by Pennsylvania State University. The participants' ages ranged from 18 to over 55 years old. In terms of race and ethnicity, the sample composition was as follows: 60.0% Caucasian, 30.0% Asian, 1.7% African-American, and 8.3% from other racial and ethnic backgrounds. Seventy percent of participants had more than 3 years of driving experience, 25% had 1 to 3 years of driving experience, and 5% had less than one year of driving experience. The study was approved by the Institutional Review Board of Pennsylvania State University. Participants were compensated with $30 after the experiment.

Experimental Design

The experiment adopted a between-subjects design, with the independent variable being the type of training content. Three distinct categories of training content were developed. Each participant was assigned at random to receive one of the three categories of training content, leading to a total of 60 participants evenly distributed across the three groups described below.

Baseline Training (T1). Participants assigned to this group received a baseline training that provided a foundational overview of the three ADAS features, including ACC, LKA, and PA. This training included general descriptions of three ADAS features, instructions on how to activate and deactivate these functions, explanations of the associated HMI designs, and a discussion of the limitations of each feature (Appendix A).

Training with Driver-Related Issues (T2). Participants assigned to this group received the same baseline training as drivers assigned to T1, and then also received supplementary training on driver-related issues. This included topics such as drivers' tendency to overtrust ADAS, the risk of diminished situation awareness, and common misconceptions about the capabilities of the systems.

Feedback-Based Training (T3). Participants assigned to this group received the same baseline training as drivers assigned to T1, with the addition of feedback-based training. The additional feedback, after completing the knowledge test (described subsequently), aimed to correct and reinforce their understanding of the ADAS features.

Procedure

Upon arrival at the lab, participants were introduced to the study and asked to sign a consent form. They then completed a demographic questionnaire (described below) and provided information on their driving experience and familiarity with ADAS features.

Following this, participants took a pre-knowledge test (described below) to assess their understanding of ACC, LKA, and PA. Participants in the T1 and T2 groups completed the pre-knowledge test without receiving feedback, whereas those in the T3 group received immediate feedback on their answers from the Qualtrics system, which marked incorrect answers and provided the correct responses. Additionally, participants in T3 group engaged in discussions with the experimenter to clarify any misconceptions. The experimenter briefly reviewed the incorrect responses, providing specific explanations about why certain answers were wrong. For example, when explaining the LKA knowledge test question, "Lane Keeping Assistance works well in bright, direct sunlight," the experimenter explained that LKA does not work well in such conditions due to the reflection of the lane lines, which interfere with system detection.

After the pre-knowledge test, all participants watched a video training that corresponded to their assigned training group (T1, T2, or T3). T1 and T3 participants viewed the basic training video, whereas T2 participants watched a video that included additional content addressing driver-related issues. Following the video training, participants completed the post-training knowledge test, which contained the same questions as the pre-knowledge test. The purpose of these tests was to compare the effectiveness of the three types of training content.

Participants then proceeded to the driving simulator (described below) where their decision-making and driving performance with ADAS were assessed in a simulated driving test. Before the test, they received a general tutorial on operating the driving simulator, which allowed them to familiarize themselves with the simulator's steering wheel, pedals, and buttons. During this tutorial, participants were also introduced to the three ADAS features: ACC, LKA, and PA. They then engaged in a practice drive that simulated a scenario similar to the tutorial, aimed at practicing their ability to operate these features successfully while navigating rural roads and highways.

Following the practice drive, participants completed a series of nine testing scenarios (see Table 2), each featuring different limitation conditions of ADAS systems, such as inclement weather, tunnels, speed changes, and heavy traffic. Before each scenario, written instructions were displayed on the driving simulator, prompting participants to activate the assigned ADAS features at the start of the scenario when they felt it was safe. Participants were instructed to deactivate the feature when they perceived the scenario had reached the limitations of the respective ADAS feature and were encouraged to reactivate it if they believed it could function properly again. At the beginning of each scenario, they were reminded to activate the instructed ADAS feature and use it appropriately based on their understanding of the feature. To mitigate driver fatigue, each trial lasted a maximum of 2 minutes, with the entire driving session lasting approximately 20 minutes.

Materials

Training Content. The baseline training program was delivered through a video program designed to acquaint participants with essential information about ADAS systems. The training focused on three specific ADAS features: ACC, LKA, and PA. For the purpose of the current study, the PA system was modeled after Hyundai's Highway Driving Assist (HDA) as implemented in the 2023 Hyundai Elantra HEV Limited, as this system comprises the core functionalities of interest for the current study and also because this was the vehicle that the research team obtained for use in Experiment 2 (described subsequently). For the purposes of Experiment 1, the PA system used throughout this part of the study was HDA.

The training program systematically introduced each feature—ACC, LKA, and HDA—starting with a comprehensive overview. This included a general description, activation and deactivation procedures, and HMI designs. The descriptions were based on the vehicle owner's manual (Figure 1), presented with textual explanations and visual aids. As illustrated in Figure 2, the training then detailed the activation and deactivation processes using both text and images. For ACC, additional guidance was provided on setting the speed and adjusting the vehicle-to-vehicle distance as part of the activation process, while for LKA and HDA, the focus was solely on turning the features on and off. The training also covered the relevant HMI indicators, explaining how these change during activation and deactivation. Since HDA integrates ACC and LC, the video first explained LC, including key differences relative to LKA, before introducing HDA, highlighting its integration with ACC to enable the full HDA functionality. The complete training materials are provided in Appendix A.

Figure 1. Description of Adaptive Cruise Control

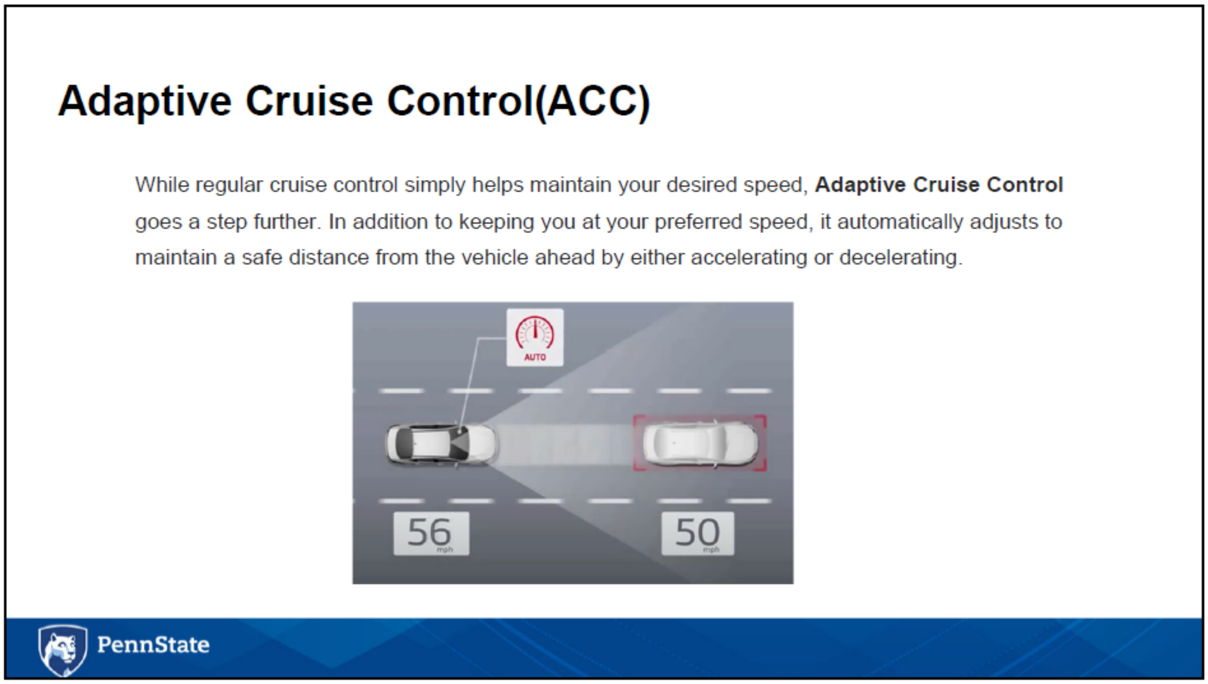
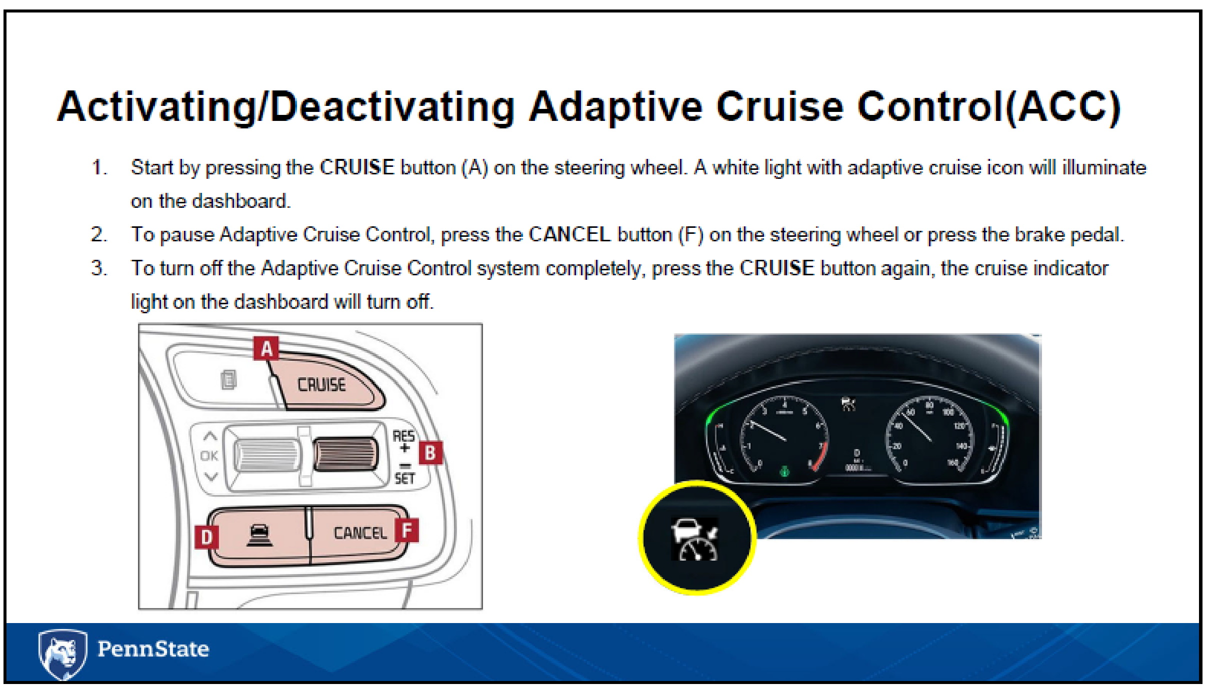
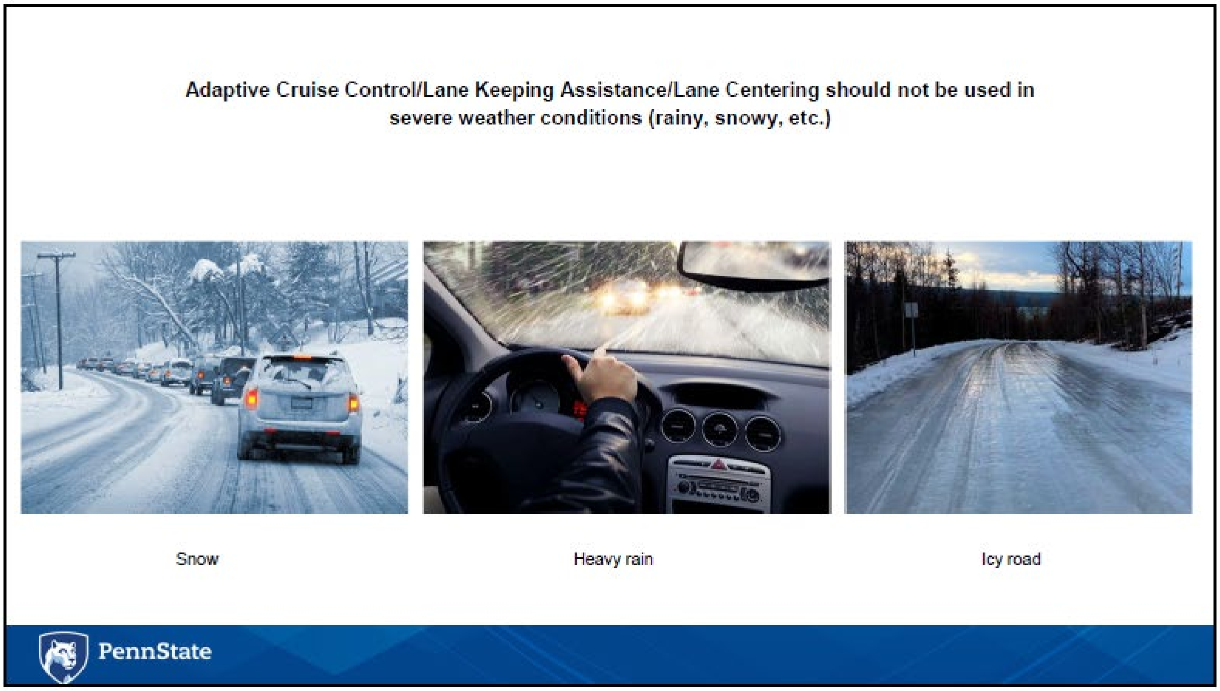


Figure 2. Detailed Procedure for Activating and Deactivating ACC



In the second part of the training, the limitations of ACC, LKA, and PA were extensively covered. A thorough review of owner's manuals, official websites, and YouTube videos was conducted to compile this information. Common limitation categories identified for ACC and LKA included adverse weather conditions, lighting conditions, roadway designs, and static and dynamic road events. An additional limitation was added for LKA concerning lane line visibility, and rapid speed changes were noted as a limitation for ACC. As shown in Figure 3, each limitation category was clearly described, with accompanying images illustrating typical examples. For HDA, the limitations were explained through the general operational rules of this L2 function.

Figure 3. An Example of Weather-Related Limitation Training



Participants assigned to receive the T3 driver-related issues training were also educated about common issues associated with ADAS, including overtrust, false assumptions, and reduced situational awareness, presented in a bullet-point format. Participants were strongly encouraged to prioritize safe driving practices and eliminate distractions.

- **Overtrust** was demonstrated through scenarios where drivers excessively relied on ADAS technology, potentially neglecting their responsibility for safe driving. The training emphasized that ADAS systems are aids, not replacements for drivers.
- **Reduced situational awareness** was explained, with an emphasis on the necessity of maintaining awareness of the driving environment to identify potential hazards and respond effectively.

- **False assumptions** were addressed by explaining how drivers mistakenly believe they can safely engage in activities like phone use or adjusting entertainment systems while driving. The training highlighted the importance of avoiding distractions.

Questionnaires.

Demographic and Driving Experience Questionnaire. This questionnaire was designed to gather demographic information from participants, including their age, gender, ethnicity, education level, and employment status. Additionally, it included questions related to participants' driving experience, such as the number of years they have been driving, their driving frequency, and their self-assessed confidence in driving. Copies of questionnaires are provided in Appendices B, C, and D.

ADAS Experience Questionnaire. This questionnaire was designed to assess participants' familiarity with ADAS functions. It included questions regarding the ownership of a vehicle equipped with key ADAS features (e.g., ACC, LKA, and HDA) and the frequency of their utilization. Additionally, participants' comfort and satisfaction levels when using ADAS functions were evaluated using a 5-point Likert scale, where a score of 1 indicated "extremely uncomfortable/unsatisfied" and a score of 5 indicated "extremely comfortable/satisfied."

Pre- and Post-Training Knowledge Test. This questionnaire was developed to assess drivers' understanding of the ADAS functions. Multiple choice questions were designed to measure participants' recognition of HMI indicators and the activation/deactivation of each ADAS function. Then a set of true or false questions were designed to measure drivers' understanding of limitations of ACC, LKA, and HDA.

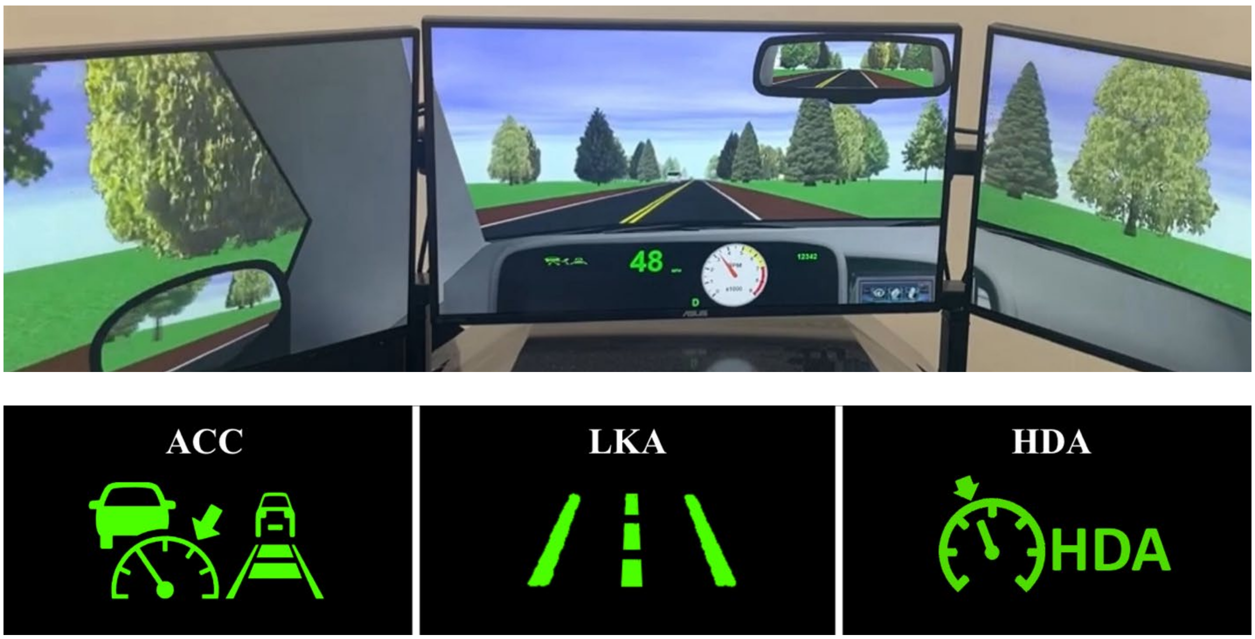
Subjective Evaluation. Additionally, participants' comfort and satisfaction levels when using ADAS functions were evaluated using a 5-point Likert scale, where a score of 1 indicated "extremely uncomfortable/unsatisfied" and a score of 5 indicated "extremely comfortable/satisfied." Drivers' subjective ratings were collected after the test drive. The subjective evaluation included driver trust (Checklist for Trust between People and Automation [Jian et al., 2000]), acceptance (Automation and System Acceptance Questionnaire [Van Der Laan et al., 1997]), and workload (NASA Task Load Index [NASA-TLX; Hart & Staveland, 1998]).

Driving Simulator Apparatus. The study employed a fixed-base console driving simulator, the STISIM Drive® M300WS-Console system, to assess drivers' decision-making concerning ADAS limitations and their post-training driving performance within the testing scenarios. As depicted in Figure 4, the driving simulator was installed on a Dell™ workstation and consisted of three driving displays, which allowed for a 135° field of view. The simulator setup also included the high-fidelity STISIM Drive® ADS, full-size steering wheel with active force feedback, and two advanced foot pedals. The STISIM

Drive® software was programmable and expandable through the Open Module, enabling the customization of ADAS features, including ACC, LKA, and Hyundai HDA as an L2 partial automation system feature.

The ADAS features implemented in the simulator was representative of the 2023 Hyundai Elantra HEV Hybrid Limited vehicle and incorporated realistic icons and indicators of the user interface, as shown in Figure 4. All the ADAS indicators were displayed on the left side of the instrument panel. The driving speed was presented in green digits on the center of the panel. The aspects of system function were designed to match the Hyundai Elantra system.

Figure 4. STISIM Driving Simulator and ADAS Indicators



Activation and Deactivation of ADAS Features. Each feature was activated by pressing the corresponding programmable buttons located on the sides of the steering wheel (see Figure 5). As shown in Figure 5(a), LKA and HDA features could be activated or deactivated by pressing the respective labeled buttons on the panel at the left-hand side of the steering wheel. The green button on the right was not used in the experiment. As shown in Figure 5(b), participants could activate ACC by pressing the ACC button on the right-hand side of the steering wheel. The driving speed could be increased or reduced by pressing the (+/-) speed button. The adjustment of the following distance was not simulated in the experiment due to the limited number of programmable buttons. A moderate following distance was preselected, and participants were informed that they could only manipulate the speed.

Figure 5. ADAS Features Activation/Deactivation and Settings in the STISIM Driving Simulator: (a) ACC System and Speed Adjustment; (b) HDA and LKA Setting

(a) Left side

(b) Right side

Simulation of ACC Functionality. In the STISIM driving simulator, the ACC was simulated so that when activated, the simulated subject vehicle automatically adjusted its speed either to the speed set by the participant or to match the speed of the car in front, ensuring a safe following distance. It could slow the vehicle down when traveling at speeds of 10 mph or higher. ACC had limitations in complex driving environments, such as low-light conditions, heavy or varying traffic, sharp curves, and could not automatically match its speed with posted speed limit.

Simulation of LKA Functionality. In the STISIM driving simulator, when the LKA was activated, the subject vehicle detected its lateral position relative to the lane lines on both sides. If the system detected that the vehicle is starting to drift out of its lane without the use of turn signals, it provided gentle steering input to steer the vehicle back into the lane. LKA relied on the clear detection of lane lines on both sides of the vehicle, which means it had limitations in conditions where lane lines are not clearly visible, such as in foggy weather or when lane lines are faded.

Simulation of L2 Partial Driving Automation Functionality. L2 partial driving automation in the STISIM driving simulator was designed to replicate the functionality of the HDA system in the 2023 Hyundai Elantra, which the research team regarded as representative example of an L2 partial driving automation feature available on the U.S. market at the time of the study and was the vehicle/system used by the research team for a portion of Experiment 2 (described subsequently). In Hyundai's HDA system, ACC and LC work in conjunction as a PA system to maintain a safe distance from the vehicle in front, keep the vehicle centered in the lane, and ensure adherence to the speed limit using GPS location and available highway data. LC is a feature of ADAS that provides continuous steering input to keep the vehicle centered in its lane. The difference between LKA and LC is that LKA activates only when the vehicle drifts toward a lane boundary, whereas LC operates continuously to keep the vehicle centered. To align with this, HDA in the driving simulator could only be activated on simulated Interstate highways. Once activated, it automatically drove the subject vehicle by following either the predetermined speed set by the driver or adjusting the speed to match the posted speed limit, while maintaining a safe distance from the vehicle in front and staying centered in the lane.

Driving Scenarios. As depicted in Table 2, a total of nine testing scenarios were created and programmed into the STISIM driving simulator to evaluate drivers' comprehension of ADAS capabilities and limitations. Scenario 1 functioned as a baseline assessment in which drivers were instructed to activate and deactivate ACC, LKA, and HDA. Conversely, Scenario 9 served as another control scenario in which drivers did not encounter any limitations. Three scenarios were designed to replicate ACC limitations (Scenarios 3, 5, and 8), whereas three scenarios simulated LKA limitations (Scenarios 2, 4, and 9). Additionally, a pair of scenarios for ACC and HDA (Scenarios 6 and 7) were developed to gauge drivers' understanding of the distinctions between ACC and HDA during curve navigation. The order of the scenarios was randomized across participants.

The limitation scenarios were designed to represent conditions where the ADAS functions may not perform optimally. To control for the influence of ADAS functioning on drivers' decision-making, all ADAS features were programmed to function correctly under these limitation scenarios. However, drivers were required to recognize the limitations and decide whether to deactivate or maintain the activation of the features.

Dependent Variables

The dependent variables were grouped into four categories, including driver knowledge of ADAS, decision-making, driving performance, and subjective evaluation.

Drivers' Knowledge of ADAS. Drivers' understanding of ADAS was assessed through a knowledge test specifically designed to evaluate all three ADAS features (i.e., ACC, LKA, and HDA) before and after the training. The test included multiple-choice questions on the activation and deactivation procedures and HMI indicators for each feature, as well as true/false questions regarding the capabilities and limitations of these features. Participants' responses were compared to the correct answers, and the number of correct responses was divided by the total number of questions to calculate the percentage of correct responses on the knowledge test. This percentage, referred to as post-training knowledge accuracy, was used as the dependent variable in this study. The difference between the percentage of correct responses in the pre-training and post-training knowledge test was then calculated as another dependent variable, denoted as knowledge improvement. Knowledge improvement was compared between the T1 and T2 experimental groups to determine whether training focused on driver-related issues enhanced understanding of ADAS. Similarly, a comparison between the T1 and T3 experimental groups was made to assess the impact of training feedback on improving drivers' understanding of ADAS.

Table 2. Driving Scenarios of ADAS Limitations.

Scenario	ADAS	Purpose of Testing	Expected Decision-Making	Measurements of Reaction Time
1: Usage of ADAS features	ACC, LKA, HDA	The driver understands how to activate and deactivate ACC, LKA, and HDA	Activate and deactivate ACC, LKA, and HDA	Reaction time: NA; evaluation: is the driver able to identify the LKA and ACC buttons?
2: Faded lane lines	LKA	Measure if a driver understands the limitation of LKA corresponding to faded lane lines	Deactivate LKA before or when encountering roads with faded lane lines and activate the LKA when the road has clear lane lines	Reaction time: when the driver turns off the LKA function – when the driver can see the faded lane lines
3: Dark tunnel	ACC	Measure if a driver understands that ACC do not work well in dimly lit places	Deactivate ACC before or when they entered the tunnel and activate ACC after exiting the tunnel	Reaction time: when the driver turns off the ACC – when the driver can see the tunnel
4: Heavy traffic	ACC	Measure if a driver understands the ACC limitation corresponding to heavy traffic	Deactivate ACC when encountering slow traffic ahead	Reaction time: when the driver turns off the ACC – when the driver can see that there is heavy traffic
5: Foggy area	LKA	Measure if a driver understands the limitation of LKA corresponding to foggy weather condition	Deactivate LKA before or when entering the foggy area	Reaction time: when the driver turns off the LKA – when the driver enters the foggy area
6: Moderate curve (interstate highway)	HDA (No limitation)	Measure if a driver understands the HDA could navigate moderate curves and automatic reduce speed to posted speed limits	Use HDA to navigate through a moderate curve and reduce the vehicle's speed to align with the posted speed limit of the curve	Reaction time: NA; no reaction is needed
7: Sharp curve (rural road)	ACC	Measure if a driver understands that the ACC could not navigate through sharp curves or automatic reduce speed to posted speed limits	Deactivate ACC when encountering a sharp curve and reduce speed to the posted speed limit of the curve	Reaction time: when the driver turns off the ACC – when the driver can see the curve
8: Speed limit change (55 to 40 mph)	ACC	Measure if a driver understands the inability of ACC to adjust speed according to the posted speed limit	Decelerate to 40 mph	Reaction time: when the driver takes over – when the driver can see the speed limit sign
9: Control scenario	LKA (No limitation)	Control scenario	Drive the roadway with LKA without deactivating LKA	Reaction time: NA

Drivers' Decision-Making. The correctness of drivers' decision-making in response to ADAS capabilities and limitations was assessed by comparing their decisions to the expected correct responses, providing insight into their behavioral use of ADAS. When an ADAS limitation was detected, drivers could deactivate the feature by pressing the respective button. For ACC and HDA, drivers could also use the brake pedal, while LKA was deactivated solely with its button. If a driver's decision matched the expected correct action—deactivating the ADAS feature when a limitation was reached or maintaining activation when no limitation was present—it was coded as 1; otherwise, it was coded as 0. Drivers' reaction time was measured as the time taken to deactivate ADAS features (i.e., ACC, LKA, and HDA) from the onset of the ADAS limitation, using either the buttons or the brake pedal. Reaction time was recorded as a dependent variable only for instances where drivers made correct decisions.

Driving Performance. The standard deviation of lane position (SDLP) was analyzed as a measure of driving performance throughout the portion of the drive in which the relevant limitation was present (Ebnali et al., 2019). The limitation period began when drivers encountered the ADAS limitation scenario. For ACC, the measurement of SDLP began as soon as drivers encountered the ADAS limitation scenario, capturing their lane-keeping performance during the scenario. For LKA and HDA, the measurement of SDLP started once drivers deactivated the feature, reflecting their ability to maintain lane position without assistance.

Subjective Evaluations. Drivers' subjective ratings were collected after the test drive. Drivers' trust in ADAS, acceptance of ADAS, and workload were evaluated as discussed below.

Drivers' trust in ADAS was measured with the Checklist for Trust between People and Automation (Jian et al., 2000), which is a questionnaire designed to assess 12 factors influencing trust between individuals and automated systems, including 'deception,' 'suspicion,' 'security,' 'integrity,' and 'reliability.' Participants rated each factor on a 7-point scale, with '1' indicating 'not at all' and '7' indicating 'extremely.'

Acceptance of ADAS was evaluated with the System Acceptance Questionnaire (Van Der Laan et al., 1997), a nine-item survey that evaluates human acceptance of new technology across two dimensions: usefulness and satisfaction. Participants rated the system on a 5-point scale ranging from −2 to +2 ('−2' = extremely negative, '+2' = extremely positive). Usefulness scores were computed as the average of questionnaire items 1, 3, 5, 7, and 9, while satisfaction scores were calculated as the average of items 2, 4, 6, and 8.

Driver's workload was measured using the NASA-TLX (Hart & Staveland, 1998), a widely used tool for assessing subjective workload. It measures workload across six dimensions: mental demand, physical demand, temporal demand, performance, effort, and frustration level. Participants rate each dimension on a 20-point scale, which provides an overall workload score.

Data Analysis

The effect of the three different training content conditions was measured using several dependent variables, including drivers' response accuracy on the knowledge test, the correctness of their decision-making in responding to ADAS limitations, driver reaction time, and driving performance.

To examine the overall effectiveness of ADAS training programs, Wilcoxon signed-rank tests were employed to determine the statistical differences in knowledge accuracy between the pre-training and post-training knowledge tests for three ADAS features within each of the three training content conditions. To further examine whether drivers in the three training groups had a similar level of knowledge of ADAS, a two-way ANOVA was conducted to assess the effect of training content and ADAS features (ACC, LKA, and L2 partial automation) on drivers' knowledge accuracy in the pre-training knowledge test. Finally, a two-way ANCOVA was conducted to examine the effects of training content on drivers' knowledge improvement across three ADAS features, while controlling for gender, age, and education level as covariates.

To evaluate drivers' usage of ADAS features, drivers' correctness of decision-making and reaction time in responding to ADAS limitations were analyzed. A logistic regression was performed to assess the impact of training content on drivers' correctness of decisions in response to ADAS limitations in eight driving scenarios, excluding the first baseline scenario. A two-way ANOVA was further conducted to examine the impact of training content and scenario types on drivers' correctness of decision-making. In terms of driver reaction time, a two-way ANCOVA was conducted on drivers' reaction time, with training content groups and ADAS features as independent variables, while controlling for gender, age, education level, and pre-training knowledge accuracy as covariates. Reaction time was recorded as a dependent variable only for instances where drivers made correct decisions.

To evaluate driving performance within ADAS, a two-way ANOVA was conducted to examine the impact of training content and ADAS features on drivers' SDLP throughout the driving course.

Results

Descriptive Analysis

The descriptive analysis was performed to examine demographic differences among three experimental groups (see Table 3). The Chi-square tests indicated that there was no statistically significant difference in driver gender (χ^2 = 0.15, p = 0.93), age (χ^2 = 5.38, p = 0.72), educational level (χ^2 = 10.29, p = 0.59), ethnicity (χ^2 = 3.75, p = 0.15), race (χ^2 = 5.43, p = 0.49), and employment status (χ^2 = 5.59, p = 0.85).

Table 3. Demographic Information of Participants across Three Training Groups

Demographic Factors and Categories		Training Group				
		T1: Baseline Training	T2: Training with driver issues	T3: Training with feedback	χ^2	p-value
Gender	Female	13	14	14	0.15	0.93
	Male	7	6	6		
Age	18–24	9	5	7	5.38	0.72
	25–34	3	6	7		
	35–44	2	4	2		
	45–54	1	0	1		
	55+	5	5	3		
Educational Level	High school graduate or equivalent	6	1	2	10.29	0.59
	Some college, no degree	3	5	4		
	Associate degree	0	0	1		
	4-year degree	1	4	4		
	Master's degree	6	4	5		
	Professional degree	1	1	1		
	Doctorate	3	5	3		
Ethnicity	Hispanic or Latino	19	17	20	3.75	0.15
	Not Hispanic or Latino	1	3	0		
Race	White	11	14	11	5.43	0.49
	Asian	6	4	8		
	Black or African American	0	1	0		
	Other	3	1	1		
Employment Status	Employed full-time	6	9	7	5.59	0.85
	Employed part-time	6	3	7		
	Retired	3	4	2		
	Self-employed part-time	1	0	1		
	Unemployed	3	4	2		
	Other	1	0	1		

As shown in Table 4, the Chi-square tests indicated that there was no statistically significant difference in driving experience ($\chi^2 = 4.18$, $p = 0.65$). Kruskal-Wallis H test was also conducted to analyze the frequency of driving differences among the three groups. The results indicated that there was no significant difference in frequency ($H(2) = 1.84$, $p = 0.4$). Kruskal-Wallis H test was conducted to analyze the different confidence levels of driving among the three groups. The results indicated that there was no significant difference in confidence level ($H(2) = 0.22$, $p = 0.90$).

Table 4. Driving Experience of the Sample

		Training Group				
		T1: Baseline Training	**T2: Training with driver issues**	**T3: Training with feedback**	**χ^2**	**p-value**
Driving Experience	Less than 1 year	0	3	2	4.18	0.65
	1–2 years	1	2	1		
	2–3 years	2	2	3		
	More than 3 years	17	13	14		

For the level of experience with ADAS, Chi-square tests were performed to analyze the differences among the three groups. As shown in Table 5, the results showed that there was no significant difference in ACC experience ($\chi^2 = 11.35$, $p = 0.18$), LKA experience ($\chi^2 = 6.15$, $p = 0.63$), and HDA experience ($\chi^2 = 6.01$, $p = 0.65$).

Table 5. Experience with ADAS across Three Training Groups

Category		Training Content: T1: Baseline Training	Training Content: T2: Training with driver issues	Training Content: T3: Training with feedback	χ²	p-value
ACC Experience	Never	9	12	9	11.35	0.18
	Sometimes	4	2	8		
	Most of the time	3	1	2		
	Every time	0	2	0		
	Don’t have the feature	4	3	1		
LKA Experience	Never	8	7	10	6.15	0.63
	Sometimes	4	2	4		
	Most of the time	0	3	1		
	Every time	2	3	2		
	Don’t have the feature	6	5	3		
HDA Experience	Never	11	10	13	6.01	0.65
	Sometimes	1	1	3		
	Most of the time	3	2	1		
	Every time	0	1	0		
	Don’t have the feature	5	6	3		

Knowledge Accuracy of ADAS

Overall Effectiveness of ADAS Training Programs. The effectiveness of the ADAS training was initially assessed by comparing drivers’ knowledge accuracy in pre-training and post-training knowledge tests across three training content groups for three ADAS features. As shown in Table 6, the results indicate that the ADAS training significantly enhanced drivers’ understanding of the capabilities and limitations of the ADAS features. Mean accuracy on knowledge questions increased significantly from pre-training to post-training in all three training groups. Notably, the training with feedback (T3) resulted in the greatest improvement in drivers’ knowledge of ADAS.

Table 6. Knowledge Accuracy in Pre-Training and Post-Training Knowledge Test

		Pre-training knowledge accuracy		Post-training knowledge accuracy		Wilcoxon	
		M	SD	M	SD	(Z)	p
T1: Baseline Training	ACC	70.38	15.24	82.31	9.03	−3.19	0.001
	LKA	81.19	9.46	86.90	8.86	−1.77	0.077
	HDA	60.41	11.43	75.42	9.92	−3.27	0.001
T2: Training with driver issues	ACC	75.00	16.15	85.77	10.07	−2.45	0.014
	LKA	79.52	11.15	89.76	6.96	−3.76	<0.001
	HDA	64.58	9.70	76.25	12.47	−3.36	<0.001
T3: Training with feedback	ACC	61.92	19.88	91.15	16.03	−3.84	<0.001
	LKA	79.52	15.22	91.90	11.78	−3.19	0.001
	HDA	63.75	14.63	79.58	10.28	−3.34	<0.001

Specifically, the Wilcoxon signed-rank test results indicated a statistically significant improvement in post-training knowledge accuracy after the baseline training (T1) for two ADAS features: ACC ($Z = -3.19$, $p = 0.001$) and HDA ($Z = -3.27$, $p = 0.001$). However, the improvement for LKA was not statistically significant ($Z = -1.77$, $p = 0.077$). After receiving the training with driver issues (T2), participants showed significant improvements in post-training knowledge accuracy across all three ADAS features compared to the pre-training knowledge test, including ACC ($Z = -2.45$, $p = 0.014$), LKA ($Z = -3.76$, $p < 0.001$), and HDA ($Z = -3.36$, $p < 0.001$). Similarly, the training group that received feedback (T3) showed statistically significant enhancements in post-training knowledge accuracy across all ADAS features, for ACC ($Z = -3.84$, $p < 0.001$), LKA ($Z = -3.19$, $p = 0.001$), and HDA ($Z = -3.34$, $p < 0.001$).

Pre-Training Knowledge Assessment of ADAS Features Across Training Groups. To ensure that drivers in the three training groups had a similar level of knowledge of ADAS prior to any training, a two-way ANOVA was conducted on drivers' knowledge accuracy in the pre-training knowledge test, with training content groups and ADAS features as independent variables. The results did not reveal any significant effect of training content ($F(2, 171) = 1.64$, $p = 0.197$, $\eta^2 = 0.02$) or two-way interactions ($F(4, 171) = 1.71$, $p = 0.15$, $\eta^2 = 0.04$), suggesting that the driver groups were similar in their pre-training knowledge.

However, a significant main effect of the ADAS feature was found on drivers' knowledge accuracy in the pre-training knowledge test ($F(2, 171) = 23.02$, $p < 0.001$, $\eta^2 = 0.21$), indicating that drivers had varying levels of knowledge across different ADAS features. Post-hoc comparisons using the Tukey test indicated that drivers had better knowledge of LKA ($M = 80.07$) compared to ACC ($M = 69.10$, $p < 0.001$) and HDA ($M = 62.92$, $p < 0.001$).

Impact of Training Content Designs on Knowledge Improvement. The descriptive statistics results of knowledge improvement are shown in the Table 7.

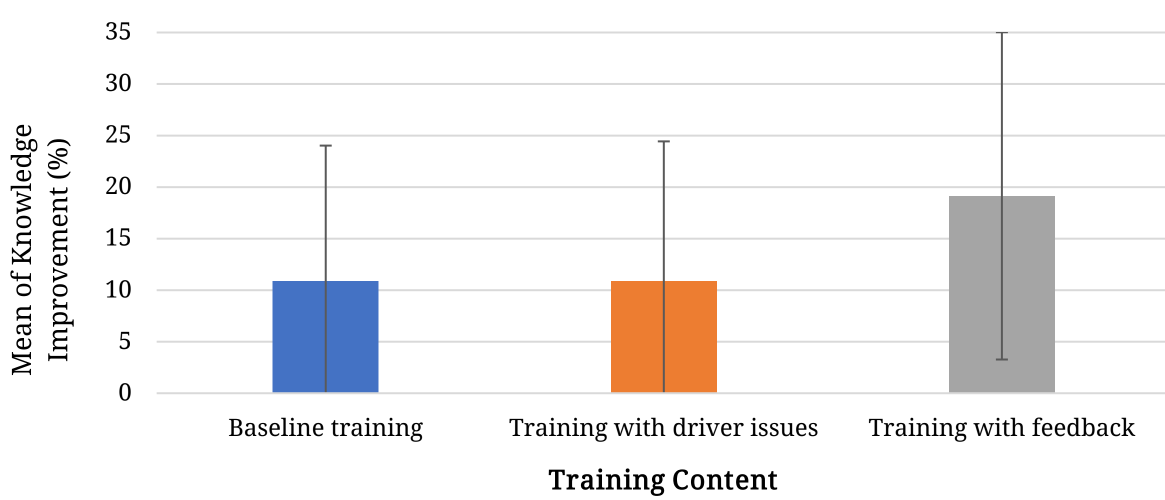
Table 7. Descriptive Statistics Results of Knowledge Improvement

	Knowledge Improvement (%)					
	ACC		LKA		HDA	
Training Content	**M**	**SD**	**M**	**SD**	**M**	**SD**
T1: Baseline training	11.92	12.09	5.71	12.89	15.00	14.46
T2: Training with driver issues	10.77	21.38	10.24	8.64	11.67	10.61
T3: Training with feedback	29.23	17.93	12.38	13.50	15.83	16.20

A two-way ANCOVA was conducted on drivers' knowledge improvement, with training content groups and ADAS features as independent variables, while controlling for gender, age, and education level as covariates. The results revealed a significant main effect of training content ($F(2, 168) = 5.99$, $p = 0.003$, $\eta^2 = 0.07$), a significant main effect of ADAS features ($F(2, 168) = 4.32$, $p = 0.015$, $\eta^2 = 0.05$), and a significant interaction effect ($F(2, 168) = 2.53$, $p = 0.042$, $\eta^2 = 0.06$). None of the covariates showed significant influence on drivers' knowledge improvement.

As shown in Figure 6, post-hoc analysis of training content showed that training with feedback led to greater knowledge improvement than both baseline training ($p = 0.004$) and training with driver issues ($p = 0.003$). Regarding ADAS features, the post-hoc analysis revealed that drivers showed greater knowledge improvement for the ACC feature compared to the LKA feature ($p = 0.01$), though the difference between the ACC and HDA features was not significant ($p = 0.47$).

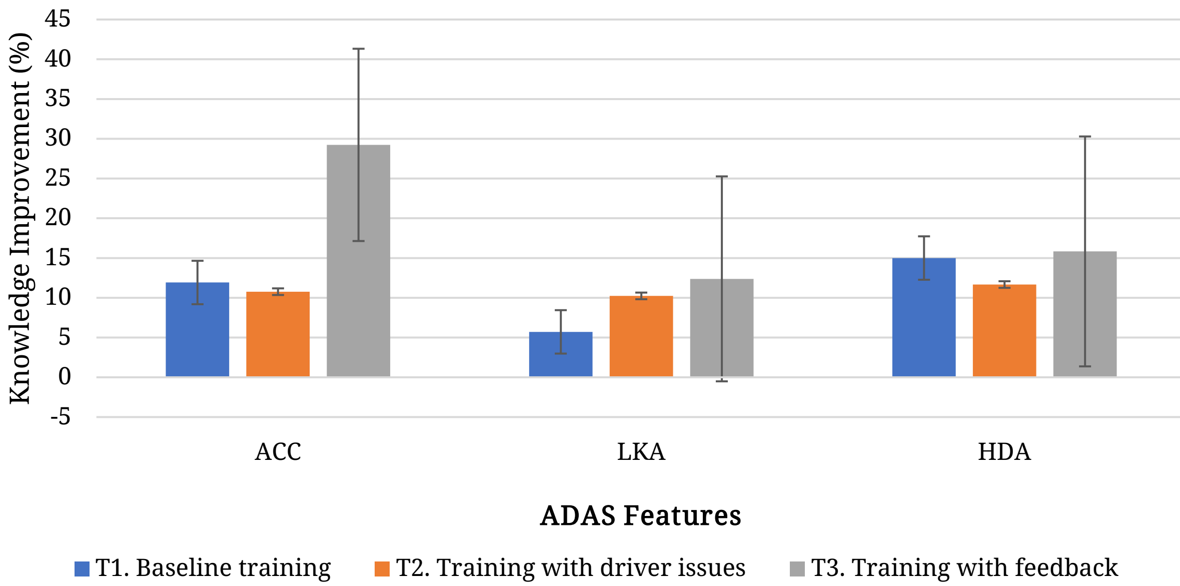
Figure 6. Drivers' Knowledge Improvement Across Three Training Groups



Note: Error bars represent ±1 standard error.

As shown in Figure 7, the interaction effect between training content and ADAS features on drivers' knowledge improvement was also significant. Specifically, knowledge improvement for LKA and HDA was similar across the three training content groups, whereas knowledge improvement for ACC was higher in the training with feedback compared to both baseline training ($p < 0.001$) and training with driver issues ($p < 0.001$). Additionally, knowledge improvement across ADAS features were similar when receiving baseline training and training with driver issues, except for knowledge improvement for HDA was higher in the baseline training than LKA ($p = 0.048$). However, drivers who received training with feedback showed significantly greater knowledge improvement for ACC than both LKA ($p < 0.001$) and HDA ($p = 0.005$).

Figure 7. The Interaction Effect of Training Content and ADAS Features on Drivers' Knowledge Improvement

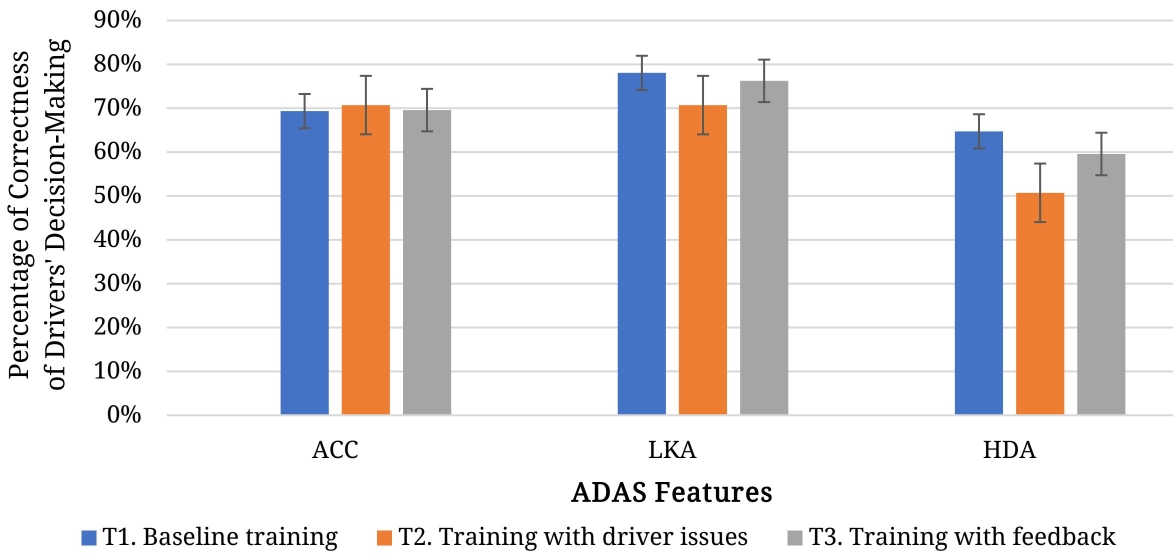


Note: Error bars represent ±1 standard error.

Decision-Making in ADAS

Correctness of Decision-Making in Responding to ADAS Capabilities and Limitations. A logistic regression analysis was performed to assess the impact of different training content groups and ADAS features on drivers' decision-making accuracy when responding to ADAS limitations (see Figure 8). The variables encompassed interactions between the training content groups (T1, T2, and T3) and ADAS features (ACC, LKA, and HDA). The overall model was not statistically significant ($\chi^2(8) = 12.18$, $p = 0.14$), suggesting that it did not adequately predict the outcome variable. Upon examining individual predictors, none showed a statistically significant contribution to predicting the correctness of drivers' decision-making. While driver decision-making accuracy ranges between 68% and 72% across different training content groups, suggesting satisfactory performance in responding to ADAS limitation scenarios, the training content did not significantly affect the correctness of their decision-making. As shown in Figure 7, the correctness of decision-making for LKA features (M = 75%) is higher than that for HDA (M = 58%) and ACC (M = 70%).

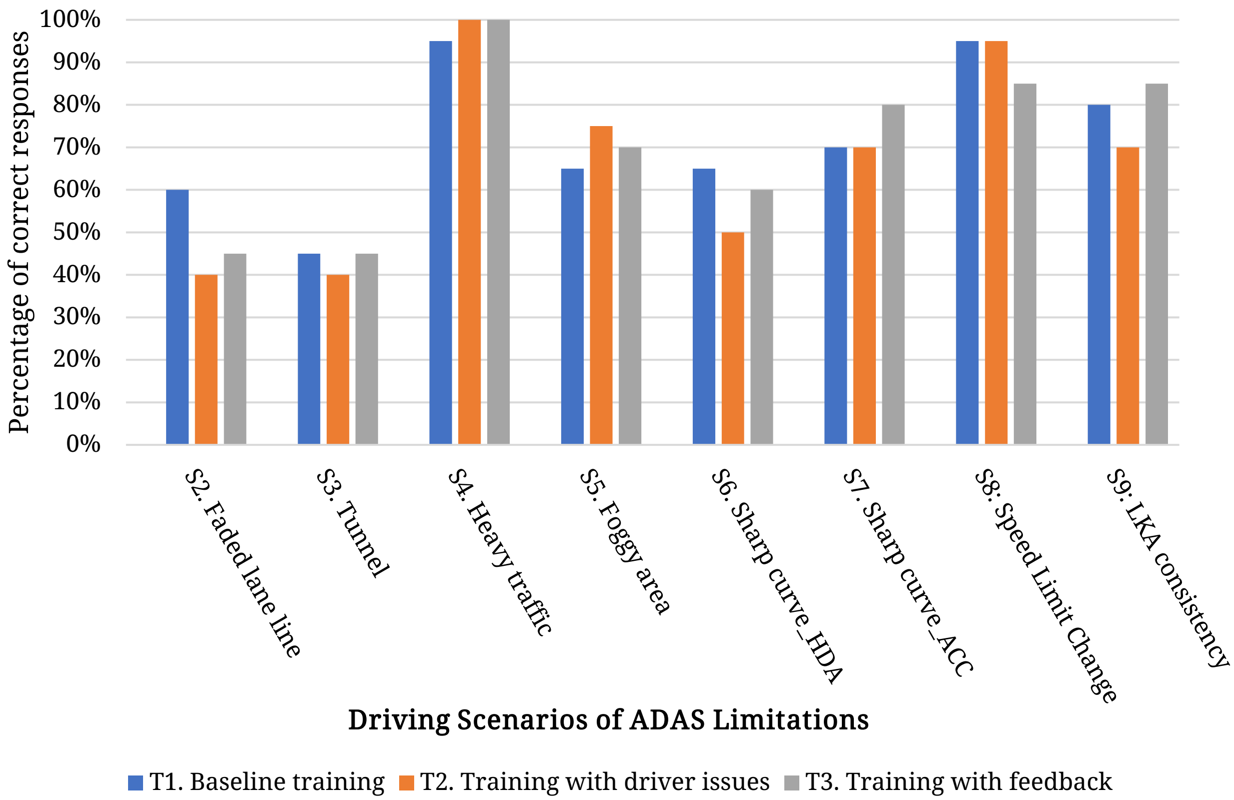
Figure 8. Drivers' Correctness of Decision-Making Across Training Content Groups and ADAS Features



Note: Error bars represent ±1 standard error.

A two-way ANOVA was conducted to examine the impact of training content and scenario types on drivers' correctness of decision-making. The results uncovered a significant main effect of ADAS limitation scenarios on drivers' response accuracy, with F (7, 456) = 12.56, $p < 0.001$. Figure 9 illustrates that drivers achieved the highest response accuracy in the heavy traffic scenario (S4, 98%) and relatively high accuracy in the speed limit change scenario (S8, 92%). The control scenario without LKA limitations (S9) also exhibited a decent response accuracy of 78%, while the sharp curve for ACC scenario (S7) had a response accuracy of 73%. In contrast, several scenarios displayed significantly lower response accuracy, including dark tunnels (S3, 43%), faded lane lines (S2, 48%), and the absence of HDA limitations in curved interstate highways (S6, 58%).

Figure 9. Drivers' Response Accuracy in Responding to ADAS Limitation Scenarios



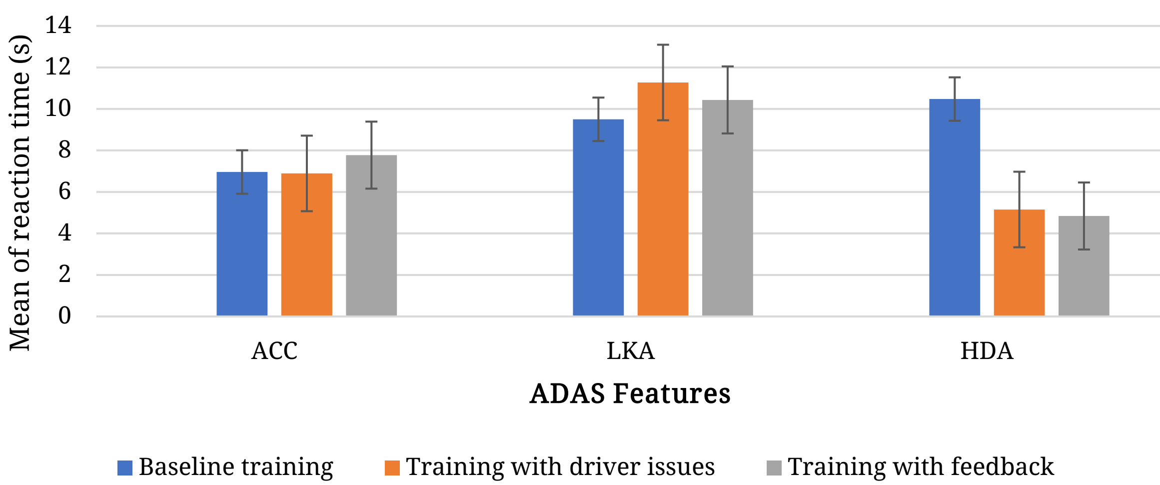
Drivers' Reaction Time to ADAS Limitations. The mean reaction time over all participants in all scenarios was M = 10.47 seconds, SD = 9.20. A breakdown of the mean and standard deviation of reaction time for each training content group is summarized in Table 8. The percentage of drivers that responded to ADAS limitations before and after the occurrence of limitation was calculated. In this analysis, 'pre-limitation reaction' was defined as drivers deactivating the system after identifying the hazard but before the designated start of the limitation scenario. For these cases, the reaction time was coded using the actual value, which could be negative. The results suggested that majority of drivers tended to respond to ADAS limitations after the starting point of the limitations, regardless of the training groups.

Table 8. The Frequency and Percentage of Pre-Limitation Reaction and Post-Limitation Reaction to ADAS Limitations in the Driving Performance

	Pre-Limitation Reaction		Post-Limitation Reaction		Mean of Post Limitation Reaction Time in seconds (SD)
	Frequency	Percentage	Frequency	Percentage	
T1. Baseline training	13	15.12%	73	84.88%	9.78 (8.31)
T2. Training with driver issues	10	11.90%	74	88.10%	10.48 (9.87)
T3. Training with feedback	11	12.94%	74	87.06%	11.12 (9.43)

A two-way ANCOVA was conducted on drivers' reaction time, with training content groups and ADAS features as independent variables, while controlling for gender, age, education level, and pre-training knowledge accuracy as covariates. As shown in Figure 10, the results revealed a significant main effect for ADAS feature categories ($F(2, 297) = 4.16$, $p = 0.017$, $\eta^2 = 0.027$), indicating that different ADAS features had a notable impact on reaction times. However, both the main effect of the training group ($F(2, 297) = 0.26$, $p = 0.768$, $\eta^2 = 0.002$) and the interaction effect between these two factors ($F(4, 297) = 0.62$, $p = 0.649$, $\eta^2 = 0.008$) were found to be statistically non-significant. Further examination through post-hoc analysis revealed that when faced with limitations related to the LKA feature, drivers exhibited significantly longer reaction times ($M = 10.40$) compared to their responses to ACC features ($M = 7.21$, $p = 0.007$), whereas the difference between LKA and HDA ($M = 6.82$), while similar in size, was not significant ($p = 0.10$).

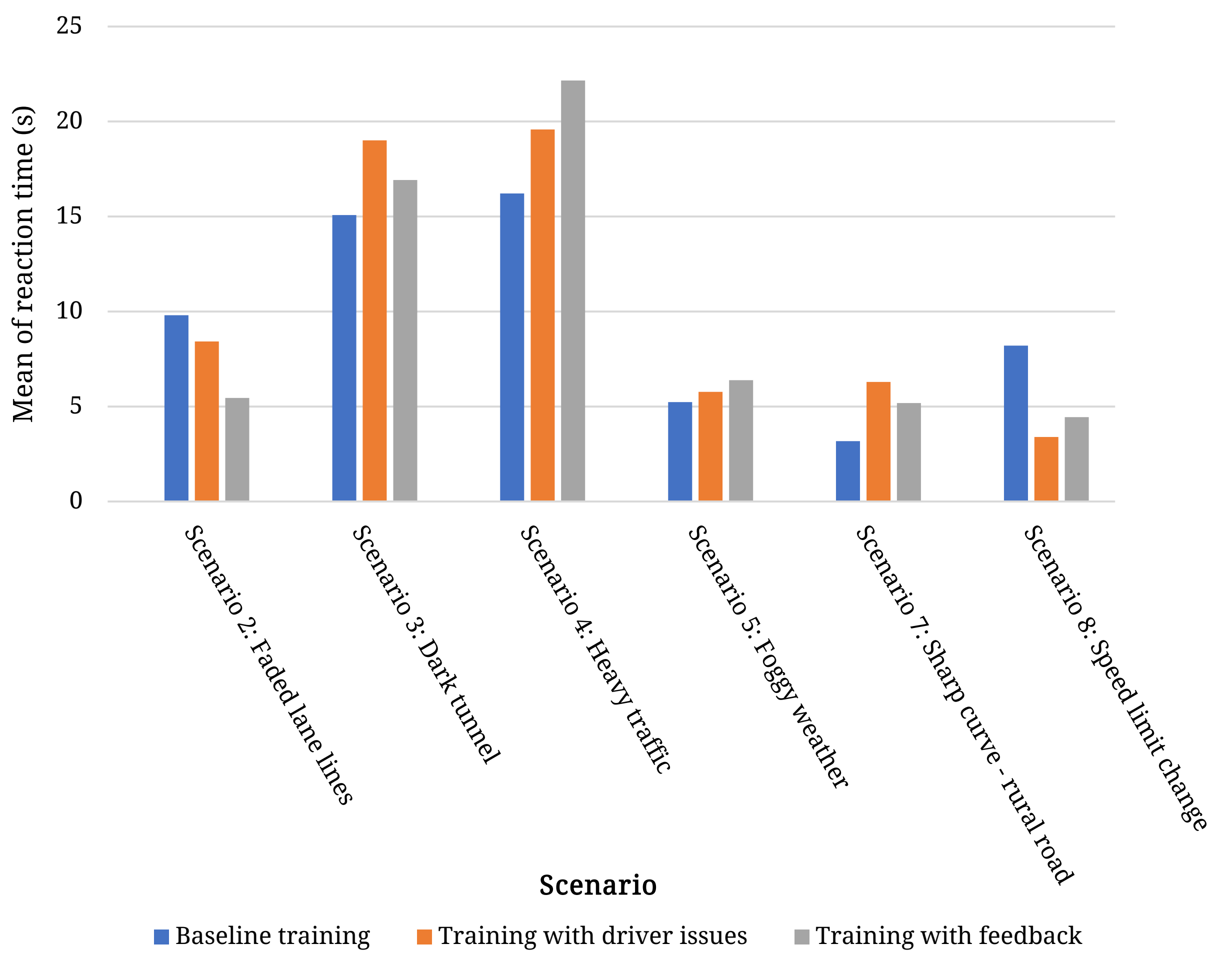
Figure 10. Drivers' Reaction Time in Responding to ADAS Features.



Note: Error bars represent ±1 standard error.

A two-way ANOVA was conducted to examine the impact of training content and scenario types on driver reaction times. Scenarios 6 and 9, which did not require the driver to take any action, were excluded from the analysis. The results revealed a significant main effect of ADAS limitation scenarios on driver reaction time ($F(5, 203) = 36.08$, $p < 0.001$). As shown in Figure 11, drivers exhibited longer reaction times in the dark tunnel scenario (S3, M = 16.84) and the heavy traffic scenario (S4, M = 19.49), both of which were ACC limitation scenarios, compared to the other scenarios.

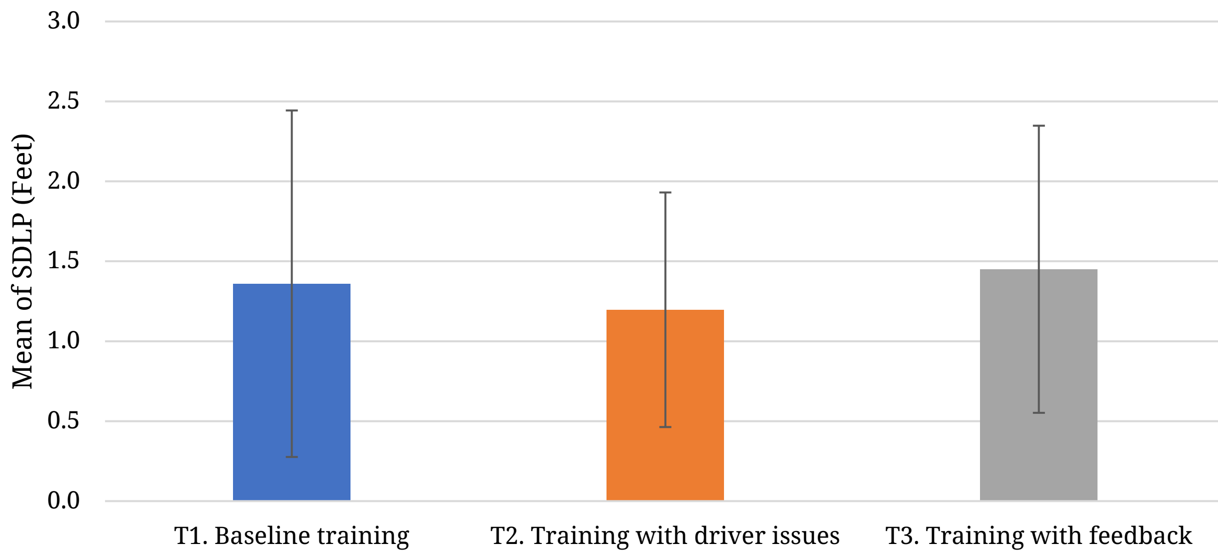
Figure 11. Drivers' Reaction Time Across ADAS Limitation Scenarios.



Driving Performance in ADAS

A one-way ANCOVA was conducted to examine the effect of different training content groups on drivers' SDLP, while controlling for driver age, gender, and education. As depicted in Figure 12, the analysis revealed a significant main effect of training content on SDLP ($F(2, 346) = 3.16$, $p = 0.044$). Pairwise comparison analysis indicated that drivers who received training with driver issues exhibited significantly smaller SDLP ($M = 1.17$) compared to those who received feedback-based training ($M = 1.46$, $p = 0.016$), and marginally smaller SDLP compared to those who underwent baseline training ($M = 1.38$, $p = 0.075$). None of the covariates reached significance.

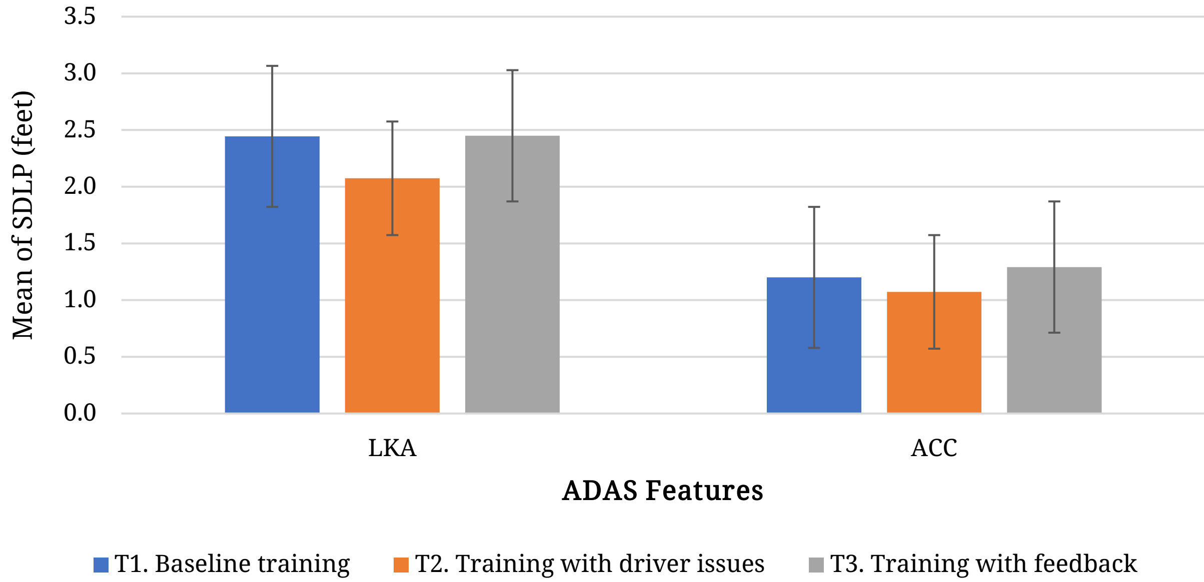
Figure 12. The Effect of Training Content on Drivers' SDLP



Note: Error bars represent ±1 standard error.

To account for the influence of ADAS features, a two-way ANOVA was then conducted to examine the effect of training content and ADAS features on drivers' SDLP. As shown in Figure 13, the analysis revealed a significant main effect of training content ($F(2, 340) = 3.29$, $p = 0.039$), indicating drivers who received training with driver issues demonstrated a significant lower SDLP ($M = 1.29$) compared to those in the baseline training group ($M = 1.54$, $p = 0.05$), and those in the training with feedback group ($M = 1.59$, $p = 0.016$). The analysis also revealed a significant main effect of ADAS feature categories ($F(2, 340) = 60.23$, $p < 0.001$). Pairwise comparisons indicated that drivers exhibited significantly higher SDLP in LKA scenarios ($M = 2.32$) compared to ACC limitation scenarios ($M = 1.19$, $p = 0.011$), and compared to control scenarios whereas no deactivation action was required ($M = 0.90$, $p < 0.001$). No significant interaction effect between these two factors were found ($F(2, 340) = 0.20$, $p = 0.94$).

Figure 13. Drivers' SDLP in Responding to ADAS Features



Note: Error bars represent ±1 standard error.

Drivers' Subjective Evaluation

Two ANCOVAs were conducted to examine the effects of training content on two subjective evaluation variables, including trust and acceptance. The covariates evaluated included gender, age, educational level, and pre-training knowledge accuracy.

For the trust variable, the main effect of training content on trust was not significant ($F(2, 51) = 0.23$, $p = 0.80$). Additionally, none of the covariates showed significant influence on driver trust, including gender ($F(1, 51) = 1.02$, $p = 0.32$), educational level ($F(1, 51) = 3.43$, $p = 0.07$), age ($F(1, 51) = 0.036$, $p = 0.85$), ACC pre-training knowledge accuracy ($F(1, 51) = 1.10$, $p = 0.30$), LKA pre-training knowledge accuracy ($F(1, 51) = 0.13$, $p = 0.72$), and HDA pre-training knowledge accuracy ($F(1, 51) = 0.061$, $p = 0.81$).

For the usefulness variable, the main effect of the training content was not significant ($F(2, 51) = 0.84$, $p = 0.44$). Among the tested covariates, only the main effects for gender ($F(1, 51) = 6.03$, $p = 0.018$) and educational level ($F(1, 51) = 15.21$, $p < 0.001$) were significant, indicating that these factors influenced perceptions of usefulness. The remaining covariates were not significant, including age ($F(1, 51) = 3.87$, $p = 0.055$), ACC pre-training knowledge accuracy ($F(1, 51) = 0.61$, $p = 0.44$), LKA pre-training knowledge accuracy ($F(1, 51) = 2.90$, $p = 0.095$), and HDA pre-training knowledge accuracy ($F(1, 51) = 0.62$, $p = 0.43$).

Table 9. Drivers' Subjective Evaluation of ADAS

	Mean (SD)		
	T1: Baseline training	**T2: Training with driver issues**	**T3: Training with feedback**
Trust	59.65 (13.25)	59.55 (14.63)	56.60 (10.41)
Acceptance (Usefulness)	0.37 (1.16)	0.31 (1.03)	0.13 (0.88)
Acceptance (Satisfaction)	0.59 (0.80)	0.18 (0.53)	0.23 (0.65)

Lastly, the main effect of training content was significant for the satisfaction variable ($F(2, 51) = 3.56$, $p = 0.036$). Pairwise comparisons indicated that the T1 baseline training group ($M = 0.59$, $SD = 0.80$) reported significantly higher satisfaction scores than those who received T2 driver-related issues training ($M = 0.18$, $SD = 0.53$, $p = 0.012$) or T3 feedback training ($M = 0.23$, $SD = 0.53$, $p = 0.045$). However, no significant difference was found between those who received T2 driver-related issues training versus T3 feedback training, $p = 0.57$. Regarding the covariates, the main effect for educational level was significant ($F(1, 51) = 5.29$, $p = 0.026$). The remaining covariates were not significant, including gender ($F(1, 51) = 1.36$, $p = 0.25$), age ($F(1, 51) = 0.43$, $p = 0.52$), ACC pre-training knowledge accuracy ($F(1, 51) = 1.29$, $p = 0.26$), LKA pre-training knowledge accuracy ($F(1, 51) = 1.79$, $p = 0.19$), and HDA pre-training knowledge accuracy ($F(1, 51) = 0.009$, $p = 0.92$).

Discussion

This study was one of the first to systematically explore the effects of training content on drivers' understanding, decision-making, and driving performance when using ADAS. The main findings from this experiment were as follows:

- Training content significantly influenced drivers' knowledge improvement and driving performance, but did not affect drivers' decision-making accuracy or reaction time in response to ADAS limitations.
- Feedback-based training led to greater knowledge improvement than baseline training or training focused on driver-related issues, whereas training with driver-related issues resulted in better steering control when encountering ADAS limitations compared to the other two training content groups.
- The effectiveness of the training varied by ADAS feature, influencing knowledge improvement, reaction time, and steering control.
- Gains in knowledge of LKA and HDA were similar across training groups, but improvements in knowledge about ACC were largest with feedback-based training.

Overall, the results indicate that the training content significantly influenced knowledge improvement and driving performance when using ADAS, but it did not affect drivers' decision-making accuracy or reaction time.

One of the key findings is that training with feedback was the most effective in improving driver knowledge accuracy. Previous studies focused primarily on training modes and styles, consistently incorporating similar content in ADAS training, such as general ADAS knowledge, HMI design, ADAS activation/deactivation, and ADAS capabilities and limitations (Beggiato et al., 2015; Ebnali et al., 2021; Forster et al., 2019a; Forster et al., 2019b; Singer & Jenness, 2020; Zahabi et al., 2020; Zahabi et al., 2021). The contribution of this study lies in its novel finding that training content can significantly influence driver knowledge and driving performance when using ADAS. All three training content groups led to improvements in drivers' knowledge accuracy when comparing pre-training and post-training measures of knowledge, but feedback-based training was particularly effective in enhancing drivers' understanding of ADAS capabilities and limitations compared to baseline training or baseline training supplemented with discussion of driver-related issues. These results align with existing studies on driver training in conventional driving (Molloy et al., 2018), which found that feedback effectively promoted enduring changes in young drivers' speed management behavior. This finding also aligns with control theory and goal-setting theory in education and training, which suggest that feedback helps individuals calibrate their performance by providing information about the gap between their current performance and their goals (Molloy, 2022). Therefore, incorporating feedback-based methods in driver education programs for ADAS training should be considered to maximize the effectiveness of the training with respect to knowledge retention.

Although training with feedback led to significant knowledge improvement compared to the other training programs, it did not result in better driving performance in the scenarios examined and as measured in terms of steering control stability. The results revealed that training emphasizing driver issues led to a lower SDLP compared to baseline training and training with feedback, suggesting more consistent lane position maintenance. This finding suggests that the knowledge advancement might not be directly transferred to improved driving performance when using ADAS. Instead, training focusing on driver issues may have heightened drivers' awareness of ADAS limitations, therefore leading to more cautious driving behaviors. This aligns with the findings of DeGuzman and Donmez (2022), who reported that training focused on driver responsibilities, similar to driver-issue training in the current study, was as effective as limitation-focused training in enhancing driver knowledge and promoting appropriate reliance intentions. However, their study, which used a video-based research methodology, did not examine driver performance. In contrast, the current study measured driving performance as one of the outcomes, demonstrating that addressing both driver issues and limitation scenarios can effectively improve driving performance compared to baseline training.

Unfortunately, neither of the enhanced designs of training content (training with driver issues and training with feedback) improved the correctness of drivers' decision-making in response to ADAS limitations encountered in the driving simulator, compared to the baseline training. This suggests that although drivers gained knowledge about ADAS limitations, this knowledge did not necessarily translate into improved decision-making accuracy or quicker responses when faced with these limitations in driving—at least in those scenarios examined.

Further analysis indicated that drivers' decision-making accuracy and reaction times were influenced by factors such as the specific driving scenarios and the ADAS features. Drivers demonstrated the highest response accuracy in the heavy traffic and speed limit change scenarios, likely due to increased attention and improved situational awareness in these dynamic traffic conditions. Regarding reaction times, drivers took significantly longer to respond in scenarios that simulated entering a dark tunnel and driving in foggy weather. One possible explanation is that drivers may hesitate to respond to ADAS limitations when system failures are not visually apparent, which reduces their perception of an immediate need for intervention. It is important to note that the current study did not implement actual system failures, as the primary objective was to assess drivers' understanding of ADAS limitations in their decision-making, rather than their reactive response performance to actual system failures during driving. These findings imply that drivers' responses to ADAS limitations may be affected by other variables, such as situational awareness and cognitive workload. Future research is needed to investigate whether different training programs influence drivers' decision-making differently in situations where actual system failures occur.

The study also revealed that knowledge improvement was significantly influenced by the specific ADAS features. While drivers initially exhibited better knowledge of LKA compared to ACC and HDA before training, the results suggested drivers receiving training with feedback showed the most knowledge improvement in ACC compared to LKA and HDA. Moreover, the study found longer reaction times and larger SDLP when drivers responded to LKA limitations compared to ACC limitations, suggesting that LKA features may present more challenges for drivers to detect, particularly in recognizing subtle changes in lane lines. These findings indicate a need for further exploration of training programs that specifically address the complexity of LKA features, ensuring that drivers can effectively interpret and respond to these subtle cues in real-world driving conditions. The interaction between training content and ADAS features also highlights the importance of tailoring training programs to address the differences posed by different ADAS technologies.

Limitation and Future Research

There are several limitations to this study that should be acknowledged. First, no actual system failures were simulated in the ADAS scenarios. The primary objective was to assess whether trained drivers could understand ADAS limitations and take over control, rather than measure their responses to system failures. This may have influenced drivers' decision-making, as in post-study debriefs a few participants reported not deactivating ADAS due to the absence of visible system failures in a few cases. This, however, may also be representative of real-world behavior, if seemingly acceptable ADAS performance in scenarios outside of its operational design domain leads drivers to trust the system in scenarios where its performance may be unreliable. Future research is needed to incorporate simulated failures to better understand drivers' real-time responses.

The participants may not be representative of the overall U.S. driving population, as they were recruited from a college town, resulting in a higher level of education compared to the general population. While some previous reported that early adopters of ADAS were disproportionately of higher socioeconomic status (e.g., McDonald et al., 2018), this may become a greater issue as ADAS becomes available in entry-level vehicles and even in used vehicles. Future research should validate these findings with a more diverse population to improve generalizability.

While representative limitation scenarios were selected, the limited number of scenarios may not fully capture the range of conditions and ADAS limitations that drivers may encounter in everyday driving. Future studies should include a wider variety of scenarios to better understand drivers' responses under diverse conditions.

Additionally, the between-subjects design used to evaluate driving performance was chosen to control learning effects. However, this design limits the ability to determine whether training led to significant improvements compared to an untrained baseline; it is possible that some of the differences attributed to the training could have been attributable to pre-existing differences between groups. While the pre-training knowledge test showed no significant differences in ADAS knowledge among the groups, their decision-making accuracy, reaction time, and driving performance could have differed.

Lastly, the buttons used to activate and deactivate the ADAS in the simulator did not perfectly match the corresponding controls in actual vehicles. Relatedly, for the purpose of the experiment, participants were required to manually deactivate LKA when they saw a limitation (to communicate that they recognized the limitation), whereas in real driving, drivers may simply continue steering without deactivating the system. This discrepancy, though necessary for measurable responses in the simulator, may have posed challenges in translating intended responses under time pressure. Future research should aim for more realistic simulator controls or field tests to enhance real-world applicability of the findings.

In summary, this study provides valuable insights into the impact of different training content on driver understanding, decision-making, and performance when using ADAS. Feedback-based training enhanced driver knowledge of ADAS, while training focused on driver-related issues improved driving performance, particularly in maintaining consistent lane position. These findings have practical implications for the design of ADAS training programs that incorporate tailored content to enhance both driver knowledge and driving performance, ultimately contributing to safer usage of ADAS in real-world driving.

EXPERIMENT 2: TRAINING STYLE AND MODE

In this experiment, a between-subject design was used to compare driver knowledge, decision-making, performance, and subjective evaluation of ADAS in relation to the style and mode of training provided. Study participants were recruited to complete training about ACC, LKA, and an L2 partial driving automation system that combined ACC with LC. Before completing the training, participants completed a questionnaire about their demographic characteristics, driving experience, and baseline knowledge of ADAS. Participants were then randomly assigned to one of two training styles (demonstration or practice) and one of two training modes (video or in-vehicle). After completing the training, participants completed another questionnaire measuring their knowledge and subjective evaluations. Various measures of their driving performance were measured in a driving simulator in which they drove with ACC, LKA, and L2 partial automation and encountered limitations of the systems. Statistical analyses compared measures of knowledge, driving performance, and subjective evaluations in relation to the style and mode of training completed.

Method

Participants

A total of sixty participants (34 male and 26 females) were recruited for this experiment. Inclusion criteria required participants to be over 18 years old, hold a valid U.S. driver's license, and have proficiency in English. Recruitment efforts were conducted through StudyFinder, email lists, and flyers distributed in the State College, Pennsylvania, region. Participants' ages ranged from 18 to over 55 years old. Regarding driving experience, 88.3% of participants had more than 3 years of driving experience, 5% had between 2 and 3 years of experience, and 6.67% had 1 to 2 years of driving experience. The study was approved by the Institution Review Board of Pennsylvania State University (STUDY00020300). Participants were remunerated with $60 after the experiment. None of the participants in Experiment 2 were participants in Experiment 1.

Experiment Design

The experiment adopted a 2 x 2 between-subjects design, where the independent variables were training modes (video, in-vehicle) and training styles (demonstration, practice). Sixty participants were divided equally into four experimental groups, each group experiencing one of the training approaches. The training was designed to cover three Advanced Driver Assistance Systems (ADAS) features, including ACC and LKA, both of which are classified as L1 partial automation, and an L2 partial driving automation system.

Procedure

Participants in the experiment were randomly assigned to one of four experimental conditions before participating the experiment. Those in the video training groups completed the training in the lab, whereas those in the in-vehicle training groups completed their training at the Larson Transportation Institute's test track (described below).

Upon arrival, participants were introduced to the study and signed a consent form. They were asked to complete a demographic questionnaire that included questions on their driving experience and a questionnaire to measure familiarity with three ADAS features, including ACC, LKA, and L2 partial driving automation. They then took a pre-knowledge test (described below) to assess their understanding of these ADAS features.

The training content on the three ADAS features was identical across all experimental groups. Participants in the video training groups watched either a basic video (video demonstration) or an interactive video with practice scenarios (video practice), depending on their assigned training style, in the lab. Meanwhile, participants in the in-vehicle training groups received their training inside the study vehicle (described below) at the test track. An experimenter, following a standardized script, provided a verbal overview of the three ADAS features, demonstrated how to activate and deactivate these features while the vehicle was stationary, and explained their capabilities and limitations. Participants in the in-vehicle demonstration group were driven through the test track three times and the experimenter demonstrated use of the vehicle's ADAS features. Those in the in-vehicle practice group drove themselves through the test track three times to practice using the three ADAS features.

After completing their training, participants in the in-vehicle training groups were driven by the experimenter to the lab. Participants took a post-training knowledge test, identical to the pre-knowledge test, either in the lab or at the test track. They then proceeded to the driving performance assessment, conducted on the driving simulator (described below) in the lab.

Before the simulator test, participants received a general tutorial on operating the STISIM simulator, allowing them to familiarize themselves with its steering wheel, pedals, and buttons. During this tutorial, they were also introduced to how the three ADAS features: ACC, LKA, and L2 partial driving automation, were implemented in the simulator. They then engaged in a practice drive, simulating a scenario similar to the tutorial, which aimed at honing their ability to operate these features effectively while navigating rural roads and highways. Participants were allowed to practice until they became familiar with the buttons and the driving simulator, as it was crucial for them to be comfortable operating the simulator for the experiment. All participants were provided the same practice drive. This was followed by three test drives, each focusing on one of the three ADAS features and incorporating three limitation scenarios. Before each drive, participants received instructions to utilize the specific ADAS feature as appropriate, and were instructed to retake manual control only when they believed the system had reached a relevant limitation. At the start of each scenario, participants were reminded to activate the assigned ADAS feature with a verbal message. Each test drive lasted between 8 and 9 minutes, resulting in a total driving session of approximately 30 minutes. After concluding the driving performance assessment in the lab, participants completed subjective evaluation questionnaires.

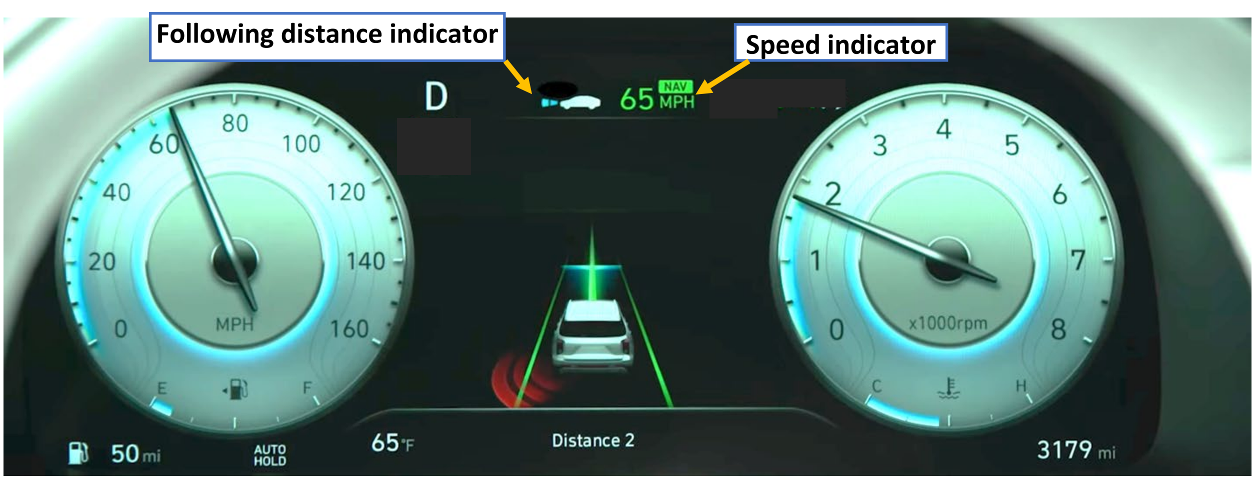
The total training time for the video training groups was approximately 1 hour and 20 minutes. For the in-vehicle training groups, the sessions lasted around 1 hour and 30 minutes, with an additional 15 minutes allocated for travel between the test track and the lab, bringing the total time to approximately 1 hour and 45 minutes.

Materials

Vehicle. A 2023 Hyundai Elantra HEV Hybrid Limited vehicle was used for drivers' in-vehicle training. This vehicle was equipped with Smart Cruise Control with Stop & Go (i.e., ACC), LKA, Lane Following Assist (i.e., LC), and Hyundai HDA, which is a Level 2 partial automation feature designed for highway driving.

Adaptive Cruise Control. As shown in Figure 14, the equipped ACC system uses radar to maintain a safe distance from the vehicle ahead while allowing drivers to set their desired speed and preferred following distance. Unlike traditional cruise control maintaining a constant speed, ACC automatically adjusted the vehicle's speed to match the speed of the car in front, ensuring a safe following distance. It can monitor traffic conditions and slow the vehicle down when traveling at speeds of 10 mph or higher. However, ACC relies heavily on sensor accuracy and has limitations in complex driving environments such as poor weather, heavy or varying traffic, sharp curves, and low-light conditions.

Figure 14. ACC Indicators

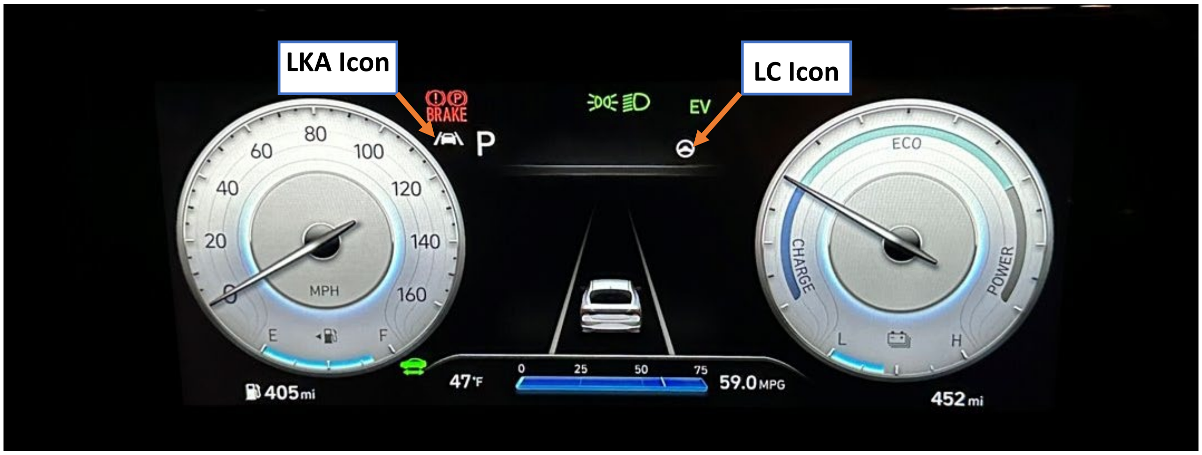


As shown in Figure 15, drivers could activate ACC by pressing the CRUISE button on the right-hand side of the steering wheel. The driving speed can be set or reduced by pressing the (RES/SET) switch down, and the speed can be increased by pressing the (RES/SET) switch up. The following distance can be adjusted by pressing the distance button, a car icon with three lines beneath it, with the distance 4 being the furthest and the distance 1 being the closest.

Figure 15. ACC Setting Buttons in Test Vehicle

Lane Keeping Assist. LKA is a safety feature designed to help prevent unintentional lane departures and reduce the risk of crashes caused by drifting out of the lane. As shown in Figure 16, it used a high-tech sensor in the windshield to continuously monitor lane markings on both sides of the road. LKA activated at speeds between 40 mph and 110 mph, if lane lines were detected on both sides of the vehicle. If the system detected that the vehicle was starting to drift out of its lane without the use of turn signals, it provided gentle steering input to guide the vehicle back into the lane. However, the system's effectiveness could be reduced on roads with poorly visible lane markings, in adverse weather conditions like fog, or when lane markings were obstructed by snow, dirt, or other debris. It also deactivated when the turn signal was engaged.

Figure 16. LKA and LC Indicators



As shown in Figure 17, this feature can be activated by pressing the LKA button on the left side of the steering wheel. A white LKA indicator appears, indicating the LKA system was ready to use, as shown in Figure 14. Once it was activated, the LKA icon changed from white to green, indicating the system was active.

Figure 17. LKA Button in Test Vehicle

Lane Centering. LC is an advanced feature that goes beyond lane keeping by actively maintaining the vehicle's position in the center of its lane. In the Hyundai test vehicle, this feature is called Lane Following Assist. This system continuously monitored the road and made small steering adjustments to keep the car centered between the lane markers. Unlike LKA that only intervened when the vehicle began to drift, LC provided continuous steering assistance, intended to reduce driver workload during long highway drives. LC can be activated at speeds below 93 mph, with a steering wheel icon turning from white to green to indicate that the system is active, as shown in Figure 16. LC requires the detection of lane markers on both sides of the vehicle, making it most effective on well-marked, straight roads. The system's effectiveness could be reduced on roads with poorly visible lane markings, in adverse weather conditions, or tight curves.

This feature can be activated by pressing the steering wheel button located on the right-side of the steering wheel, as shown in Figure 18.

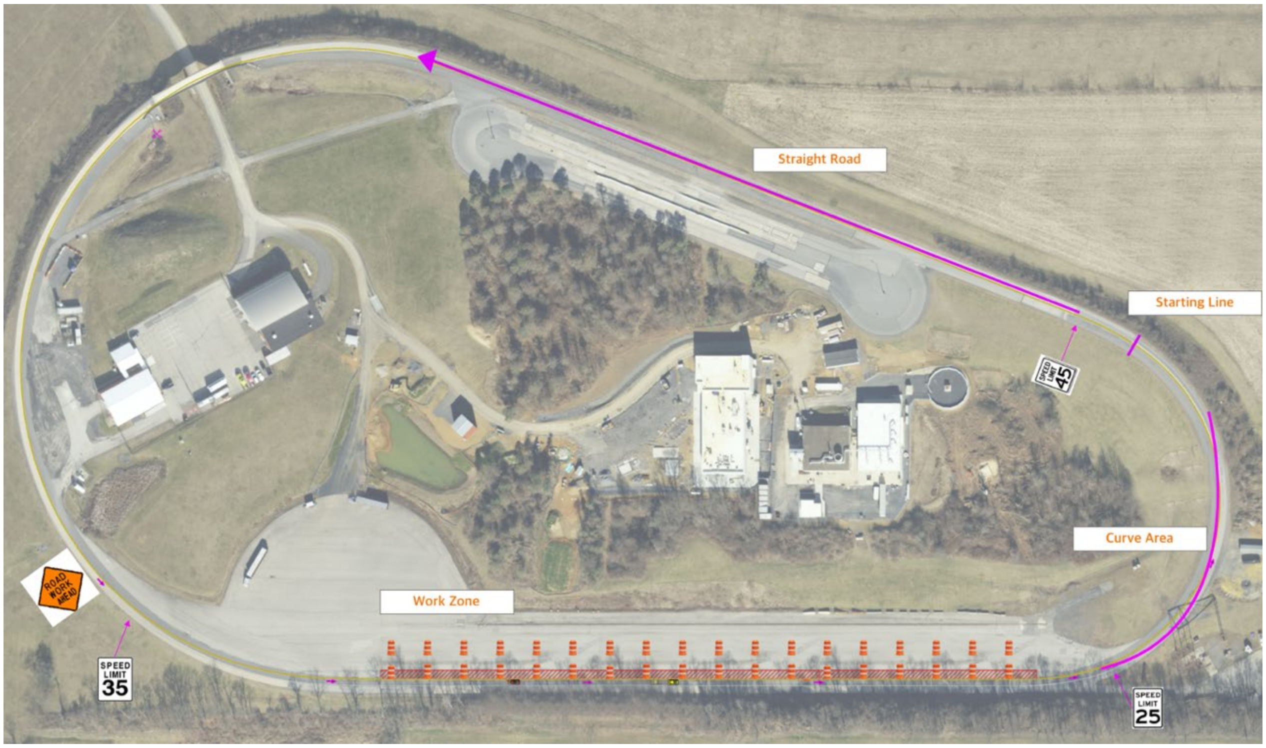
Figure 18. LC Button in Test Vehicle

Partial Automation. In this experiment, a PA feature was simulated by activating ACC and LC simultaneously at the test track, as shown in Figure 19. Drivers were told to activate the LC first by pressing the LC button on the steering wheel then, activate the ACC. (Note: PA was simulated in this manner because the official PA feature, HDA, is geofenced and can only be activated on highways.) The limitations of PA are consistent with the limitations of the individual features.

Figure 19. Partial Automation (ACC + LC) Indicators.

Test Track. As shown in Figure 20, the in-vehicle training was performed at the test track of the Larson Transportation Institute. This one-mile oval track was constructed with three curves with radii of 318, 546, and 900 ft, respectively. The length of the large-radius curve is 1,325 feet, and the length of the small-radius curve is 840 feet. Additionally, the track includes two straight road segments, with the back-side section being 1,700 feet long, and the front-side section being 1,375 feet long.

Figure 20. One-Mile Oval Test Track at Larson Transportation Institute



Starting from the designated point, the course includes a long straight road section (990 inch) followed by two curves. The in-vehicle training began at the predefined starting line, marked by two straight lines on the road surface and a 45-mph speed limit sign. The speed limit was set at 45 mph on the straight road because the LKA in the test vehicle activates only when the vehicle is traveling at or above 40 mph. At the end of the first curve, a work zone sign was placed alongside a 35-mph speed limit sign. The work zone was designed on a straight road section where barrels were used to block the lane lines. After passing through the work zone, the road leads into a second curve, where a sharp curve scenario was introduced. A 25-mph speed limit sign was installed before the sharp curve to alert drivers to reduce their speed.

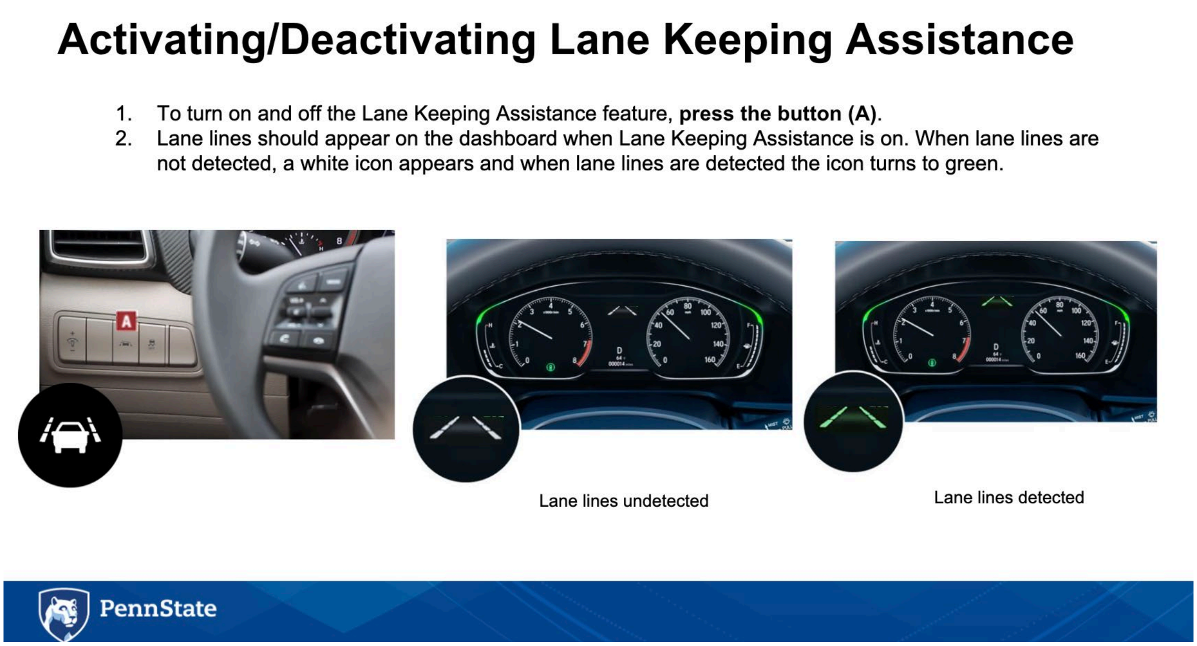
Training Materials. Participants in all groups received the essential training information comparable to that provided to the training with driver-related issues (T2) group in Experiment 1, acquainting them with fundamental information about ADAS systems. This training covered three ADAS features: ACC, LKA, and PA. For each feature, the training began with a comprehensive description derived from the owner's manual and proceeded to illustrate activation and deactivation procedures, including the associated HMI indicators and their changes during activation and deactivation. Additionally, the training extensively covered the limitations of ACC, LKA, and PA, presenting each limitation category with clear descriptions and typical examples. The following driver-related issues were covered during all the training groups. Participants were allowed to ask questions throughout the training.

- ***ACC***—The training included a detailed explanation of ACC, focusing on its functionality and operational steps. Participants learned that ACC goes beyond traditional cruise control by automatically adjusting the vehicle's speed to maintain a safe distance from the vehicle ahead. The training covered how to activate and deactivate ACC using the CRUISE button on the steering wheel and how to set the desired speed by toggling the SET button. Additionally, it was highlighted that the system allows for adjusting the following distance using a dedicated button, with visual indicators on the dashboard showing the selected distance setting.
- ***LKA***—The training on LKA explained its role in preventing unintentional lane departures. Trainees were instructed on how to activate and deactivate the system, with an emphasis on understanding the dashboard indicators that signify when the system is operational. LKA uses lane detection technology to gently steer the vehicle back into its lane if it detects that the driver is drifting.
- ***PA***—Since L2 partial automation was simulated with the simultaneous activation of ACC and LC, the training first explained LC, which provides continuous assistance in keeping the vehicle centered within its lane, and the key differences between LC and LKA, before introducing PA. The training detailed the activation process, which involves pressing the PA button on the steering wheel, and explained the visual cues that indicate whether the system is active or not. Participants were informed that while LC automates steering inputs, it requires the driver's hands to remain on the steering wheel. Participants would receive a warning from the experimenter if they kept their hands off the steering wheel for more than five seconds.
- ***Technology Limitations***—A significant portion of the training was dedicated to understanding the limitations of these ADAS technologies. The content highlighted that while ACC, LKA, and PA offer valuable assistance, they are not foolproof. For instance, these systems rely heavily on clear sensor input, which can be compromised in adverse weather conditions like heavy rain, snow, or glare from bright sunlight. The training emphasized that these systems should not be relied upon in conditions where lane markings are unclear or when the road has sharp curves or sudden changes in speed limits. Participants were reminded that these technologies are meant to assist, not replace, human judgment and that drivers should always be prepared to take control. The training content regarding ACC and LKA limitations was consistent with Experiment 1, while the information on PA was adjusted to reflect the limitations of ACC and LC. The same limitation categories from Experiment 1 were maintained, including adverse weather conditions, lighting conditions, roadway designs, and both static and dynamic road events for all ADAS features, with additional limitations on lane line visibility for LKA and rapid

speed changes for ACC. The content of the ADAS limitations training was consistent across all four training groups. However, in video training, information was delivered through textual instructions accompanied by visual illustrations, whereas in in-vehicle training, the content was conveyed verbally. Additionally, participants in the in-vehicle training experienced two specific scenarios, such as construction zones and curve limitations, directly on the test track.

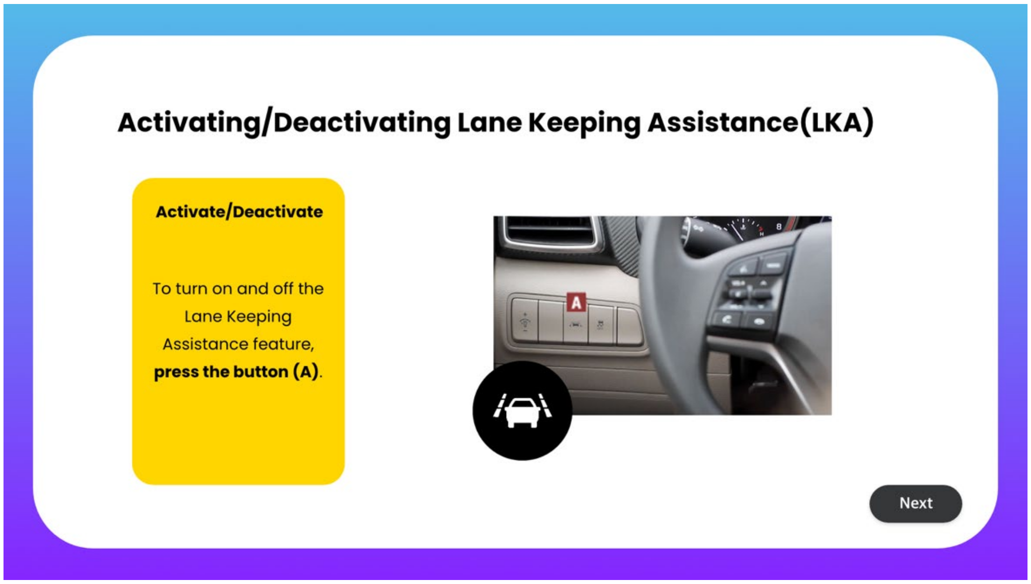
Video Demonstration Training. In the video demonstration training, participants watched a training video covering the essential information of three ADAS features and the limitations of these features. The essential training content mentioned above was conveyed through written and verbal descriptions, complemented by visual resources within the videos. For example, Figure 21 illustrates the training on how to activate LKA, with verbal instructions provided during the video. The complete training content for the video demonstration is available in Appendix E.

Figure 21. A Screenshot of the Video Demonstration Training



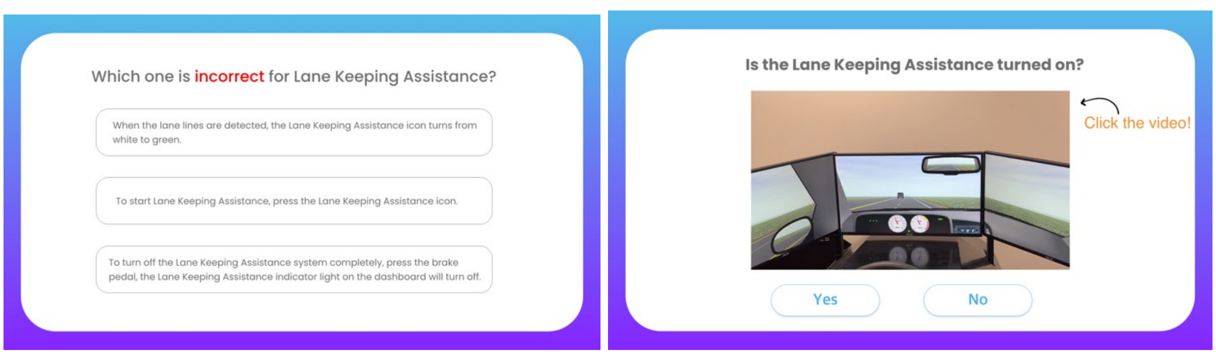
Video Practice Training. In the video practice training, participants engaged in interactive video training designed with Adobe XD, which required them to click through pages and modules to review the essential training information, as shown in Figure 22. The complete training content for the video practice is available in Appendix F.

Figure 22. A Screenshot of the Video Practice Training



As depicted in Figure 23, the practice features of this training were implemented by using prompts with interactive questions and by presenting video clips of driving scenarios related to the ADAS interface designs and the limitations of these features.

Figure 23. Interactive Questions and Sample Scenarios for LKA Feature Training



In-vehicle Demonstration Training. In the in-vehicle demonstration training, an experimenter sat in the driver's seat while the participant sat in the passenger seat. The experimenter provided a verbal overview of the three features, demonstrated the activation and deactivation of these features while the vehicle was stopped, and explained the capabilities and limitations of these features. The experimenter then drove through the test track three times to train participants with each of the three ADAS features, respectively. The training script for in-vehicle demonstration and practice training was provided in Appendix G.

On the test track (see Figure 20), the experimenter demonstrated the limitations of each feature in two specific scenarios: a work zone and sharp curve navigation. Both scenarios presented challenges for ACC, LKA, and PA. At the beginning of the training, the experimenter drove the vehicle from the starting point and accelerated to 45 mph on the first straight road segment before entering the first curve. Upon reaching this speed, the experimenter demonstrated the activation of ACC, LKA, or PA during respective rounds of driving. Since there was no car in front at the test track, the drivers did not test the distance adjustment function in ACC.

The work zone scenario, illustrated in Figure 24, included a work zone sign and a 35 mph speed limit sign posted on the side of the road before entering the work zone. At this point, the experimenter demonstrated the limitations of ACC, LKA, and PA. For the ACC demonstration, the experimenter deactivated ACC and manually drove through the work zone, instructing participants about the limitations of ACC in this scenario. For LKA and PA, the experimenter emphasized the unreliability of these features in the work zone by showing how the LKA and LC icons would blink or change from green to white, indicating the need for manual control in this situation.

Figure 24. The Work Zone Limitation Scenario

The sharp curve scenario, shown in Figure 25, included a 25-mph speed limit sign posted as the vehicle approached the curve. The experimenter deactivated ACC or PA by pressing the brake pedal, or deactivated LKA by pressing the corresponding LKA button, to manually navigate the curve. During this time, the experimenter explained to the participants the limitations of these ADAS features in situations like the sharp curve.

Figure 25. The Sharp Curve Limitation Scenario

In-vehicle Practice Training.In the in-vehicle practice training, the experimenter sat in the passenger seat while the participant sat in the driver's seat. The experimenter verbally provided an overview of the three features, presented instructions on their activation and deactivation, and explained their capabilities and limitations. The training content was identical to that of the in-vehicle demonstration training.

Participants practiced activating and deactivating these features while the vehicle was stationary. They also drove around the test track manually to become familiar with the driving environment, ensuring their safety when using ADAS. After this familiarization, they were instructed to drive through the test track three times, each round focusing on one of the three ADAS features. During these drives, they also encountered the limitations of these features in two scenarios, similar to the in-vehicle demonstration training.

Questionnaires.

Demographic and Driving Experience Questionnaire. This questionnaire was designed to gather demographic information from participants, including their age, gender, ethnicity, education level, and employment status. Additionally, it included questions related to participants' driving experience, such as the number of years they have been driving, their driving frequency, and their self-assessed confidence level in driving with a 5-point Likert scale with 1 denoting "Not at all confident" and 5 denoting "Completely confident."

ADAS Experience Questionnaire. This questionnaire was designed to assess participants' familiarity with ADAS functions. It included questions regarding the ownership of a vehicle equipped with key ADAS features (e.g., ACC, LKA, and PA) and the frequency of their utilization.

Pre- and Post-Training Knowledge Test. This questionnaire was developed to assess drivers' understanding of the ADAS functions. Multiple choice questions were designed to measure participants' recognition of HMI indicators and the activation/deactivation of each ADAS function. Then a set of true or false questions were designed to measure drivers' understanding of limitations of ACC, LKA, and PA. The complete questionnaire was presented in Appendix H.

Subjective Evaluation. Additionally, participants' comfort and satisfaction levels when using ADAS functions were evaluated using a 5-point Likert scale, where a score of 1 indicated "extremely uncomfortable/unsatisfied" and a score of 5 indicated "extremely comfortable/satisfied." Drivers' subjective ratings were collected after the test drive. The subjective evaluation included driver trust (Checklist for Trust between People and Automation [Jian et al., 2000]), acceptance (Automation and System Acceptance Questionnaire [Van Der Laan et al., 1997]), and workload (NASA-TLX [Hart & Staveland, 1998]).

Driving Simulator. The study utilized a fixed-base driving simulator, the STISIM Drive® M300WS-Console system, to assess drivers' decision-making in ADAS limitation scenarios and their driving performance while utilizing ADAS systems. The driving simulator was installed on a Dell™ workstation and consisted of three driving displays, which allowed for a 135° field of view. The simulator setup also included the high-fidelity advanced full-size steering wheel with active force feedback, and two advanced foot pedals. The STISIM Drive® software was programmable and expandable using Open Module, which allowed for the programming of ACC, LKA, and PA features. Each feature was activated by pressing the corresponding programmable button located on the sides of the steering wheel.

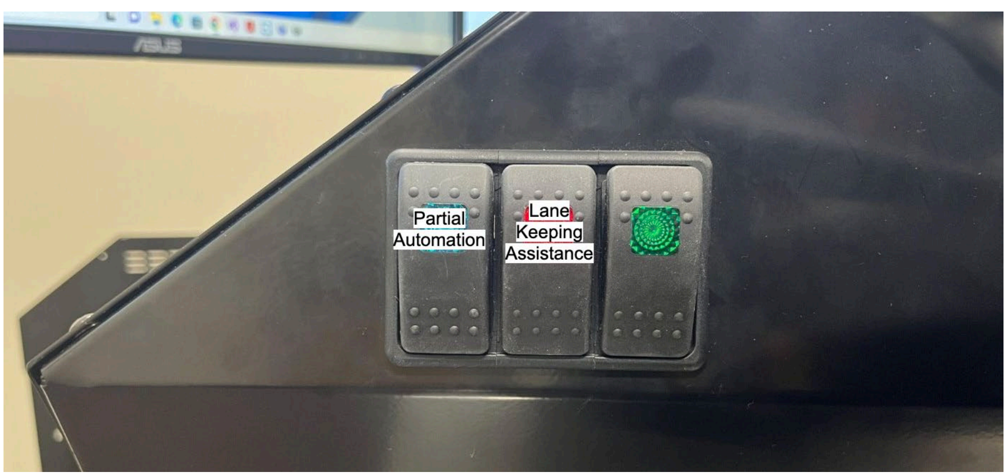
ACC. As shown in Figure 26, participants could activate ACC by pressing the "Adaptive Cruise Control" button on the right-hand side of the steering wheel. The driving speed could be increased or reduced by pressing the "+" or "−" button. The adjustment of the following distance was not simulated in the experiment due to the limited number of programmable buttons in the simulator. A medium following distance was preselected, and participants were informed that they could only manipulate the speed.

Figure 26. ACC setting buttons in the STISIM Driving Simulator (right side)

LKA. As shown in Figure 27, participants could activate and deactivate LKA by pressing the middle "Lane Keeping Assistance" button on the panel at the left-hand side of the steering wheel, consistent with the design in the real vehicle.

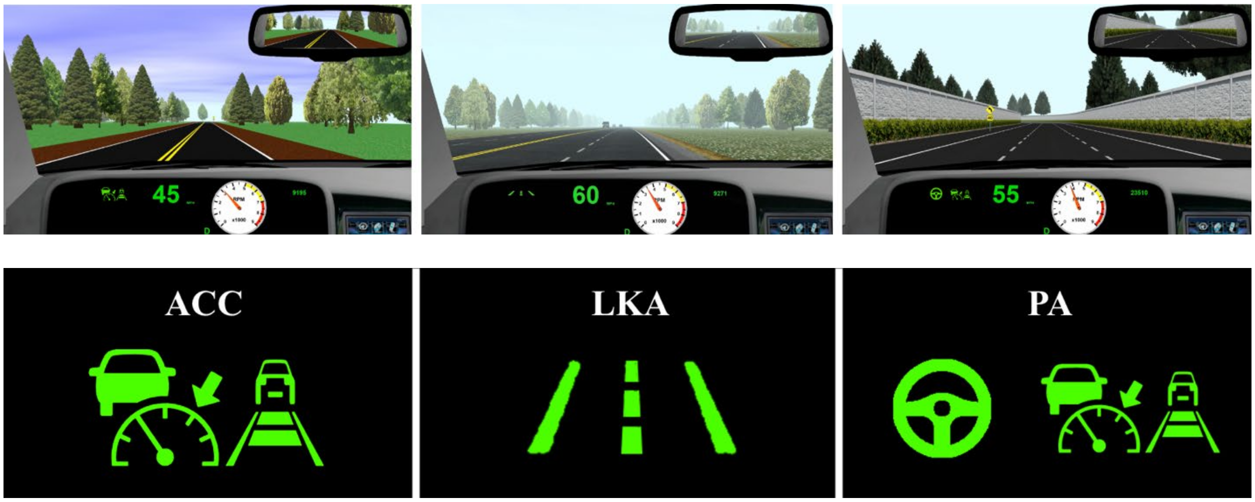
PA. Since the primary purpose of the driving simulation was to examine drivers' understanding of ADAS limitations and capabilities, the activation and deactivation of the L2 partial automation were simplified in the experiment. This was achieved by using the left "Partial Automation" button on the panel located on the left-hand side of the steering wheel (see Figure 27), not requiring the separate activation of ACC and LC.

Figure 27. LKA and PA buttons in the STISIM driving simulator (left side)



ADAS Indicators. The ACC indicator was displayed on the right side of the instrument panel, while the LKA and PA indicators were shown on the left side, as shown in Figure 28. The driving speed was presented in green digits on center of the panel. The design of these indicators were consistent with those used in the Hyundai vehicle for the in-vehicle training.

Figure 28. ACC, LKA, PA indicators in the STISIM driving simulator



Driving Scenarios. As depicted in Table 10, a total of nine testing scenarios were created and programmed into the STISIM driving simulator to evaluate drivers' comprehension of ADAS capabilities and limitations. Three scenarios were developed to simulate the limitation of ACC, three to simulate the limitation of LKA, and three to simulate the limitation of PA. The order of the scenarios was randomized across participants. Scenario 3 specifically involved actual system failures of the ACC. In this scenario, the ACC failed to maintain the preset distance from the vehicle ahead, leading to improper speed adjustments and creating potentially unsafe driving situations, such as when the front vehicle suddenly stopped. This failure was demonstrated to participants to highlight the system's limitations under certain conditions.

Table 10. Testing Driving Scenarios of ADAS Limitation Events

Scenario	ADAS	Purpose of Testing	Expected Decision-Making	Measurements of Reaction Time
1: Sharp curve	ACC	Measure if a driver understands the limitation of ACC in navigating sharp curves	Deactivate ACC when encountering the curve	Response time: when the driver turns off the ACC − when the driver can see the curve
2: Dark tunnel	ACC	Measure if a driver understands that ACC do not work well in dimly lit places	Deactivate ACC before or when they entered the tunnel and activate ACC after exiting the tunnel	Response time: when the driver turns off the ACC − when the driver can see the tunnel
3: Heavy traffic	ACC	Measure if a driver understands the ACC limitation corresponding to heavy traffic	Deactivate ACC when encountering slow traffic ahead	Response time: when the driver presses the brake pedal - when the driver can see that there is heavy traffic
4: Front vehicle blocking lane line	LKA	Measure if a driver understands the limitation of LKA corresponding to blocked lane lines	Deactivate LKA before or when the front vehicle blocks the lane line and activate the LKA when the road has clear lane lines	Response time: when the driver turns off the LKA − when the front vehicle blocks the lane line
5: Faded lane lines	LKA	Measure if a driver understands the limitation of LKA corresponding to faded lane lines	Deactivate LKA before or when encountering roads with faded lane lines and activate the LKA when the road has clear lane lines	Response time: when the driver turns off the LKA − when the driver can see the faded lane lines
6: Foggy weather condition	LKA	Measure if a driver understands the limitation of LKA corresponding to foggy weather condition	Deactivate LKA before or when entering the foggy area	Response time: when the driver turns off the LKA − when the driver enters the foggy area
7: Rainy weather condition	PA	Measure if a driver understands the limitation of PA corresponding to rainy weather condition	Deactivate PA when the rainy weather starts	Response time: when the driver turns off the PA − when the rainy weather starts
8: Sharp curve	PA	Measure if a driver understands the need to manually steer the steering wheel given PA could not navigate through sharp curves	Deactivate PA when encountering the curve	Response time: when the driver turns off the PA − when the driver can see the curve
9: Construction zone	PA	Measure if a driver understands the inability of PA to adjust speed according to the posted speed limit for the construction zone	Deactivate PA when encountering the construction zone	Response time: when the driver turns off the PA - when the driver can see the construction zone

Dependent Variables

Training effectiveness was measured with four categories of dependent variables, including driver knowledge of ADAS, decision-making, driving performance, and subjective evaluations.

Knowledge of ADAS. Drivers' understanding of ADAS was assessed through a knowledge test specifically designed to evaluate all three ADAS features (i.e., ACC, LKA, and PA) before and after the training. The test included multiple-choice questions on the activation and deactivation procedures and HMI indicators for each feature, as well as true/false questions regarding the capabilities and limitations of these features. Participants' responses were compared to the correct answers, and the number of correct responses was divided by the total number of questions to calculate the percentage of correct responses on the knowledge test. This percentage was referred to as pre-training and post-training knowledge accuracy. The difference between the percentage of correct responses in the pre-training and post-training knowledge test was then calculated as the dependent variable of this study, denoted as the knowledge improvement.

Decision-Making. The correctness of drivers' decision-making in response to ADAS capabilities and limitations was assessed by comparing their actions to the expected correct responses in the driving simulation. During the simulation, participants encountered various driving scenarios that presented the limitations of ACC, LKA, and PA. If a driver's decision aligned with the expected correct action (e.g., deactivating the ADAS feature when a limitation was reached), it was coded as 1; otherwise, it was coded as 0. In this experiment, participants were instructed to deactivate ACC and PA when they perceived a limitation of the feature and to press the LKA button to indicate their perception of an LKA limitation during the driving scenario.

Drivers' reaction time was measured as the time taken to deactivate ACC and PA features or press the LKA button, starting from the onset of the ADAS limitation. Reaction time was recorded as a dependent variable only for instances where drivers made correct decisions. For those who made incorrect decisions or no decisions, their data were omitted from the analysis. The response time for each event was calculated by subtracting the limitation occurrence time from the driver's reaction time.

Driving Performance. The standard deviation of lane position (SDLP) was analyzed as a measure of driving performance throughout the portion of the drive in which the relevant limitation was present (Ebnali et al., 2019). The limitation period began when drivers encountered the ADAS limitation scenario. For ACC, the measurement of SDLP began as soon as drivers encountered the ADAS limitation scenario, capturing their lane-keeping performance during the scenario. For LKA and

HDA, the measurement of SDLP started once drivers deactivated the feature, reflecting their ability to maintain lane position without assistance.

Subjective Evaluations. Drivers' subjective ratings were collected after the driving simulation, including driver trust, acceptance, and workload.

Driver trust was measured with the Checklist for Trust between People and Automation (Jian et al., 2000). This is a questionnaire designed to assess 12 factors influencing trust between individuals and automated systems, including 'deception,' 'suspicion,' 'security,' 'integrity,' and 'reliability.' Participants rated each factor on a 7-point scale, with '1' indicating 'not at all' and '7' indicating 'extremely.'

Driver acceptance was assessed with the System Acceptance Questionnaire (Van Der Laan et al., 1997), which is a nine-item survey that evaluates human acceptance of new technology across two dimensions: usefulness and satisfaction. Participants rated the system on a 5-point scale ranging from -2 to +2 ('-2' = extremely negative, '+2' = extremely positive). Usefulness scores were computed as the average of items 1, 3, 5, 7, and 9, while satisfaction scores were calculated as the average of items 2, 4, 6, and 8.

Drivers' workload was measured using the NASA Task Load Index (NASA-TLX; Hart & Staveland, 1998). It assesses workload across six dimensions: mental demand, physical demand, temporal demand, performance, effort, and frustration level. Participants rate each dimension on a 20-point scale, which provides an overall workload score.

Data Analysis

This study assessed the effects of training style (demonstration, practice) and training mode (video, in-vehicle) on four groups of dependent variables, including drivers' knowledge improvement, the correctness of their decision-making and reaction time in responding to ADAS limitations, driving performance utilizing ADAS, and subjective evaluation.

To examine the overall effectiveness of ADAS training programs, paired samples t-tests were employed to determine the statistical differences in pre- and post-training knowledge accuracy for the three ADAS features. Then, a two-way ANCOVA was conducted to examine effects of the training modes and training styles on drivers' knowledge improvement across the three ADAS features, while controlling for gender, age, education level, and pre-training knowledge accuracy as covariates.

To evaluate drivers' usage of ADAS features, drivers' correctness of decision-making and reaction time in responding to ADAS limitations were analyzed. A logistic regression was conducted to examine the impact of training style and training mode on drivers' correctness of decisions in response to ADAS limitations in nine driving scenarios. In terms of driver reaction time, a two-way ANCOVA was conducted on drivers' reaction time, with training style and training modes as independent variables, while controlling for gender, age, education level, and pre-training knowledge accuracy as covariates. Reaction time was recorded as a dependent variable only for instances where drivers made correct decisions.

To evaluate driving performance within ADAS, a two-way ANOVA was conducted to examine the effects of training style and training modes on drivers' SDLP during the limitation period, while controlling for gender, age, education level, and pre-training knowledge accuracy as covariates.

Lastly, a two-way ANCOVA was conducted to examine the effects of training style and training mode on three subjective evaluation variables: trust, workload, and usefulness. The covariates evaluated included gender, age, and educational level.

Comparison of groups revealed a statistically significant imbalance between groups in driving experience. Thus, the planned analyses were re-run with driving experience included as an additional covariate. This adjustment impacted the results for knowledge improvement accuracy, but had no material impact on other outcome measures. Thus, covariate-adjusted results reported subsequently for knowledge accuracy are based on analyses with driving experience included as an additional covariate.

Results

Descriptive analysis

Chi-square tests were conducted to analyze the demographic differences among the four training groups (see Table 11). The results indicated that there was no statistically significant difference in driver gender (χ^2 = 5.701, p = 0.127), ethnicity (χ^2 = 2.143, p = 0.543), race (χ^2 = 9.950, p = 0.355), and employment status (χ^2 = 19.857, p = 0.178). There was significant difference in driver age (χ^2 = 21.455, p = 0.044) and educational level (χ^2 = 25.102, p = 0.049). The Video Practice group included no drivers aged 18 to 24 and a higher proportion of drivers aged 25 to 34 than the other groups.

Table 11. Demographic Information of Participants in Four Training Groups

		Video Demo		Video Practice		In-Vehicle Demo		In-Vehicle Practice	
		N	%	N	%	N	%	N	%
Gender	Female	11	73.3%	8	53.3%	10	66.7%	10	66.7%
	Male	4	26.7%	7	46.7%	5	33.3%	5	33.3%
Age	18–24 years old	6	40.0%	0	0%	6	40.0%	3	20.0%
	25–34 years old	5	33.3%	13	86.7%	5	33.3%	7	46.7%
	35–44 years old	2	13.3%	1	6.7%	4	26.7%	4	26.7%
	45–54 years old	0	0%	0	0%	0	0%	1	6.7%
	55 years or older	2	13.3%	1	6.7%	0	0%	0	0%
Race	White	10	66.7%	5	33.3%	8	53.3%	8	53.3%
	Asian	4	26.7%	10	66.7%	4	26.7%	5	33.3%
	Black or African American	1	6.7%	0	0%	2	13.3%	1	6.7%
	Other	0	0%	0	0%	1	6.7%	1	6.7%
Ethnicity	Hispanic or Latino	1	6.7%	1	6.7%	2	13.3%	0	0%
	Not Hispanic or Latino	14	93.3%	14	93.3%	13	86.7%	15	100%
Education Level	Less than high school	0	0%	0	0%	0	0%	0	0%
	High school graduate or equivalent	1	6.7%	0	0%	2	13.3%	0	0%
	Some college, no degree	3	20.0%	0	0%	1	6.7%	1	6.7%
	Associate degree	0	0%	0	0%	0	0%	0	0%
	4-year degree	2	13.3%	3	20.0%	2	13.3%	7	46.7%
	Master's degree	8	53.3%	9	60.0%	5	33.3%	7	46.7%
	Professional degree	1	6.7%	1	6.7%	0	0%	0	0%
	Doctorate	0	0%	2	13.3%	5	33.3%	0	0%
Employment status	Employed full-time	3	20.0%	9	60%	10	66.70	9	60.0%
	Employed part-time	6	40.0%	6	40%	4	26.6%	3	20.0%
	Retired	1	6.7%	0	0%	0	0%	0	0%
	Unemployed	4	26.7%	0	0%	1	6.7%	3	20.0%
	Other	1	6.7%	0	0%	0	0%	0	0%

Note: column heads are grouped under "Training Groups".

As shown in Table 12, Chi-square tests were performed to analyze the differences among the four groups on drivers' driving experience. The results showed that there was significant difference in their driving experience (χ^2 = 14.26, p = 0.027). Specifically, all drivers both In-vehicle conditions had at least 3 years of driving experience, whereas two drivers in the Video Demo group and five drivers in the Video Practice group had fewer than 3 years of driving experience. Although non-significant after Bonferroni correction for multiple comparisons, subsequent analyses were re-run with driving experience as an additional covariate due to the potential substantive impact of this imbalance in the distribution of relatively less-experienced drivers. Kruskal-Wallis H test was also conducted to analyze the frequency of driving differences among the four groups. The results indicated that there was no significant difference in frequency ($H(3) = 2.14$, $p = 0.54$). Kruskal-Wallis H test was also conducted to analyze the confidence level of driving experience differences among the four groups. The results indicated that there was no significant difference in the level of experience ($H(3) = 6.20$, $p = 0.10$).

Table 12. Participants' Driving Experience Across Four Training Groups

Category		Training Group					
		Video Demo	Video Practice	In-Vehicle Demo	In-Vehicle Practice	x^2	p-value
Driving experience	Less than 1 year	0	0	0	0	14.26	0.027
	1–2 years	2	2	0	0		
	2–3 years	0	3	0	0		
	More than 3 years	13	10	15	15		

For the experience of ADAS features, Chi-square tests were performed to analyze the differences among the four groups. As shown in Table 13, there was no significant difference in drivers' experience with ACC ($\chi^2 = 12.11$, $p = 0.44$), LKA ($\chi^2 = 7.28$, $p = 0.84$), or PA ($\chi^2 = 7.08$, $p = 0.85$) across four training groups.

Table 13. Participants' Experience with ADAS Features Across Four Training Groups

Category		Training Group: Video Demo	Video Practice	In-Vehicle Demo	In-Vehicle Practice	x^2	p-value
ACC Experience	Never	2	2	3	6		
	Sometimes	5	5	7	1		
	Most of the time	2	0	0	1	12.11	0.44
	Every time	1	1	1	1		
	Don't have the feature	5	7	4	6		
LKA Experience	Never	5	2	3	6		
	Sometimes	1	2	3	1		
	Most of the time	2	2	2	2	7.28	0.84
	Every time	2	1	3	1		
	Don't have the feature	5	8	4	5		
PA Experience	Never	6	3	4	6		
	Sometimes	2	3	2	1		
	Most of the time	0	0	1	1	7.08	0.85
	Every time	0	0	1	1		
	Don't have the feature	7	9	7	6		

Knowledge Accuracy of ADAS

Overall Effectiveness of ADAS Training Programs. The effectiveness of the ADAS training was initially assessed by comparing drivers' knowledge accuracy in pre-post-training tests across four training approach groups for three ADAS features. As shown in Table 14, the results of a repeated measures one-way ANOVA indicated that the ADAS training significantly enhanced drivers' knowledge accuracy overall, regardless of the training methods used and across different ADAS features. There were two exceptions including the video demonstration for the PA feature ($F(1, 14) = 4.42$, $p = 0.054$) and the in-vehicle practice training for the LKA feature ($F(1, 14) = 1.91$, $p = 0.19$). For these groups, knowledge accuracy was higher post-training than pre-training but the difference was not statistically significant.

Table 14. Knowledge Accuracy in The Pre-Training and Post-Training Knowledge Test

Training Method	ADAS Feature	Pre-training Knowledge accuracy		Post-training Knowledge accuracy		F value	p
		M	SD	M	SD		
Video Demonstration	ACC	61.67	24.76	85.00	12.28	18.21	<0.001
	LKA	76.00	10.02	88.44	10.83	28.44	<0.001
	PA	74.44	17.67	81.11	12.39	4.42	0.054
Video Practice	ACC	68.89	18.49	86.11	12.06	10.82	0.005
	LKA	77.78	17.76	88.89	9.32	8.93	0.010
	PA	80.00	14.36	93.33	8.45	10.84	0.005
In-vehicle Demonstration	ACC	76.11	17.78	92.78	7.63	11.35	0.005
	LKA	81.78	9.58	90.67	6.57	10.00	0.007
	PA	78.89	20.38	95.56	7.63	10.50	0.006
In-vehicle Practice	ACC	61.67	20.36	86.67	12.52	14.77	0.002
	LKA	86.22	10.22	90.22	7.07	1.91	0.189
	PA	75.56	17.67	90.00	13.80	4.97	0.043

Pre-Training Knowledge Assessment of ADAS Features Across Training Approaches. To examine whether drivers in the four training groups had a similar level of knowledge accuracy before training, a mixed ANOVA was conducted on drivers' pre-training knowledge accuracy, with training style and training modes as between-subjects independent variables and ADAS features as a within-subjects independent variable. The results did not reveal any significant association of training style ($F(1, 56) = 0.004$, $p = 0.95$, $\eta^2 = 0.000$), training mode ($F(1, 56) = 1.24$, $p = 0.269$, $\eta^2 = 0.022$), or their two-way interactions ($F(1, 56) = 2.10$, $p = 0.15$, $\eta^2 = 0.036$) with knowledge accuracy, suggesting that the drivers exhibited similar levels of ADAS knowledge across training groups prior to training.

However, a significant main effect of the ADAS feature was found on drivers' knowledge accuracy in the pre-training knowledge test, $F(2, 112) = 13.77$, $p < 0.001$, $\eta^2 = 0.20$), indicating that drivers had varying levels of knowledge across different ADAS features before training. Pairwise comparisons using the Tukey test indicated that drivers had better knowledge of LKA ($M = 80.44$, $F(1, 56) = 29.54$, $p < 0.001$, $\eta^2 = 0.35$) and PA ($M = 77.22$, $F(1, 56) = 10.59$, $p = 0.002$, $\eta^2 = 0.16$) compared to ACC ($M = 67.08$).

A mixed ANOVA was also conducted on drivers' post-training knowledge accuracy, with training style and training modes as between-subjects independent variables and ADAS features as a within-subjects independent variable. The results showed significant main effect for training mode on post-training knowledge accuracy ($F(1, 56) = 4.49$, $p = 0.038$, $\eta^2 = 0.074$), suggesting in-vehicle training results in higher knowledge accuracy than video training. There was also a significant interaction between training style and training mode on post-training knowledge accuracy (F(1,

56) = 5.69, p = 0.020, η^2 = 0.092). Specifically, the in-vehicle demonstration training resulted in significantly higher post-training knowledge accuracy compared to the video demonstration (F(1, 56)=10.15, p = 0.002), but there was no difference for the practice training style (p= 0.85). The results did not reveal significant effect of ADAS features (F(2, 56) = 1.09, p = 0.34, η^2 = 0.019), suggesting drivers gained similar levels of knowledge of three ADAS features after training. These findings illustrate that drivers did not exhibit significant differences in their post-training knowledge accuracy among the three ADAS features. Therefore, any potential differences in their decision-making and driving performance when using ADAS features in the subsequent analysis were not likely due to differences in their knowledge of these features.

Impact of Training Mode and Training Style on Knowledge Improvement. A three-way ANCOVA was firstly performed to examine the effects of training styles and training modes on drivers' knowledge improvement across three ADAS features.

The results showed significant a main effect for training mode on knowledge improvement (F(1, 164) = 5.00, p = 0.027, η^2 = 0.030), suggesting in-vehicle training resulted in greater knowledge improvement than video training. The main effects of training style (F(1, 164) = 0.31, p = 0.580, η^2 = 0.002) and ADAS features (F(2, 164) = 0.16, p = 0.85, η^2 = 0.002) were not significant. The interaction between training style and training mode on the knowledge improvement approached statistical significance (F(1, 164) = 3.56, p = 0.061, η^2 = 0.021). None of the other two-way interaction terms nor the three-way interaction term was significant.

Pre-training knowledge accuracy was a significant covariate predicting knowledge improvement (F(1, 164) = 312.13, p< 0.001, η^2 = 0.66). Higher pre-training knowledge is associated with less improvement, as individuals with greater initial knowledge have less room for growth during the training.

Table 15 presented drivers' knowledge improvement across four combined training conditions and across ADAS features.

Table 15. Drivers' Knowledge Improvement Under Varying Training Approaches and Across Three ADAS Features

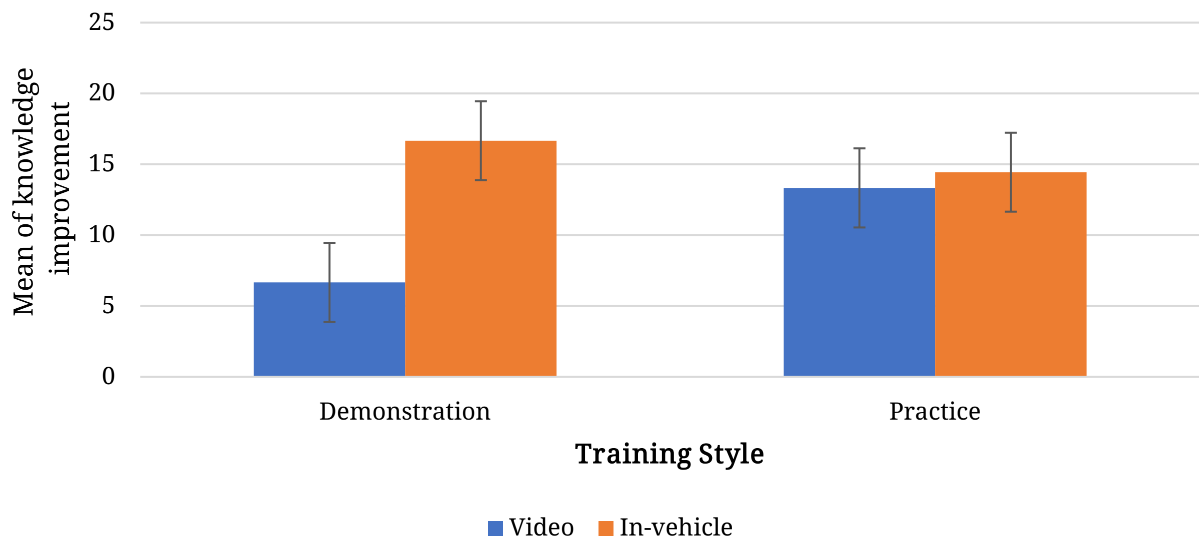
Training Style	Demonstration				Practice			
Training Mode	Video		In-Vehicle		Video		In-Vehicle	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
ACC	23.33	21.18	16.67	19.16	17.22	20.28	25.00	25.20
LKA	12.44	9.04	8.89	10.89	11.11	14.40	4.00	11.21
PA	6.67	12.28	16.67	19.92	13.33	15.69	14.44	25.09

Three two-way ANCOVAs were then performed to examine the effects of training style and training mode on the drivers' knowledge improvement for the three ADAS features.

For PA, the results showed a non-significant main effect for training mode (F(1, 51) = 2.27, p = 0.14 η^2 = 0.043) and a non-significant main effect for training style (F(1, 51) = 1.67, p = 0.20, η^2 = 0.032). The pre-training knowledge score was not a significant covariate (F(1, 51) = 0.94, p = 0.34, with η^2 = 0.018).

As shown in Figure 29, there was a significant interaction between training style and training mode on the knowledge improvement (F(1, 51) = 6.98, p = 0.011, partial η^2 = 0.12). Specifically, the simple main effects analysis indicated that for the demonstration training style, the in-vehicle training mode resulted in significantly more improvement in drivers' knowledge compared to the video training mode (F(1, 51) = 7.67, p = 0.008), but there was no difference by mode for the practice training style (p= 0.35). Additionally, for the video training mode, the practice style resulted in significantly greater improvement in PA correctness post-test scores than the demonstration style (F(1, 51) = 8.95, p = 0.004), whereas no significant differences were observed between the two training styles for the in-vehicle training mode (p = 0.46).

Figure 29. Improvement of Drivers' Knowledge Test Scores Pre-Training Versus Post-Training for the Partial Automation Feature



For ACC, the main effects on knowledge accuracy of training style (F(1, 51) = 0.03, p = 0.86) and training mode (F(1, 51) = 1.85, p = 0.18) were not significant. There was no significant interaction between training style and training mode (F(1, 51) = 0.35, p = 0.56). Driving experience was not statistically significant as a covariate (F(1,51) = 0.097, p = 0.76). The pre-training knowledge score was a significant covariate, (F(1, 51) = 120.15, p < 0.001, η^2 = 0.72).

For LKA, the main effects of training style ($F(1, 51) = 0.15$, $p = 0.70$) and training mode ($F(1, 51) = 0.07$, $p = 0.80$) were not significant. There was no significant interaction between training style and training mode ($F(1, 51) = 0.03$, $p = 0.87$). Driving experience was not significant as a covariate ($F(1,51) = 0.02$, $p = 0.90$). Pre-training knowledge score was a significant covariate ($F(1, 51) = 59.36$, $p < 0.001$, $\eta^2 = 0.53$).

Decision-Making with ADAS

Correctness of Decision-Making in Responding to ADAS Limitations. The percentage of participants who responded correctly to each decision-making scenario in relation to training mode and training style is shown in Table 16.

A logistic regression analysis was conducted to evaluate the effects of training style and training mode on drivers' decision-making accuracy in relation to ADAS features. The overall model was statistically significant ($\chi^2(5) = 12.40$, $p = 0.03$). However, the model explained only a small portion of the variance in decision-making accuracy, with a Nagelkerke R^2 value of 0.001, and it correctly classified 69.8% of cases. The Wald criterion indicated that the ADAS feature was a significant predictor of decision-making accuracy. Specifically, drivers were significantly less likely to make correct decisions when using LKA features compared to ACC features (*OR* = 0.52, 95% *CI* [0.33, 0.81], $p = 0.002$). The difference in decision-making accuracy between ACC and PA features was not significant (*OR* = 1.03, 95% *CI* [0.64, 1.66], $p = 0.90$). Neither the training mode ($p = 0.59$) nor the training style ($p = 0.79$) was found to have a significant impact on decision-making accuracy.

Table 16. Drivers' Correctness of Decision-Making across Training Approaches

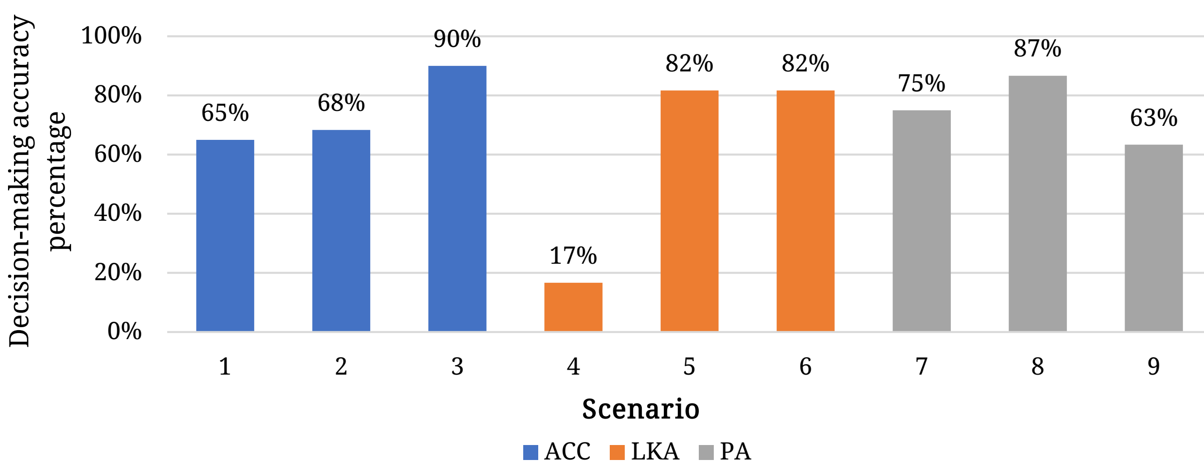
ADAS	Scenario	Number of Correct Decisions (%)				
		Video Demo	Video Practice	In-Vehicle Demo	In-Vehicle Practice	Total
ACC	1. Sharp Curve	8 (53%)	11 (73%)	10 (67%)	8 (53%)	37 (62%)
	2. Dark Tunnel	12 (80%)	12 (80%)	8 (53%)	9 (60%)	41 (68%)
	3. Heavy Traffic	12 (80%)	15 (100%)	14 (93%)	13 (87%)	54 (90%)
LKA	4. Vehicle Blocking Lane Line	3 (20%)	1 (7%)	1 (7%)	5 (33%)	10 (17%)
	5. Faded Lane Lines	14 (93%)	11 (73%)	11 (73%)	13 (87%)	49 (82%)
	6. Foggy Weather	13 (87%)	14 (93%)	11 (73%)	11 (73%)	49 (82%)
PA	7. Rainy Weather	14 (93%)	10 (67%)	11 (73%)	10 (67%)	45 (75%)
	8. Sharp Curve	11 (73%)	12 (80%)	15 (100%)	14 (93%)	52 (87%)
	9. Construction Zone	9 (60%)	8 (53%)	9 (60%)	9 (60%)	35 (58%)

Three logistic regression analyses were then performed to assess the effects of training style and training mode on drivers' decision-making accuracy when responding to ACC, LKA, and PA limitations, respectively. The logistic regression models were not statistically significant (χ^2 (3) = 3.40, p = 0.33 for the ACC; χ^2(3) = 2.77, p = 0.43 for the LKA; and χ^2 (3) = 2.93, p = 0.40 for the PA). The models explained only a small portion of the variance in correctness, with Nagelkerke R^2 values of 0.028, 0.021, and 0.024, respectively. The classification accuracy of the models was 74%, 60%, and 75%, respectively.

Neither training mode nor training style influenced drivers' decision-making in responding to ADAS limitations. For ACC, the interaction between training mode and training style was not significant (p = 0.26), and neither were the main effects of training style (p = 0.13) or training mode (p = 1.00). For LKA, the interaction between training mode and training style was also not significant (p = 0.13), nor were the main effects of training style (p = 0.39) and training mode (p = 0.14). For PA, the interaction between training mode and training style was not significant (p = 0.96), nor were the main effects of training style (p = 0.35) and training mode (p = 0.44).

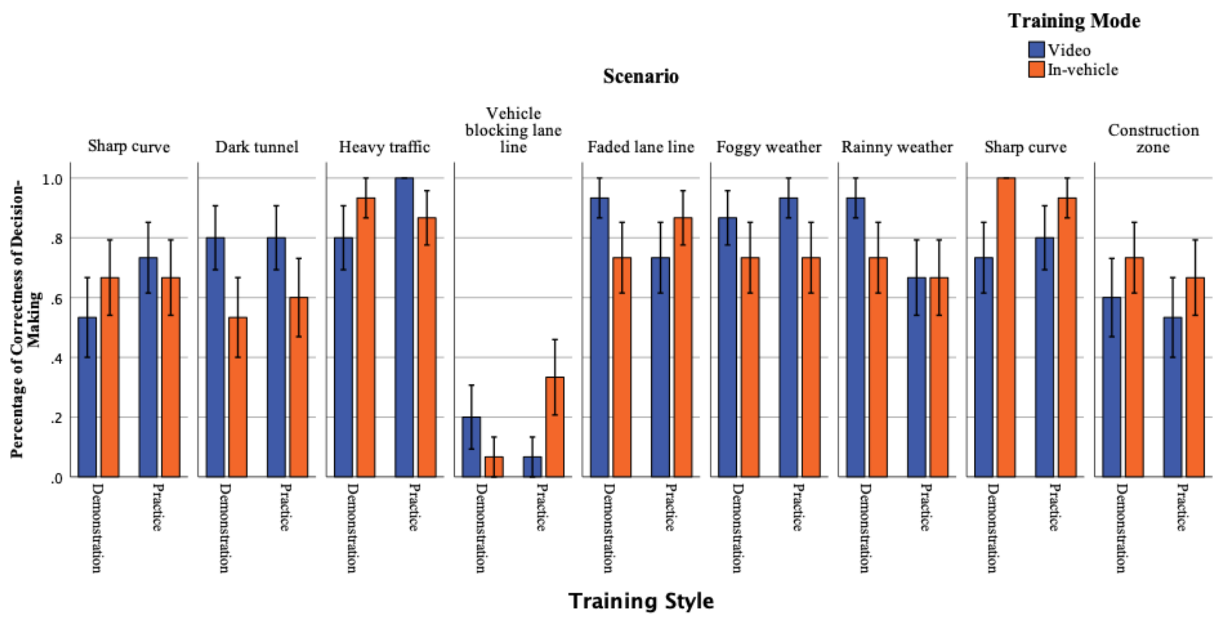
In terms of drivers' responses in different scenarios, a one-way ANOVA was conducted to examine the effect of driving scenarios on drivers' decision-making. As shown in Figure 30, the result revealed a significant main effect of driving scenarios on drivers' decision-making accuracy (F(8, 531) = 17.46, p < 0.001). As shown in Figure 30, the post-hoc analysis revealed that Scenario 4: Front Vehicle Blocking Lane Line, resulted in significantly lower accuracy in drivers' decision-making in responding to ADAS limitations compared to the rest of the scenarios, whereas Scenario 3: Heavy Traffic led to significantly higher accuracy in drivers' decision-making compared to Scenario 1: Sharp Curve, Scenario 9: Construction Zone, and Scenario 4.

Figure 30. The Correctness of Drivers' Decision-Making Across ADAS Limitation Scenarios



When analyzing the impact of training mode and style on drivers' decision-making accuracy for each scenario, no significant effects were found. Figure 31 illustrates the effect of training modes and training styles on drivers' decision-making accuracy across various scenarios. Although not statistically significant, in scenarios that closely resembled the practice scenarios in the in-vehicle training groups, such as Scenario 1 (sharp curve) and Scenario 9 (construction zone), drivers who received in-vehicle training demonstrated a higher percentage of correct decision-making compared to those who received video training. In contrast, in most remaining scenarios, video training generally resulted in a higher percentage of correct decision-making. This suggests that while in-vehicle training is particularly effective for scenarios that mirror the training environment, video training may be more advantageous for preparing drivers to handle a broader range of situations.

Figure 31. Effect of Training Modes and Training Styles on Driver' Correctness of Decision-Making Across Varying Scenarios



Finally, out of 540 trials, there were a total of 28 collisions. The distribution of collisions across different scenarios was as follows:

- 12 collisions during Scenario 1: sharp curve (ACC limitation)
- 8 collisions during Scenario 3: Heavy Traffic (ACC limitation)
- 1 collision during Scenario 4: Vehicle Blocking Lane Line (LKA limitation)
- 2 collisions during Scenario 5: Faded Lane Lines (LKA limitation)
- 5 collisions during Scenario 9: Construction Zone (PA limitation)

The most common reason for collisions in the Scenario 1: Sharp Curve was that participants apparently failed to anticipate the curve ahead and/or failed to recognize that ACC would not automatically slow to a speed appropriate for the curve and relied on ACC instead of taking manual control. In Scenario 3: Heavy Traffic, participants were unsure whether the ACC would adjust to the speed of the very slow traffic ahead, or they disengaged it too late, resulting in a failure to brake in time. In Scenario 4: Vehicle Blocking Lane Line, the collision occurred because the participant lost control of the vehicle after turning off the LKA. In Scenario 9: Construction Zone, some participants did not recognize the need to deactivate the PA.

Reaction Time. Three-way ANCOVAs were performed to examine the effects of training styles and training modes on drivers' reaction times, among drivers who responded appropriately in each scenario, across three ADAS features. As shown in Table 17, the results revealed a statistically significant interaction effect of training style and training mode on drivers' reaction time ($F(1, 303) = 3.93$, $p = 0.048$, $\eta^2 = 0.013$). The pairwise comparisons revealed that in-vehicle demonstration training led to significantly shorter reaction time than in-vehicle practice training for the ACC limitation scenarios ($p = 0.044$). The main effect of training style ($F(1, 303) = 0.20$, $p = 0.653$, $\eta^2 = 0.013$), training modes ($F(1, 303) = 0.02$, $p = 0.88$, $\eta^2 = 0.000$), or ADAS features ($F(1, 303) = 2.58$, $p = 0.077$, $\eta^2 = 0.017$) were not significant. None of the covariates were significant.

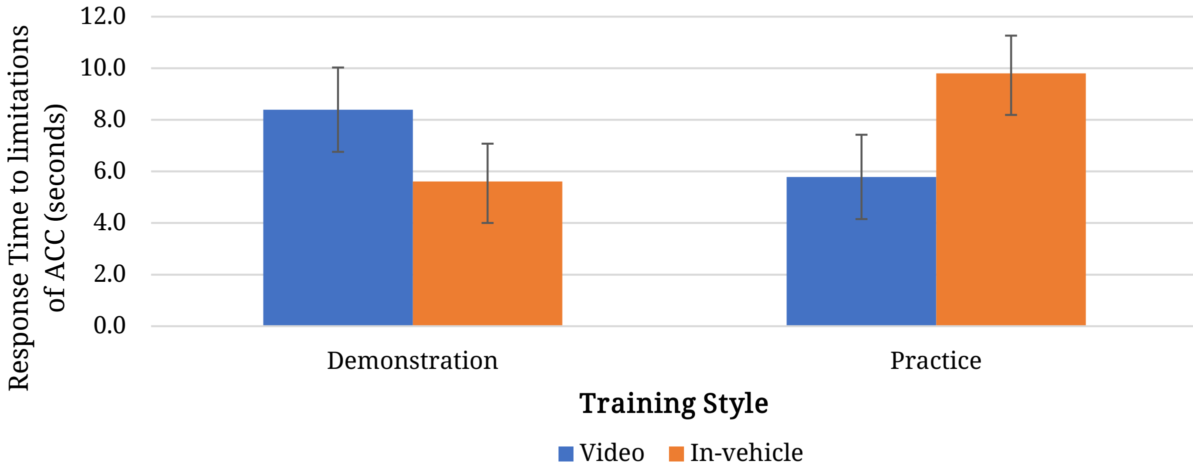
Table 17. Driver Reaction Time Across Training Approaches and ADAS Features

Training Style	Demonstration				Practice			
Training Mode	**Video**		**In-Vehicle**		**Video**		**In-Vehicle**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
ACC	8.16	8.53	5.62	5.19	5.80	5.42	10.01	9.77
LKA	8.20	9.69	7.71	7.46	7.25	6.64	8.51	8.33
PA	5.94	4.21	4.64	3.35	6.90	5.82	6.25	7.10

Three ANCOVAs were then conducted to assess the effect of training style and training mode on drivers' response time in responding to ADAS limitations for the three ADAS features.

For ACC, as shown in Figure 32, the results revealed a statistically significant interaction effect of training style and training mode on drivers' response time ($F(1, 88) = 4.61$, $p = 0.035$). The simple main effect analysis revealed that after receiving the in-vehicle training, drivers showed a significantly longer response time in responding to ACC limitation scenarios when the training style was practice ($M = 9.80$, $SD = 1.61$) compared to the demonstration training ($M = 5.61$, $SD = 1.46$). Additionally, when receiving the training in the practice style, drivers showed a significantly longer response time in responding to ACC limitation scenarios when the training mode was in-vehicle ($M = 9.80$, $SD = 1.61$) compared to the video training ($M = 5.79$, $SD = 1.42$). The main effect of training style was not significant ($F(1, 88) = 0.26$, $p = 0.61$), nor was the main effect of training mode ($F(1, 88) = 0.17$, $p = 0.68$). None of the covariates were significant, including gender ($F(1, 88) = 2.67$, $p = 0.11$), age ($F(1, 88) = 0.77$, $p = 0.38$), and educational level ($F(1, 88) = 0.06$, $p = 0.80$).

Figure 32. Drivers' Reaction Time in Responding to Limitations of ACC Features



For LKA, no significant main effect of training style ($F(1, 99) = 0.01$, $p = 0.94$) or training mode ($F\ (1, 99) = 0.03$, $p = 0.86$) on reaction time was found. The interaction effect between training mode and training style was not significant ($F(1, 99) = 0.61$, $p = 0.44$). None of the covariates were significant, including gender ($F(1, 99) = 0.03$, $p = 0.87$), age ($F(1, 99) = 0.35$, $p = 0.55$), and educational level ($F(1, 99) = 0.53$, $p = 0.47$).

For PA, no significant main effect of training style ($F(1, 110) = 0.13$, $p = 0.72$) nor training mode ($F\ (1, 110) = 1.38$, $p = 0.24$) was found. The interaction effect between training mode and training style was not significant ($F(1, 110) = 0.03$, $p = 0.85$). Among the covariates, gender was significantly associated with drivers' response time ($F(1, 110) = 5.23$, $p = 0.024$). The effects of age ($F(1, 110) = 1.72$, $p = 0.19$) and educational level ($F(1, 110) = 0.54$, $p = 0.82$) were not significant.

Table 18 presents the drivers' reaction time across four training groups under varying scenarios. To be noted, drivers' reaction time was calculated only for instances where drivers made correct decisions.

Table 18. Drivers' Reaction Time Across Four Training Approach Groups

System	Scenarios	Reaction Time (Mean (SD))			
		Video Demo	Video Practice	In-Vehicle Demo	In-Vehicle Practice
ACC	1. Sharp Curve	4.58 (12.24)	2.90 (2.64)	3.10 (1.79)	8.99 (12.10)
	2. Dark Tunnel	9.32 (8.20)	8.96 (6.87)	12.42 (3.80)	13.82 (8.49)
	3. Heavy Traffic	-.61 (2.11)	-0.53 (3.19)	0.15 (2.36)	-1.25 (5.19)
LKA	4. Vehicle Blocking Lane Line	2.29 (18.69)	16.13 (0)	12.48 (0)	7.32 (5.43)
	5. Faded Lane Lines	10.32 (10.82)	8.63 (7.20)	10.73 (8.90)	12.37 (9.44)
	6. Foggy Weather	4.48 (8.13)	5.54 (5.85)	1.44 (18.10)	5.34 (6.99)
PA	7. Rainy Weather	5.85 (3.59)	5.35 (2.71)	3.92 (2.34)	5.90 (5.56)
	8. Sharp Curve	3.21 (3.80)	3.96 (4.59)	11.16 (28.22)	4.23 (2.82)
	9. Construction Zone	4.01 (8.49)	6.88 (12.62)	3.41 (7.49)	4.67 (14.67)

Driving Performance

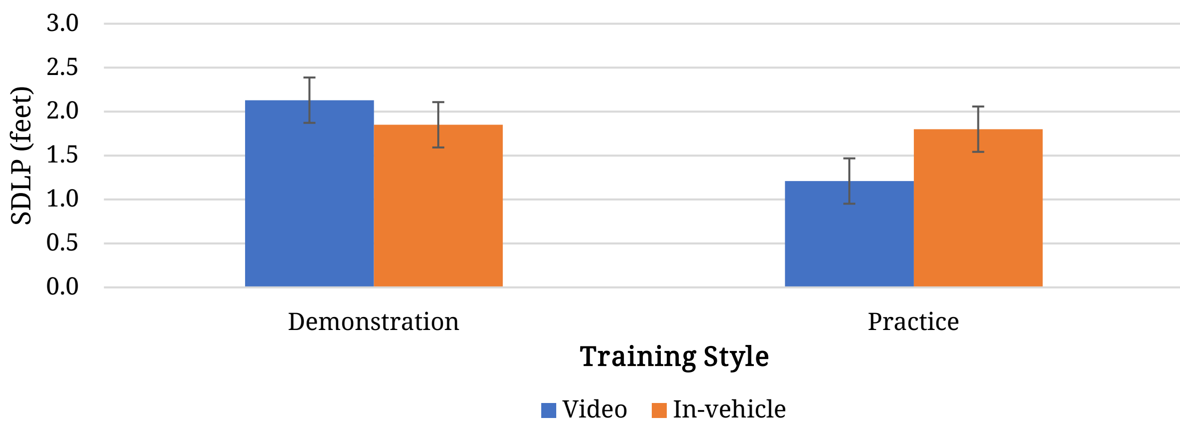
Table 19 shows drivers' SDLP across training groups during the portion of each scenario in which the relevant system limitation was present. An ANCOVA was conducted to assess the effect of training style and training mode on drivers' SDLP in responding to ADAS limitations for the three ADAS features.

Table 19. Standard Deviation of Lane Position Across Training Groups

System	Mean (SD) for SDLP			
	Video Demo	Video Practice	In-Vehicle Demo	In-Vehicle Practice
ACC	1.33 (1.38)	0.92 (0.68)	0.85 (1.07)	1.11 (0.95)
LKA	1.331 (1.00)	0.94 (0.62)	0.96 (0.54)	1.17 (0.83)
PA	2.29 (2.76)	2.37 (2.81)	2.17 (1.90)	1.86 (1.90)

For ACC, the analysis revealed no significant main effect of training style ($F(1, 124) = 0.70$, $p = 0.40$) and no significant main effect of training mode ($F(1, 124) = 0.37$, $p = 0.54$), indicating that neither training style nor training mode had a measurable impact on SDLP. The interaction effect between training style and training mode approached significance ($F(1, 124) = 3.76$, $p = 0.055$), suggesting a potential interaction effect (Figure 33). Among the covariates, gender ($F(1, 124) = 0.86$, $p = 0.36$), educational level ($F(1, 124) = 0.002$, $p = 0.96$), age ($F(1, 124) = 1.69$, $p = 0.20$), and driving experience ($F(1, 124) = 0.51$, $p = 0.48$) were not significant predictors of SDLP.

Figure 33. Standard Deviation of Lane Position in Responding to ACC Limitations



For LKA, the analysis revealed no significant main effects were observed for training style ($F(1, 99) = 0.204$, $p = 0.653$) or training mode ($F(1, 99) = 0.054$, $p = 0.82$), indicating that neither training style nor training mode had a notable impact on SDLP. The interaction effect between training style and training mode approached significance ($F(1, 99) = 2.86$, $p = 0.094$), suggesting a potential interaction effect, though it did not meet the conventional threshold for significance. Among the covariates, gender ($F(1, 99) = 0.032$, $p = 0.86$), educational level ($F(1, 99) = 0.058$, $p = 0.81$), age ($F(1, 99) = 0.015$, $p = 0.90$), and driving experience ($F(1, 99) = 0.026$, $p = 0.87$) were not significant predictors of SDLP.

For PA, there was no significant main effect of training style ($F(1, 122) = 0.035$, $p = 0.85$) or training mode, ($F(1, 122) = 0.66$, $p = 0.42$), indicating that neither training style nor training mode had a notable impact on SDLP. The interaction effect between training style and training mode also did not reach significance ($F(1, 122) = 1.84$, $p = 0.18$). Among the covariates, gender ($F(1, 122) = 0.60$, $p = 0.44$), educational level ($F(1, 122) = 3.60$, $p = 0.060$), age ($F(1, 122) = 0.062$, $p = 0.80$), and driving experience ($F(1, 122) = 0.22$, $p = 0.64$) were not significant predictors of SDLP.

Table 20. Drivers' SDLP Across Limitation Scenarios

System	Scenarios	SDLP Mean (SD)			
		Video Demo	Video Practice	In-Vehicle Demo	In-Vehicle Practice
ACC	1. Sharp Curve	2.49 (0.882)	1.66 (0.687)	1.32 (0.466)	2.22 (1.091)
	2. Dark Tunnel	1.07 (0.518)	0.80 (0.251)	0.92 (0.312)	1.00 (0.409)
	3. Heavy Traffic	0.40 (0.116)	0.76 (0.729)	0.53 (0.460)	0.78 (0.628)
LKA	4. Vehicle Blocking Lane Line	0.69 (0.138)	0.56 (0)	0.74 (0)	1.58 (1.744)
	5. Faded Lane Lines	1.73 (0.981)	1.27 (0.813)	1.38 (0.638)	1.42 (0.666)
	6. Foggy Weather	0.69 (0.213)	0.70 (0.285)	0.65 (0.173)	0.73 (0.225)
PA	7. Rainy Weather	1.00 (1.051)	0.78 (0.447)	1.34 (2.216)	0.63 (0.356)
	8. Sharp Curve	3.49 (4.545)	1.64 (0.697)	1.84 (1.580)	2.06 (1.511)
	9. Construction Zone	3.40 (2.240)	6.19 (4.210)	4.10 (2.520)	4.07 (2.429)

Drivers' Subjective Evaluation

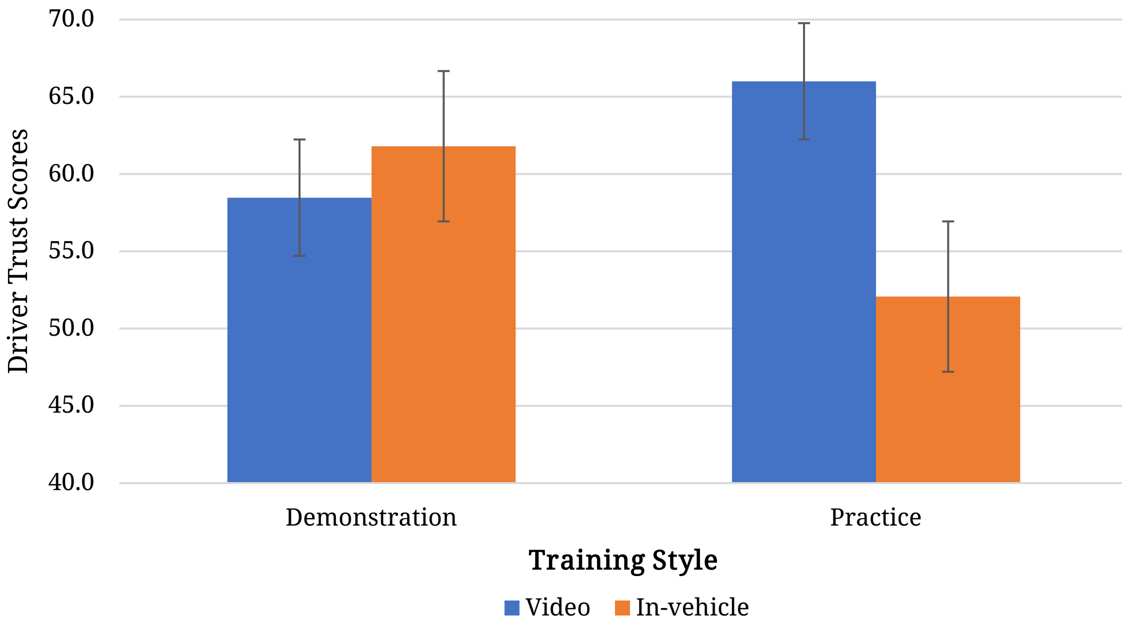
As shown in Table 21, three ANCOVAs were conducted to examine the effects of training style (demonstration, practice) and training mode (video, in-vehicle) on subjective evaluation variables, including trust, workload, and acceptance, respectively, with gender, age, and educational level as covariates.

Table 21. Drivers' Subjective Evaluation of ADAS

	Mean (SD)			
	Video Demo	Video Practice	In-Vehicle Demo	In-Vehicle Practice
Trust	58.47 (9.583)	66.00 (9.366)	61.80 (8.604)	52.07 (14.210)
Workload	48.97 (20.130)	34.92 (21.910)	57.56 (23.89)	42.74 (16.952)
Acceptance (Usefulness)	-0.853 (0.498)	-0.840 (0.757)	-1.173 (0.427)	-0.347 (0.711)
Acceptance (Satisfying)	-1.000 (0.627)	-1.133 (0.626)	-0.733 (0.747)	-0.217 (1.056)

Driver Trust. The effect of training style and training mode on driver trust was analyzed with a two-way ANCOVA. The results showed that the main effects for training style ($F(1, 53) = 0.003$, $p = 0.959$) and training mode ($F(1, 53) = 3.59$ $p = 0.064$) on driver trust were not significant. As shown in Figure 34, the results revealed a significant interaction between training style and training mode on driver trust in ADAS ($F(1, 53) = 9.50$, $p = 0.003$). Simple main effects analysis suggested that within the video training mode, the practice training style ($M = 66.00$, $SD = 9.37$) was associated with significantly higher trust scores than the demonstration training style ($M = 58.47$, $SD = 9.58$), with $p = 0.038$. In contrast, within the in-vehicle training mode, the demonstration training style (M = 61.80, SD = 8.60) was associated with higher trust scores than the practice training style (M = 52.07, SD = 14.21), with p = 0.032. Additionally, with the practice driving style, the video training mode (M = 66.00, SD = 9.37) resulted in significantly higher trust scores compared to the in-vehicle training mode (M = 52.07, SD = 14.21), with p = 0.001. However, no difference between modes (video vs. in-vehicle) was found for the demonstration training style (p = 0.38).

Figure 34. Driver Trust in ADAS

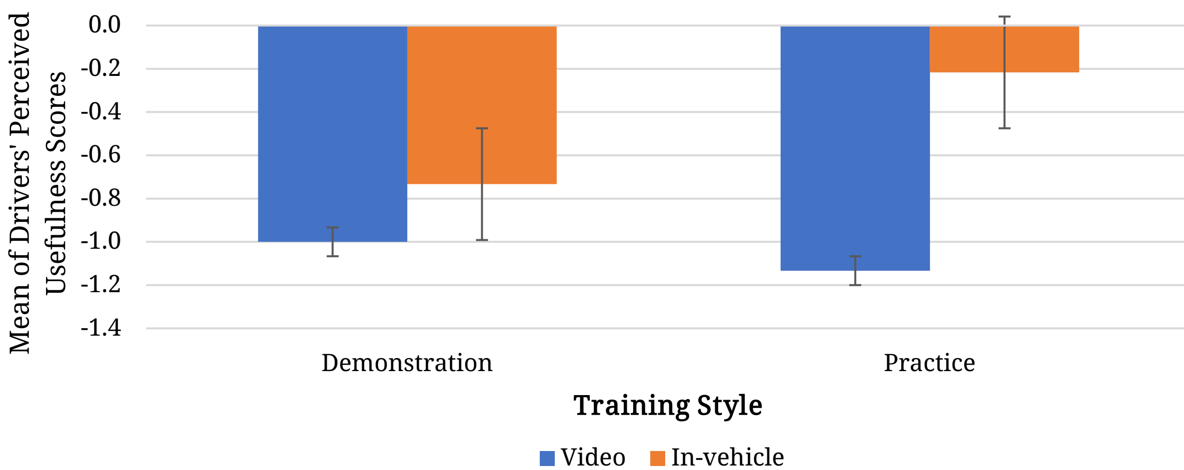


Driver Workload. In terms of self-reported driver workload, the main effects for training style ($F(1, 53) = 2.55$, $p = 0.12$), training mode ($F(1, 53) = 3.51$, $p = 0.066$), and their interaction were not significant ($F(1, 53) = 0.002$, $p = 0.97$). Among the covariates considered, only gender was significantly associated with driver workload ($F(1, 53) = 8.98$, $p = 0.004$). Other covariates, such as age ($F(1, 53) = 3.57$, $p = 0.065$) and educational level ($F(1, 53) = 0.55$, $p = 0.46$) did not have significant impact on driver workload.

Driver Acceptance of ADAS. Drivers' acceptance of ADAS was analyzed on two dimensions, usefulness and satisfaction. As shown in Figure 35 for the Usefulness variable, the main effect for training mode ($F(1, 53) = 6.63$, $p = 0.013$) was significant, indicating the in-vehicle training leading to higher acceptance of ADAS than the video training. The results showed that the main effect for training style ($F(1, 53) = 0.48$, $p = 0.49$) was not significant. As shown in Figure 35, there was a significant interaction between training style and training mode on usefulness ratings ($F(1, 53) = 6.15$, $p = 0.016$). Simple main effects analysis suggested that within the in-vehicle training mode, the practice training style (M = −0.32, SD = 0.17) resulted in significantly higher usefulness scores compared to the demonstration training style (M = −0.86, SD = 0.17), with p = 0.030.

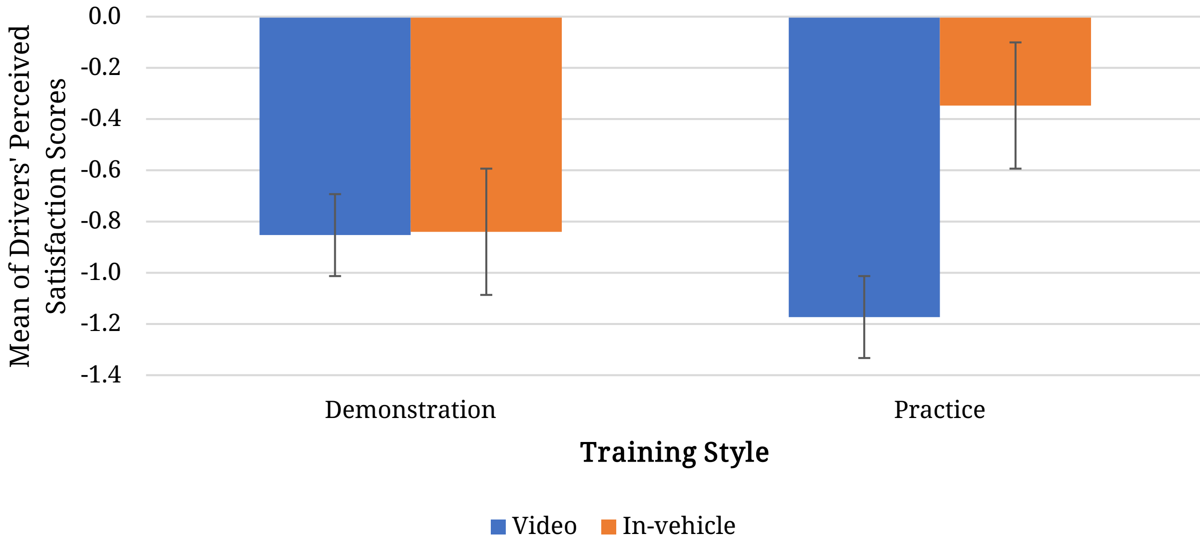
However, within the video training mode, no significant difference was found between the demonstration ($M = -0.87$, $SD = 0.17$) and practice training styles ($M = -1.16$, $SD = 0.17$), with $p = 0.22$. Regarding the covariates, the results showed that gender ($F(1, 53) = 0.22$, $p = 0.64$), age ($F(1, 53) = 0.27$, $p = 0.60$), and educational level ($F(1, 53) = 0.00$, $p = 0.99$) did not have significant effects on usefulness.

Figure 35. Drivers' Perceived Usefulness of ADAS



For the Satisfaction variable shown in Figure 36, the results indicated that the main effect for training style ($F(1, 53) = 0.61$, $p = 0.44$) was not significant. However, the main effect for training mode ($F(1, 53) = 8.16$, $p = 0.006$) was significant, suggesting the in-vehicle training leading to higher acceptance of ADAS than the video training. The interaction between training style and training mode on satisfying ratings was not significant ($F(1, 53) = 1.93$, $p = 0.17$), indicating no significant difference between the combined effects of training style and mode on satisfying scores. The covariates gender ($F(1, 53) = 0.039$, $p = 0.84$), age ($F(1, 53) = 0.56$, $p = 0.46$), and educational level ($F(1, 53) = 0.096$, $p = 0.76$) were not significant.

Figure 36. Driver Perceived Satisfaction with ADAS.



Discussion

The primary focus of this study was to systematically evaluate two dimensions of training approaches for ADAS by comparing different training modes with varying degrees of immersivity (video versus in-vehicle) and training styles with varying levels of interaction (demonstration versus practice). This investigation provides insights into our understanding of how these factors influence drivers' comprehension of ADAS, their behavior and performance using ADAS, and subjective attitudes towards ADAS.

Understanding of ADAS

Overall, all training approaches examined improved drivers' knowledge of ADAS relative to their baseline levels of knowledge measured prior to training. However, some approaches to training appeared to be more effective than others with respect to improving drivers' knowledge of ADAS. A key finding was the significant effect of training mode on knowledge improvement, with in-vehicle training leading to greater knowledge improvement than video training. Given that the substantive content of the training was the same in both conditions, this finding suggests that more immersive training modes lead to a better understanding of ADAS. This is consistent with the findings of Koustanaï et al. (2012), who found similar results when comparing simulator-based training with manual instructions.

In contrast, Zahabi et al. (2021) and Singer and Jenness (2020) did not observe a significant influence of training modes on knowledge improvement. The discrepancy between these studies and the current findings may be due to the interaction effect between training mode and training style identified in this study. Specifically, the current results revealed that the difference between in-vehicle and video training modes was significant primarily for the demonstration style, not the practice style. This suggests that practice training might lead to similar levels of knowledge improvement in both training modes, possibly due to its interactive nature, whereas in-vehicle demonstration was particularly more effective than video demonstration perhaps due to the enhanced immersive nature of the training. Additionally, the differences between the present study and those two previous studies might also be attributed to the different ADAS features examined. Zahabi et al. (2021) focused on ACC and LKA, and Singer and Jenness (2020) investigated Super Cruise, both of which have some different features compared to the specific implementation of PA used in the present study, which was based on Hyundai's Highway Driving Assist feature. The present study revealed that the interaction effect between training modes and training styles was significant only for the PA feature, not for ACC or LKA, suggesting that the benefits of immersive observational learning may be more relevant for more complex ADAS functions such as partial driving automation features.

Drivers' Decision-Making and Performance

A key contribution of this study is the systematic evaluation of drivers' decision-making accuracy and speed in responding to ADAS limitation scenarios. The analysis of driver reaction time revealed a significant interaction effect between training style and training mode, particularly in scenarios involving ACC limitations. The findings indicated that in-vehicle demonstration training led to significantly shorter reaction times compared to in-vehicle practice training. This suggests that the immersive and observational nature of demonstration training may better prepare drivers to respond quickly to ADAS limitations. Furthermore, when the practice style was employed, drivers who received in-vehicle training showed longer reaction times compared to those who received video training. This suggests that while in-vehicle demonstration training enhances reaction times, the practice style may be less effective in this context, possibly due to the higher cognitive load inherent in hands-on practice in a real-world environment for unfamiliar ADAS system features. This finding is partially consistent with the findings of Zahabi et al (2020), who compared video training similar to our video-demonstration training with in-person practice training using a driving simulator similar to our in-vehicle practice training. While Zahabi et al. utilized a driving simulator, our study was conducted in an actual vehicle. Their findings indicated that video-based training resulted in lower mental workload for drivers using ADAS compared to in-person practice training. Further research is needed to confirm these findings by directly measuring both the workload during training and the workload during the usage of ADAS.

It is important to note, however, that neither the training mode nor the training style had a significant influence on drivers' decision-making accuracy in responding to ADAS limitations. The results suggested that decision-making accuracy was influenced by the specific ADAS features and driving scenarios. It was found that drivers were less likely to respond appropriately when faced with limitations of the LKA feature compared to ACC, despite comparable post-training knowledge accuracy for both features, which contrasts with the findings of Experiment 1. Further analysis indicated that this difference was mainly attributable to one specific scenario with which very few participants in any of the training groups responded appropriately, the ‘front vehicle blocking lane line’ scenario. In contrast, the ‘heavy traffic’ scenario, which provided a greater number of visual cues, resulted in higher decision-making accuracy. These findings highlight the importance of training drivers to recognize subtle environmental changes, in order to enhance their decision-making accuracy. Effective training programs should incorporate these challenging scenarios that require drivers to identify the limitations of ADAS to enhance drivers’ ability to recognize and respond to ADAS limitations effectively.

Furthermore, an important observation was that in scenarios closely mirroring those practiced during in-vehicle training, drivers who received in-vehicle practice demonstrated a higher percentage of correct decisions compared to those who received video training. However, for most other scenarios, video training generally led to better decision-making accuracy, as it offers the advantage of exposing drivers to a broader range of scenarios. According to knowledge transfer theory, analogical transfer—where similarities can be readily mapped between learned scenarios and the current, yet different situation—relies on similarities that can be surface-level (matching object features and context), structural (matching relationships between objects), or both (Nokes, 2009). Previous research in the knowledge transfer literature has demonstrated that analogical retrieval is often facilitated by surface similarity to the target scenario (Catrambone, 2002; Chen, 2004). Consequently, when scenarios experienced during video or in-vehicle training, such as curves or construction zones, share similar features with those in the driving test, drivers can more easily transfer their knowledge due to these surface similarities. This suggests that drivers are more likely to engage in analogical reasoning when tasks involve near transfer, where scenarios share surface-level and relational similarities. Conversely, scenarios with fewer surface similarities require greater effort for knowledge transfer, which may have contributed to reduced decision-making accuracy in ADAS limitation scenarios. From a practical perspective, in-vehicle training—in a form in which it might plausibly be implemented at scale in the real world—is limited to a few scenarios, whereas video training can encompass a wider variety of situations, providing drivers with more comprehensive exposure and better preparation for real-world driving challenges.

In summary, in determining the training approach that leads to optimal decision-making and performance outcomes, results were mixed. It was observed that while in-vehicle demonstration training improved reaction times for ACC and enhanced knowledge acquisition for PA, no approach was associated with significantly more accurate decision-making overall, and there was some suggestive albeit inconclusive evidence that video-based training may have led to better decision-making in a greater variety of situations beyond those most similar to those encountered during in-vehicle practice. This suggests that the selection of training methods could be tailored to the specific objectives of the training or combined to target the different skill sets required for ADAS systems.

Drivers' Attitude Towards ADAS

Drivers' attitudes towards ADAS were evaluated across trust, acceptance, and workload. The results revealed a significant interaction effect between training mode and training style on drivers' trust. Specifically, in-vehicle demonstration training consistently led to higher trust compared to in-vehicle practice training. This may be because expert demonstrations provided clear guidance and reduced uncertainty, potentially fostering greater trust in the system, whereas a relatively short period of in-vehicle practice using unfamiliar ADAS in an unfamiliar vehicle may increase uncertainty and workload. In contrast, video demonstration training resulted in lower trust scores compared to video practice training, indicating that active interactions within video mode may foster higher trust in ADAS than passive observation. Active engagement may enhance drivers' motivation and involvement in learning, whereas passive observation in video demonstration training may not provide the same level of engagement, leading to lower trust. Zahabi et al. (2021) did not observe significant differences in driver trust following video or demonstration training. This discrepancy may be due to the interaction effect between training mode and training style identified in the present study, whereas their study did not differentiate between these two factors.

Regarding ADAS acceptance, which was assessed on the usefulness and satisfaction dimensions, in-vehicle training generally led to higher acceptance than video training. A significant interaction effect was found on the usefulness dimension, with in-vehicle practice training resulting in higher usefulness scores compared to demonstration training. However, no significant difference was observed between training styles within the video mode for usefulness, and no interaction effect was found for satisfaction.

Limitations and Future Directions

There are several limitations that should be considered when interpreting the findings of this study.

Firstly, a primary goal of this study was to examine the effect of training mode on effectiveness. However, due to logistical constraints with implementing in-vehicle training, only two limitation scenarios were included in the in-vehicle training. Although fewer scenarios are typical for in-vehicle training compared to video training, this limited exposure may not have fully captured the range of scenarios needed for optimal training. Furthermore, safety concerns prevented the inclusion of dynamic traffic elements in the in-vehicle training, which may have limited its realism. Future studies could address this by incorporating dynamic traffic scenarios, potentially through naturalistic driving methodologies to enhance ecological validity.

Secondly, the study compared only two training modes, video and in-vehicle. Recent research suggests driving simulators as an additional promising training mode. Therefore, future studies should consider including video-based, in-vehicle, simulator, and VR training modes to provide a comprehensive understanding of their relative benefits.

Furthermore, the participants in this study had a higher level of education compared to the general population, which may limit the generalizability of the findings. Future research should aim to include a more diverse sample to ensure that the results are applicable to a broader population.

Drivers' decision-making and performance were evaluated using a finite set of simulated scenarios that certainly did not capture the full array of system limitations that a driver might encounter on the road. Moreover, analyses revealed that a few of the scenarios were much easier or harder than intended, potentially masking training effects that might have occurred but not manifested in participants' performance in these specific scenarios. It would be useful for researchers to develop a standard set of scenarios and measures to use when evaluating drivers' understanding of and performance with ADAS. This would also enhance comparability across studies.

Another limitation is the relatively short duration of the training and testing sessions, which may not capture the long-term retention and effectiveness of the training methods. Future studies could explore the impact of extended training and retention periods to better understand the durability of the training effects over time.

Conclusion

In the current study, results across both experiments confirmed that all types of training examined in both experiments, regardless of content, style, or mode, generally increased the accuracy of drivers' knowledge about ADAS. More specifically, results showed:

- Training that included feedback produced the greatest increases in knowledge.
- In-vehicle training resulted in greater knowledge gains than video-based training.
- Video-based practice led to marginally greater knowledge gains than video-based demonstration, but knowledge gains associated with in-vehicle training did not differ between demonstration versus practice.

Results related to driving performance measures were mixed.

- There was no evidence that any type of training led to significantly better decision-making in terms of deactivating the ADAS in situations where they would not work reliably.
- Some findings suggested that in-vehicle training might lead to better decision-making in situations most similar to situations in the training, and that video-based training might produce better decision-making across a wider range of scenarios, but those findings were inconclusive.
- Some training types led to faster response times or better steering control in some specific comparisons, but those results were inconsistent and were tempered by the lack of evidence that they led to better decision-making.

Overall, results confirm that drivers' understanding of the capabilities and limitations of ADAS can be improved through training, and provide valuable insights into the features of training that lead to greater gains in knowledge. More research is needed to understand the relationship between training drivers about ADAS and real-world safe driving performance.

References

AAA. (2022). *Evaluation of active driving assistance systems*. [Final Report]. Heathrow, FL: AAA, Inc.

Abraham, H., Reimer, B., & Mehler, B. (2017). Advanced driver assistance systems (ADAS): A consideration of driver perceptions on training, usage & implementation. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 61(1), 1954–1958*. https://doi.org/10.1177/1541931213601967

Anstey, K. J., Wood, J., Lord, S., & Walker, J. G. (2005). Cognitive, sensory and physical factors enabling driving safety in older adults. *Clinical psychology review*, *25*(1), 45–65. https://doi.org/10.1016/j.cpr.2004.07.008

Beggiato, M., Pereira, M., Petzoldt, T., & Krems, J. (2015). Learning and development of trust, acceptance and the mental model of ACC: A longitudinal on-road study. *Transportation Research Part F: Traffic Psychology and Behaviour, 35,* 75–84.

Boelhouwer, A., van den Beukel, A. P., van der Voort, M. C., & Martens, M. H. (2019). Should I take over? Does system knowledge help drivers in making take-over decisions while driving a partially automated car?. *Transportation research part F: traffic psychology and behaviour*, *60*, 669–684. https://doi.org/10.1016/j.trf.2018.11.016

Catrambone, R. (2002). The effects of surface and structural feature matches on the access of story analogs. J*ournal of Experimental Psychology: Learning, Memory, and Cognition, 28*(2), 318–334. https://doi.org/10.1037/0278-7393.28.2.318

Chen, C. J. (2004). The effects of knowledge attribute, alliance characteristics, and absorptive capacity on knowledge transfer performance. *R&D Management*, *34*(3), 311–321. http://dx.doi.org/10.1111/j.1467-9310.2004.00341.x

DeGuzman, C.A., & Donmez, B. (2022). Drivers don't need to learn all ADAS limitations: A comparison of limitation-focused and responsibility-focused training approaches. *Accident Analysis & Prevention, 178*, 106871. https://doi.org/10.1016/j.aap.2022.106871

Ebnali, M., Hulme, K., Ebnali-Heidari, A., & Mazloumi, A. (2019). How does training effect users' attitudes and skills needed for highly automated driving?. *Transportation research part F: traffic psychology and behaviour*, *66*, 184–195. https://doi.org/10.1016/j.trf.2019.09.001

Ebnali, M., Lamb, R., Fathi, R., & Hulme, K. (2021). Virtual reality tour for first-time users of highly automated cars: Comparing the effects of virtual environments with different levels of interaction fidelity. *Applied Ergonomics,* 90, 103226. https://doi.org/10.1016/j.apergo.2020.103226

Forster, Y., Hergeth, S., Naujoks, F., Krems, J., & Keinath, A. (2019a). User education in automated driving: Owner's manual and interactive tutorial support mental model formation and human-automation interaction. *Information*, *10*(4), 143. https://doi.org/10.3390/info10040143

Forster, Y., Hergeth, S., Naujoks, F., Beggiato, M., Krems, J. F., & Keinath, A. (2019b). Learning and development of mental models during interactions with driving automation: A simulator study. *Driving Assessment Conference 10*(2019), 398–404. https://doi.org/10.17077/drivingassessment.1724.

Gaspar, J.G., Carney, C., Shull, E., & Horrey, W.J. (2020). *The Impact of Driver's Mental Models of Advanced Vehicle Technologies on Safety and Performance* [Technical Report]. Washington, DC: AAA Foundation for Traffic Safety.

Hart, S.G., & Staveland, L.E. (1988). Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. *Advances in Psychology, 52*(1988) 139–183. https://doi.org/10.1016/S0166-4115(08)62386-9

Highway Loss Data Institute. (2022). Predicted availability of safety features on registered vehicles – 2022 update. *HLDI Bulletin*, *39*(2).

Jian, J. Y., Bisantz, A. M., & Drury, C. G. (2000). Foundations for an Empirically Determined Scale of Trust in Automated Systems. *International Journal of Cognitive Ergonomics*, *4*(1), 53–71. https://doi.org/10.1207/S15327566IJCE0401_04

Koustanaï, A., Cavallo, V., Delhomme, P., & Mas, A. (2012). Simulator training with a forward collision warning system: effects on driver-system interactions and driver trust. *Human factors*, *54*(5), 709–721. https://doi.org/10.1177/0018720812441796

Lindgren, A., & Chen, F. (2006). State of the art analysis: An overview of advanced driver assistance systems (ADAS) and possible human factors issues. *Human factors and economics aspects on safety*, *38*, 50. https://api.semanticscholar.org/CorpusID:107304074

McDonald, A., Carney, C. & McGehee, D.V. (2018). *Vehicle Owners' Experiences with and Reactions to Advanced Driver Assistance Systems* (Technical Report). Washington, D.C.: AAA Foundation for Traffic Safety.

Molloy, O., Molesworth, B. R., & Williamson, A. (2018). Cognitive training interventions to improve young drivers' speed management behaviour: Effects, implications, and perspectives. *Transportation research part F: traffic psychology and behaviour*, *55*, 325–340. https://doi.org/10.1016/j.trf.2018.03.001

Molloy, O. (2022). How to provide effective feedback to young learners: lessons learnt from driver training. *Journal of traffic and transportation engineering, 10*(3), 83–94. http://doi.org/10.17265/2328-2142/2022.03.001

Mueller, A. S., Cicchino, J. B., Singer, J., & Jenness, J. W. (2020). Effects of training and display content on Level 2 driving automation interface usability. *Transportation research part F: traffic psychology and behaviour*, *69*, 61–71. https://doi.org/10.1016/j.trf.2019.12.010

Nokes, T. J. (2009). Mechanisms of knowledge transfer. *Thinking & Reasoning*, *15*(1), 1–36. https://doi.org/10.1080/13546780802490186

Society of Automotive Engineers. (2016). Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles. J3016_202104. https://doi.org/10.4271/J3016_202104

Saffarian, M., De Winter, J. C., & Happee, R. (2012, September). Automated driving: human-factors issues and design solutions. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *56*(1), 2296–2300. https://doi.org/10.1177/1071181312561483

Sahaï, A., Barré, J., & Bueno, M. (2021). Urgent and non-urgent takeovers during conditional automated driving on public roads: The impact of different training programmes. *Transportation Research Part F: Traffic Psychology and Behaviour, 81*, 130–143. https://doi.org/10.1016/j.trf.2021.06.001

Singer, J. & Jenness, J. W. (2020). *Impact of Information on Consumer Understanding of a Partially Automated Driving System* (Technical Report). Washington, D.C.: AAA Foundation for Traffic Safety.

Stanton, N. A., & Young, M. S. (2005). Driver behaviour with adaptive cruise control. *Ergonomics*, *48*(10), 1294–1313. https://doi.org/10.1080/00140130500252990

Van Der Laan, J.D., Heino, A., and De Waard, D. (1997). A simple procedure for the assessment of acceptance of advanced transport telematics. *Transportation Research Part C: Emerging Technologies*, *5*(1), 1–10. https://doi.org/10.1016/S0968-090X(96)00025-3

Victor, T. W., Tivesten, E., Gustavsson, P., Johansson, J., Sangberg, F., & Ljung Aust, M. (2018). Automation expectation mismatch: Incorrect prediction despite eyes on threat and hands on wheel. *Human factors*, *60*(8), 1095–1116. https://doi.org/10.1177/0018720818788164

Wang, J. S. (2019). *Target crash population for crash avoidance technologies in passenger vehicles (Report No. DOT HS 812 653)*. Washington, DC: National Highway Traffic Safety Administration.

Zahabi, M., Abdul Razak, A. M., Shortz, A. E., Mehta, R. K., & Manser, M. (2020). Evaluating advanced driver-assistance system trainings using driver performance, attention allocation, and neural efficiency measures. *Applied ergonomics*, *84*, 103036. https://doi.org/10.1016/j.apergo.2019.103036

Zahabi, M., Razak, A. M. A., Mehta, R. K., & Manser, M. (2021). Effect of advanced driver-assistance system trainings on driver workload, knowledge, and trust. *Transportation Research Part F: Traffic Psychology and Behaviour*, *76*, 309–320. https://doi.org/10.1016/j.trf.2020.12.003

Appendix A: Training Material for Experiment 1

Advanced Driver Assistance Systems(ADAS)

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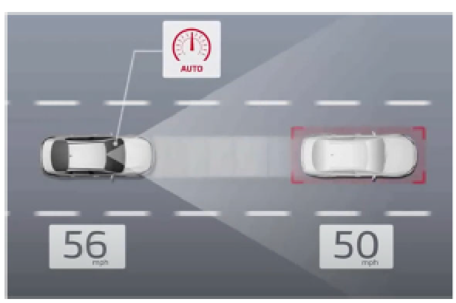
1

Adaptive Cruise Control(ACC)

While regular cruise control simply helps maintain your desired speed, **Adaptive Cruise Control** goes a step further. In addition to keeping you at your preferred speed, it automatically adjusts to maintain a safe distance from the vehicle ahead by either accelerating or decelerating.

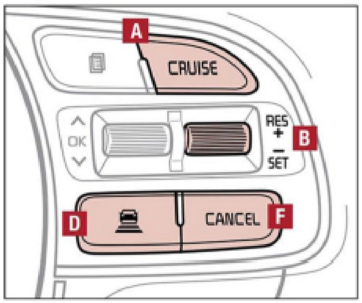


PennState

2

Activating/Deactivating Adaptive Cruise Control(ACC)

1. Start by pressing the **CRUISE** button (A) on the steering wheel. A white light with adaptive cruise icon will illuminate on the dashboard.
2. To pause Adaptive Cruise Control, press the **CANCEL** button (F) on the steering wheel or press the brake pedal.
3. To turn off the Adaptive Cruise Control system completely, press the **CRUISE** button again, the cruise indicator light on the dashboard will turn off.



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3

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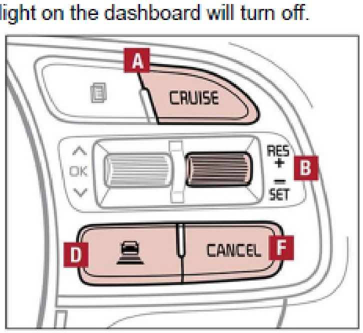
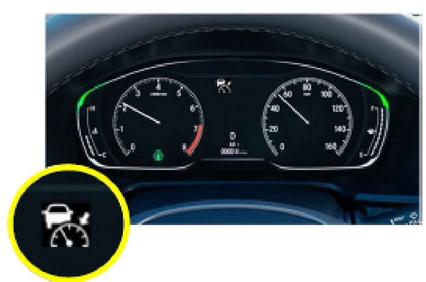


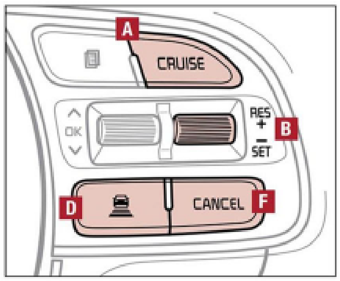


PennState

4

Setting the speed

1. Accelerate or decelerate the vehicle to the desired speed.
2. Toggle the **SET** button (B) down to set cruise speed. Previous white light with adaptive cruise icon will change to green light and the following distance indicator will appear on the dashboard.
3. Toggle + or – button (B) on the steering wheel to adjust cruise speed by 1mph.



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5

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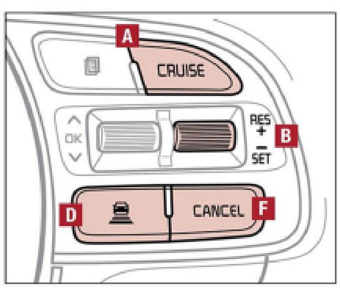

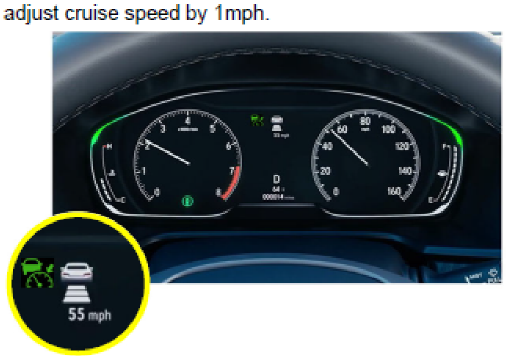

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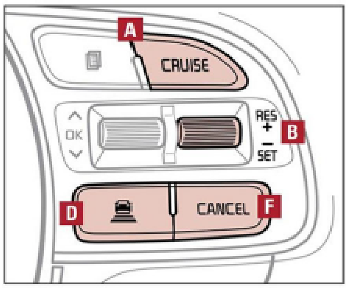
6

Adjusting the vehicle-to-vehicle distance

1. When Adaptive Cruise Control is activated, you can set **how closely your car will follow the car directly in front of you**.
2. To change the following distance setting, press the **button** (D) to adjust the distance between the vehicles.
3. It uses white bars to show the current distance setting. One bar is the shortest following distance setting. Two bars are the medium setting. Three bars are the longest setting.



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7

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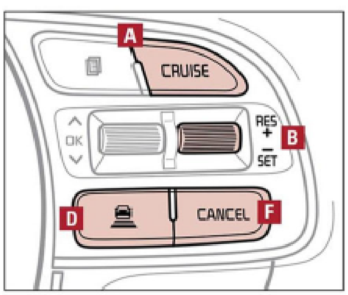

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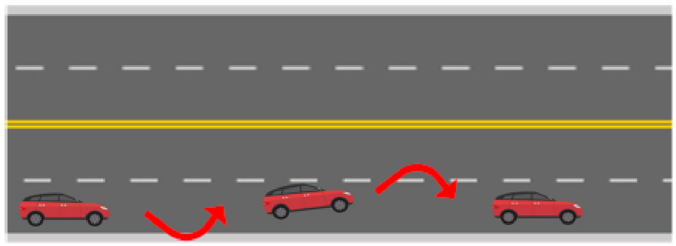
8

Lane Keeping Assistance (LKA)

- **Lane Keeping Assistance** uses lane detection to alert or move the driver back into their lane when the driver ***drifts out of their lane line***.
- This system functions only when both lane lines can be detected.
- Lane Keeping Assistance does not steer the car for you, it just helps you avoid drifting out of your lane by accident.



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9

Activating/Deactivating Lane Keeping Assistance

1. To turn on and off the Lane Keeping Assistance feature, **press the button (A)**.
2. Lane lines should appear on the dashboard when Lane Keeping Assistance is on. When lane lines are not detected, a white icon appears and when lane lines are detected the icon turns to green.

Lane lines undetected

Lane lines detected

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Lane Centering

- **Lane Centering** helps drivers stay in the ***center of their lane lines*** while driving.

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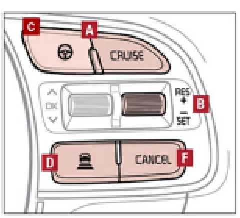
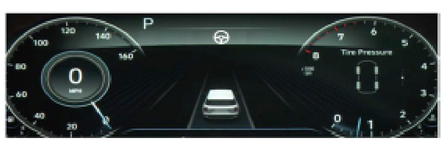
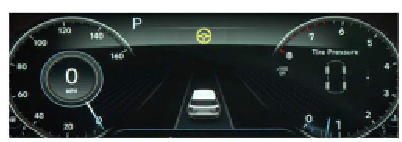
Activating/Deactivating Lane Centering

- To turn on and off, press the **Lane Centering button** (C) located on the steering wheel.
- Once the system is enabled, you will see the white lane centering icon display on your dashboard.
- When **both lane lines are detected** the lane centering icon will change from **white to green** to indicate the system is now active.
- If you take your hands off the steering wheel for several seconds while Lane Centering is active, you will receive a visual alert on your dashboard.





Lane lines undetected



Lane lines detected

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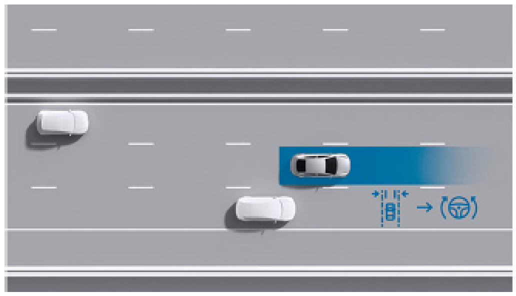
12

Partial Automation (LC + ACC)

- **Partial Automation** is a combination of **Lane Centering and Adaptive Cruise Control**
- It assists you in keeping a safe distance from the vehicle ahead and staying in the center of your lane



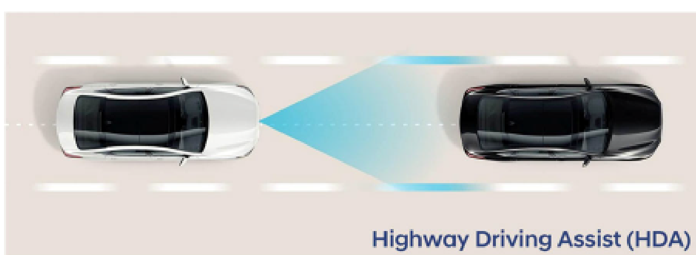
13

Highway Driving Assist (HDA)

Highway Driving Assist works together with Adaptive Cruise Control and Lane Centering to assist you in keeping a safe distance from the vehicle ahead, staying in the center of your lane, and ensuring that your vehicle follows the speed limit by utilizing GPS location and available highway data.

This is a unique system that only functions on interstate highways.

***Interstate highways:** An interstate highway is a major highway in the United States that is designed for high-speed, long-distance travel between cities and states.

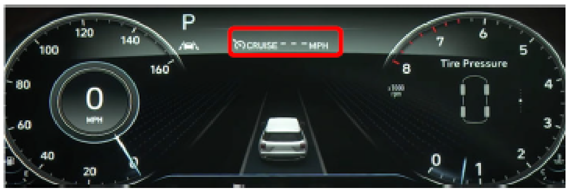


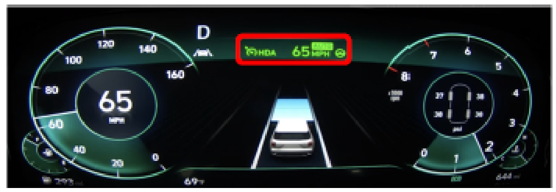
Reference:
https://www.verneidehyundaisiouxcity.com/hyundai-highway-driving-assist-hda-smartsense-feature/

14

Activating/Deactivating Highway Driving Assist

- To use Highway Driving Assist, you will first need to **turn on the Adaptive Cruise Control feature** by pressing the CRUISE button on your steering wheel. Adaptive Cruise Control icon will **automatically change to Highway Driving Assist icon** in the dashboard **after entering the interstate highway**.
- To turn off Highway Driving Assist, press CRUISE button on your steering wheel.





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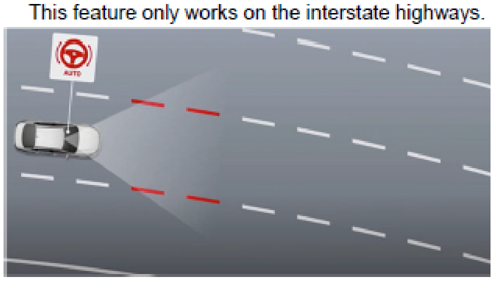
Additional Features of Highway Driving Assist

Highway Auto Curve Slowdown

- While driving with Highway Driving Assist, the system **automatically reduces the vehicle's speed** when entering a curve and resumes with the set speed after the curve if your set speed is higher than the navigation recommended speed for that curve.
- This feature only works on the interstate highways.



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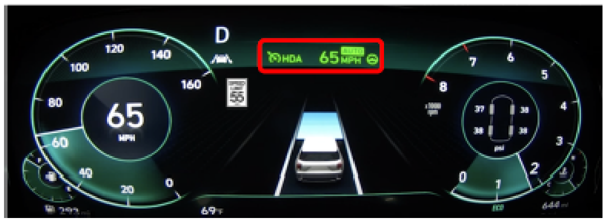
Additional Features of Highway Driving Assist

Highway Auto Speed Change

- While driving with Highway Driving Assist, the system **automatically adjusts the vehicle speed equal to the speed limit** on a highway based on the navigation data.
- If you adjust your **set speed to match the posted speed limit, Highway Auto Speed Change activates.**
- If the posted speed limit changes, the set speed will automatically **change to the new speed limit**.
- This feature only works on interstate highways.



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Training with Driver Issues

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Important things to keep in mind

- **Overtrust**
  - Some drivers trust the technology more than they should, such as lane keeping assist or adaptive cruise control, and **neglect to pay attention to the road**, leading to potential accidents.
  - The driver assumes that that they can **take their hands off the steering wheel**.
  - **Remember,** these technologies are designed to help the driver, not to replace them. The car cannot do everything that a good driver can do. You always need to be ready to respond if there is a situation that the technology in your car can't handle.

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Important things to keep in mind

- **False assumptions**
  - The driver thinks that they **don't have to worry about driving** and can **engage in other tasks other than driving** such as using phone, eating, and adjusting entertainment systems.
  - **Remember,** drivers should avoid engaging in secondary tasks while driving to maintain focus and reduce the risk of accidents. It is essential to prioritize driving safety and eliminate any unnecessary distractions.

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Important things to keep in mind

- Reduced Situation Awareness
  - **Situation awareness** refers to an individual's ability to perceive and understand the environment (e.g., identify potential hazards) around them and to predict what may happen the next.
  - Reduced situation awareness can result in a **driver failing to perceive and respond to potential hazards**, such as sudden braking, changes in road conditions, or other road users' actions.
  - **Remember,** it is crucial to maintain good situation awareness while driving and to prioritize safe driving practices at all times.

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Technology Limitations

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Adaptive Cruise Control/Lane Keeping Assistance/Lane Centering should not be used in severe weather conditions (rainy, snowy, etc.)

Snow

Heavy rain

Icy road

23

Adaptive Cruise Control/Lane Keeping Assistance/Lane Centering does not work well in curvy, narrow lanes or lane closure

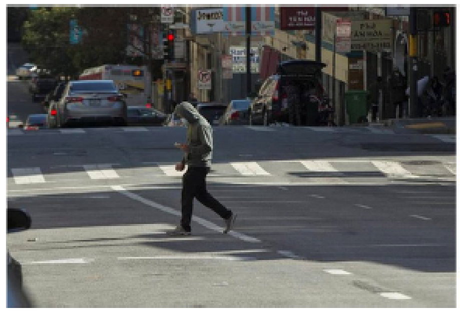
Curvy lane

Lane closure

24

Adaptive Cruise Control/Lane Keeping Assistance/Lane Centering does not track pedestrians and objects on the road

Objects on the road



Pedestrians on the road

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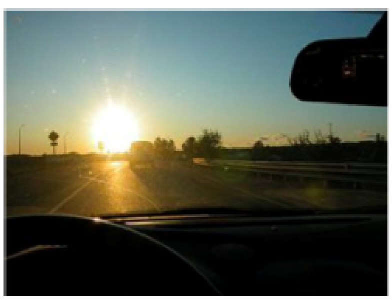
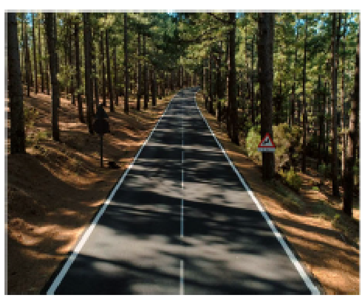
Adaptive Cruise Control/Lane Keeping Assistance/Lane Centering works best with good lighting
(not in shadows, tunnels, extremely bright sunlight)



Extremely bright sunlight



Shadows

Tunnels

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Lane Keeping Assistance/Lane Centering can only be used when both lane lines are clearly visible

Faded lane line

Clear lane line

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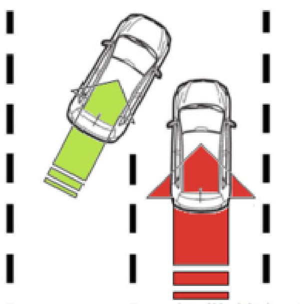
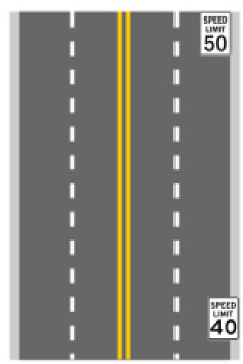
Adaptive Cruise Control doesn't work well when there's rapid speed change (sudden braking, speed limit increase/decrease, etc)



Vehicle cuts in front of your vehicle



Speed limit change

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HDA Limitations

- Highway Driving Assist can **only** be activated after **Adaptive Cruise Control is turned on**.
- Highway Driving Assist can **only** be activated in **interstate highways**.
- Highway Driving Assist still requires you to **keep your hands on the steering wheel**.
- Highway Driving Assist does not work when **navigation is not working properly**.

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Summary

- ADAS technology has benefits but also limitations.
- Use ADAS technology as a tool to support safe driving, not rely on it completely.
- ADAS technology is designed to assist drivers, not replace them.
- Drivers must make responsible choices and prioritize safe driving practices.
- Always drive responsibly and prioritize safety on the road.

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Appendix B: ADAS Knowledge Test- ACC without feedback

Start of Block: ACC HMI

Using your knowledge about the Adaptive Cruise Control (ACC) feature, please respond to the images and questions.

The following questions and prompts in this survey will be from the perspective of a vehicle currently in the market. It's possible you've never been in this make of vehicle and that is okay. Please answer as honestly as you can.

Q1 Does this vehicle have Adaptive Cruise Control(ACC)?

○ Yes (4)

○ No (5)

○ I don't know (7)

Skip To: End of Block If Does this vehicle have Adaptive Cruise Control(ACC)? = I don't know

Display This Question:
If Does this vehicle have Adaptive Cruise Control(ACC)? = Yes

Display This Question:
If Does this vehicle have Adaptive Cruise Control(ACC)? = Yes

Q2 Which of the buttons turns on Adaptive Cruise Control?

○ A (1)

○ B (2)

○ C (3)

○ D (4)

○ F (5)

○ I don't know (7)

○ The car does not have Adaptive Cruise Control (6)

Skip To: : End of Block If Which of the buttons turns on Adaptive Cruise Control? = I don't know

Display This Question:
If Which of the buttons turns on Adaptive Cruise Control? != I don't know

Q3 How do you start the Adaptive Cruise Control feature?

- ○ Pressing the Adaptive Cruise Control feature button (1)
- ○ Adaptive Cruise Control automatically starts itself when the car turns on (2)
- ○ When entering the highway, Adaptive Cruise Control automatically starts itself (4)
- ○ Adaptive Cruise Control automatically starts itself when I open navigation/GPS system (5)

Display This Question:
If Which of the buttons turns on Adaptive Cruise Control? != I don't know

Q4 If you are using Adaptive Cruise Control and want to cancel the feature how do you do it? (Select all that apply)

- ☐ Change lanes (1)
- ☐ Press the cancel button (2)
- ☐ Operate the turn signal lights (3)
- ☐ Press the brake pedal (4)

Display This Question:
If Which of the buttons turns on Adaptive Cruise Control? != I don't know

Q5 How do you adjust the speed setting for the Adaptive Cruise Control feature? (2 choices)

- ☐ Push the toggle switch down (SET-) to decrease speed or press the switch up (RES+) to increase the speed (B) (1)
- ☐ Press Cruise button (A) (6)
- ☐ Press on the accelerator and press the SET button (4)
- ☐ Press the brake pedal (7)

Display This Question:
If Which of the buttons turns on Adaptive Cruise Control? != I don't know

Q6 How do you adjust the distance between you and the vehicle in front of you with the Adaptive Cruise Control feature?

- Drive closer/further to the lead vehicle and then press the SET button (1)
- Press the +/- buttons (B) (2)
- Press the Interval button (D) (3)
- Press the Cruise button (A) (4)

End of Block: ACC HMI

Start of Block: Knowledge test

Using your knowledge about the Adaptive Cruise Control feature, please respond to the images and questions.

Q1 Is Adaptive Cruise Control designed to be safe to use without your hands on the steering wheel?

- True (1)
- False (2)

How confident are you with your answer?

	No Confidence (1)	Slight Confidence (2)	Moderate Confidence (3)	High Confidence (4)
Answer (1)	○	○	○	○

Q2 Adaptive Cruise Control allows you to increase/decrease the speed of your vehicle

- True (1)
- False (2)

How confident are you with your answer?

	No Confidence (1)	Slight Confidence (2)	Moderate Confidence (3)	High Confidence (4)

Answer (1)	○	○	○	○

Q3 Adaptive Cruise Control automatically speeds up or slows down when the speed limit on the road changes

○ True (1)

○ False (2)

How confident are you with your answer?

	No Confidence (1)	Slight Confidence (2)	Moderate Confidence (3)	High Confidence (4)
Answer (1)	○	○	○	○

Q4 Adaptive Cruise Control adjusts your vehicle speed when a car suddenly crosses in front of your vehicle

○ True (1)

○ False (2)

How confident are you with your answer?

	No Confidence (1)	Slight Confidence (2)	Moderate Confidence (3)	High Confidence (4)
Answer (1)	○	○	○	○

Q5 Adaptive Cruise Control is meant to be used in slow and heavy traffic

○ True (1)

○ False (2)

How confident are you with your answer?

	No Confidence (1)	Slight Confidence (2)	Moderate Confidence (3)	High Confidence (4)

Answer (1)	○	○	○	○

Q6 Adaptive Cruise Control detects all sizes of vehicle ahead

○ True (1)

○ False (2)

How confident are you with your answer?

	No Confidence (1)	Slight Confidence (2)	Moderate Confidence (3)	High Confidence (4)
Answer (1)	○	○	○	○

Q7 Adaptive Cruise Control automatically merges with other traffic if your lane ends

○ True (1)

○ False (2)

How confident are you with your answer?

	No Confidence (1)	Slight Confidence (2)	Moderate Confidence (3)	High Confidence (4)
Answer (1)	○	○	○	○

Q8 Adaptive Cruise Control may not work properly during heavy rainfall

○ True (1)

○ False (2)

How confident are you with your answer?

	No Confidence (1)	Slight Confidence (2)	Moderate Confidence (3)	High Confidence (4)

Answer (1)	○	○	○	○

Q9 Adaptive Cruise Control automatically slows to a safe speed when driving around the sharp curves

○ True (1)

○ False (2)

How confident are you with your answer?

	No Confidence (1)	Slight Confidence (2)	Moderate Confidence (3)	High Confidence (4)
Answer (1)	○	○	○	○

Q10 Adaptive Cruise Control will automatically steer or brake to avoid pedestrians or bicyclists on the road

○ True (1)

○ False (2)

How confident are you with your answer?

	No Confidence (1)	Slight Confidence (2)	Moderate Confidence (3)	High Confidence (4)
Answer (1)	○	○	○	○

Q11 Adaptive Cruise Control does not work when the windshield is covered with dirt or snow

○ True (1)

○ False (2)

How confident are you with your answer?

	No Confidence (1)	Slight Confidence (2)	Moderate Confidence (3)	High Confidence (4)

Answer (1)	○	○	○	○

Q12 Adaptive Cruise Control is not affected by low or high camera temperatures

○ True (1)

○ False (2)

How confident are you with your answer?

	No Confidence (1)	Slight Confidence (2)	Moderate Confidence (3)	High Confidence (4)
Answer (1)	○	○	○	○

Q13 Adaptive Cruise Control automatically slows down when you exit the highway

○ True (1)

○ False (2)

How confident are you with your answer?

	No Confidence (1)	Slight Confidence (2)	Moderate Confidence (3)	High Confidence (4)
Answer (1)	○	○	○	○

End of Block: Knowledge test

Appendix C: ADAS Knowledge Test- LKA without feedback

Start of Block: LKA HMI

Using your knowledge about the Lane Keeping Assistance feature, please respond to the images and questions.

The following questions and prompts in this survey will be from the perspective of a vehicle currently in the market. It's possible you've never been in this make of vehicle and that is okay. Please answer as honestly as you can.

Q1 Does this vehicle have Lane Keeping Assistance?

- ○ Yes (4)
- ○ No (5)
- ○ I don't know (7)

Skip To: End of Block If Does this vehicle have Lane Keeping Assistance? = No

Q2 If this vehicle has Lane Keeping Assistance, which button do you use to turn it on?

- ○ 1 (2)
- ○ 2 (3)
- ○ 3 (4)
- ○ 4 (5)
- ○ I don't know (6)
- ○ This vehicle does not have Lane Keeping Assistance (7)

Q3 How do you start the Lane Keeping Assistance feature?

○ Press the LKA feature button (1)

○ Press the brake pedal (2)

○ LKA automatically starts itself when I am not driving in between lanes (4)

○ LKA automatically starts itself when I am using navigation/the GPS (6)

Q4 If you are using Lane Keeping Assistance and want to cancel the feature how do you do it?

○ Press the LKA feature button (1)

○ Turn the car off (2)

○ Turn off navigation (3)

○ Swerve outside of the lane (4)

End of Block: LKA HMI

Start of Block: Knowledge test

Using your knowledge about the Lane Keeping Assist (LKA) feature, please respond to the questions.

Q1 Lane Keeping Assistance keeps track of where a vehicle is within its lane

○ True (1)

○ False (2)

How confident are you with your answer?

	No Confidence (1)	Slight Confidence (2)	Moderate Confidence (4)	High Confidence (5)
Answer (1)	○	○	○	○

Q2 Lane Keeping Assistance offers steering wheel input and centers the vehicle when it gets too close to a lane marker

○ True (1)

False (2)

How confident are you with your answer?

	No Confidence (1)	Slight Confidence (2)	Moderate Confidence (4)	High Confidence (5)
Answer (1)				

Q3 Lane Keeping Assistance still requires you to keep your hands on the steering wheel

True (1)

False (2)

How confident are you with your answer?

	No Confidence (1)	Slight Confidence (2)	Moderate Confidence (4)	High Confidence (5)
Answer (1)				

Q4 Lane Keeping Assistance tracks pedestrians and bicycles

True (1)

False (2)

How confident are you with your answer?

	No Confidence (1)	Slight Confidence (2)	Moderate Confidence (4)	High Confidence (5)
Answer (1)				

Q5 Lane Keeping Assistance is ideally used when towing heavy loads

True (1)

○ False (2)

How confident are you with your answer?

	No Confidence (1)	Slight Confidence (2)	Moderate Confidence (4)	High Confidence (5)
Answer (1)	○	○	○	○

Q6 Lane Keeping Assistance offers audible/vibrational warnings before moving your vehicle back inside the lane line

○ True (1)

○ False (2)

How confident are you with your answer?

	No Confidence (1)	Slight Confidence (2)	Moderate Confidence (4)	High Confidence (5)
Answer (1)	○	○	○	○

Q7 Lane Keeping Assistance works well in bright, direct sunlight

○ True (1)

○ False (2)

How confident are you with your answer?

	No Confidence (1)	Slight Confidence (2)	Moderate Confidence (4)	High Confidence (5)
Answer (1)	○	○	○	○

Q8 Lane Keeping Assistance can be overridden with resistance to the steering wheel

○ True (1)

○ False (2)

How confident are you with your answer?

	No Confidence (1)	Slight Confidence (2)	Moderate Confidence (4)	High Confidence (5)
Answer (1)	○	○	○	○

Q9 Lane Keeping Assistance works perfectly fine on snowy and icy roads

○ True (1)

○ False (2)

How confident are you with your answer?

	No Confidence (1)	Slight Confidence (2)	Moderate Confidence (3)	High Confidence (4)
Answer (1)	○	○	○	○

Q10 Lane Keeping Assistance is not ideally used for curvy, bumpy roads

- True (1)
- False (2)

How confident are you with your answer?

	No Confidence (1)	Slight Confidence (2)	Moderate Confidence (3)	High Confidence (4)
Answer (1)				

Q11 Lane Keeping Assistance works well when going through dark tunnels

- True (1)
- False (2)

How confident are you with your answer?

	No Confidence (1)	Slight Confidence (2)	Moderate Confidence (3)	High Confidence (4)
Answer (1)				

Q12 Lane Keeping Assistance can be overridden if your turn signal is on

- True (1)
- False (2)

How confident are you with your answer?

	No Confidence (1)	Slight Confidence (2)	Moderate Confidence (3)	High Confidence (4)
Answer (1)				

Q13 Lane Keeping Assistance cannot be affected by your vehicle's speed

○ True (1)

○ False (2)

How confident are you with your answer?

	No Confidence (1)	Slight Confidence (2)	Moderate Confidence (3)	High Confidence (4)
Answer (1)	○	○	○	○

Q14 Lane Keeping Assistance avoids potholes

○ True (1)

○ False (2)

How confident are you with your answer?

	No Confidence (1)	Slight Confidence (2)	Moderate Confidence (3)	High Confidence (4)
Answer (1)	○	○	○	○

Q15 Lane Keeping Assistance detects faded lane lines

○ True (1)

○ False (2)

How confident are you with your answer?

	No Confidence (1)	Slight Confidence (2)	Moderate Confidence (3)	High Confidence (4)
Answer (1)	o	o	o	o

Q16 Lane Keeping Assistance will function completely fine even when the windshield wipers are on HIGH

o True (1)

o False (2)

How confident are you with your answer?

	No Confidence (1)	Slight Confidence (2)	Moderate Confidence (3)	High Confidence (4)
Answer (1)	o	o	o	o

Q17 Lane Keeping Assistance is ideally used for tight, sharp curves in roads

o True (1)

o False (2)

How confident are you with your answer?

	No Confidence (1)	Slight Confidence (2)	Moderate Confidence (3)	High Confidence (4)
Answer (1)	o	o	o	o

End of Block: Knowledge test

Appendix D: ADAS Knowledge Test- HDA without feedback

Start of Block: Knowledge test

Please write your Subject ID

____

Using your knowledge about the Lane Centering feature, please respond to the questions.

Q1 Lane centering helps you stay centered within your lane lines

- True (1)
- False (2)

How confident are you with your answer?

	No Confidence (1)	Slight Confidence (2)	Moderate Confidence (3)	High Confidence (4)
Answer (1)	o	o	o	o

Q2 Lane centering can be activated with any vehicle speed

- True (1)
- False (2)

How confident are you with your answer?

	No Confidence (1)	Slight Confidence (2)	Moderate Confidence (3)	High Confidence (4)
Answer (1)	o	o	o	o

Q3 Lane centering can only be activated while smart cruise control is on

- True (1)
- False (2)

How confident are you with your answer?

	No Confidence (1)	Slight Confidence (2)	Moderate Confidence (3)	High Confidence (4)
Answer (1)				

Q4 Lane centering does not require you to keep your hands on the steering wheel

- True (1)
- False (2)

How confident are you with your answer?

	No Confidence (1)	Slight Confidence (2)	Moderate Confidence (3)	High Confidence (4)
Answer (1)				

Q5 Lane centering uses vehicles in front and lane lines to center your car

- True (1)
- False (2)

How confident are you with your answer?

	No Confidence (1)	Slight Confidence (2)	Moderate Confidence (3)	High Confidence (4)
Answer (1)				

End of Block: Knowledge test

Start of Block: Knowledge test

Using your knowledge about the Highway Driving Assist (HDA) feature, please respond to the questions.

Q1 Highway Driving Assist is a combination of Adaptive Cruise Control and Lane Centering

- True (1)
- False (2)

How confident are you with your answer?

	No Confidence (1)	Slight Confidence (2)	Moderate Confidence (3)	High Confidence (4)
Answer (1)	○	○	○	○

Q2 Highway Driving Assist is activated through pressing the Highway Driving Assist button

- True (1)
- False (2)

How confident are you with your answer?

	No Confidence (1)	Slight Confidence (2)	Moderate Confidence (3)	High Confidence (4)
Answer (1)	○	○	○	○

Q3 Highway Driving Assist has a speed slowdown feature in the curved road

- True (1)
- False (2)

How confident are you with your answer?

	No Confidence (1)	Slight Confidence (2)	Moderate Confidence (3)	High Confidence (4)
Answer (1)	○	○	○	○

Q4 Highway Driving Assist can only be activated after Adaptive Cruise Control is turned on

○ True (1)

○ False (2)

How confident are you with your answer?

	No Confidence (1)	Slight Confidence (2)	Moderate Confidence (3)	High Confidence (4)
Answer (1)	○	○	○	○

Q5 Highway Driving Assist can only be activated in interstate highways

○ True (1)

○ False (2)

How confident are you with your answer?

	No Confidence (1)	Slight Confidence (2)	Moderate Confidence (3)	High Confidence (4)
Answer (1)	○	○	○	○

Q6 Highway Driving Assist works even though navigation is not working properly

○ True (1)

○ False (2)

How confident are you with your answer?

	No Confidence (1)	Slight Confidence (2)	Moderate Confidence (3)	High Confidence (4)
Answer (1)	o	o	o	o

Q7 Highway Driving Assist still requires you to keep your hands on the steering wheel

- True (1)
- False (2)

How confident are you with your answer?

	No Confidence (1)	Slight Confidence (2)	Moderate Confidence (3)	High Confidence (4)
Answer (1)	o	o	o	o

End of Block: Knowledge test

Appendix E: Video Demonstration Training Material for Experiment 2

Advanced Driver Assistance Systems(ADAS)

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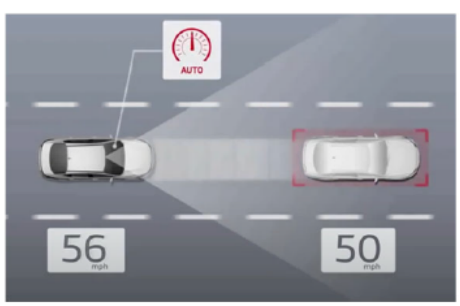
1

Adaptive Cruise Control(ACC)

While regular cruise control simply helps maintain your desired speed, **Adaptive Cruise Control** goes a step further. In addition to keeping you at your preferred speed, it automatically adjusts to maintain a safe distance from the vehicle ahead by either accelerating or decelerating.

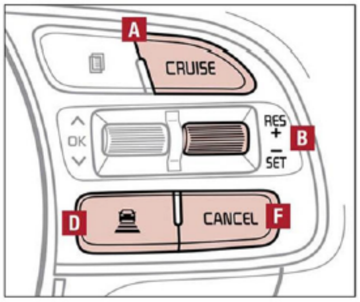


PennState

2

Activating/Deactivating Adaptive Cruise Control(ACC)

1. Start by pressing the **CRUISE button (A)** on the steering wheel. A white light with adaptive cruise icon will illuminate on the dashboard.
2. To pause Adaptive Cruise Control, press the **CANCEL button (F)** on the steering wheel or press the brake pedal.
3. To turn off the Adaptive Cruise Control system completely, press the **CRUISE button (A)** again, the cruise indicator light on the dashboard will turn off.

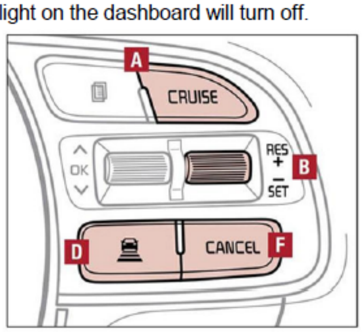


PennState

3

Activating/Deactivating Adaptive Cruise Control(ACC)

1. Start by pressing the **CRUISE button (A)** on the steering wheel. A white light with adaptive cruise icon will illuminate on the dashboard.
2. To pause Adaptive Cruise Control, press the **CANCEL button (F)** on the steering wheel or press the brake pedal.
3. To turn off the Adaptive Cruise Control system completely, press the **CRUISE button (A)** again, the cruise indicator light on the dashboard will turn off.



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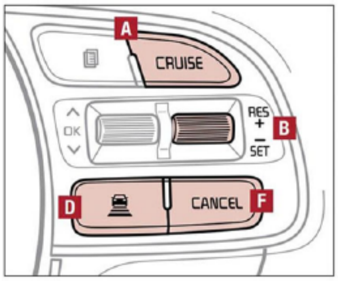
4

Setting the speed

1. Accelerate or decelerate the vehicle to the desired speed.
2. Toggle the **SET button (B)** down to set cruise speed. Previous white light with adaptive cruise icon will change to green light and the following distance indicator will appear on the dashboard.
3. Toggle **+** or **– button (B)** on the steering wheel to adjust cruise speed by 1mph.



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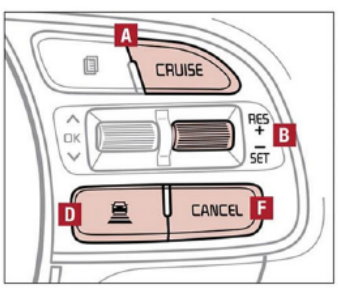
5

Setting the speed

1. Accelerate or decelerate the vehicle to the desired speed.
2. Toggle the **SET button (B)** down to set cruise speed. Previous white light with adaptive cruise icon will change to green light and the following distance indicator will appear on the dashboard.
3. Toggle **+** or **– button (B)** on the steering wheel to adjust cruise speed by 1mph.



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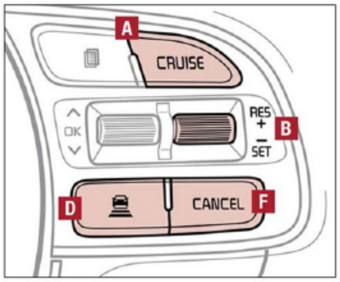
6

Adjusting the vehicle-to-vehicle distance

1. When Adaptive Cruise Control is activated, you can set **how closely your car will follow the car directly in front of you**.
2. To change the following distance setting, press the **button (D)** to adjust the distance between the vehicles.
3. It uses white bars to show the current distance setting. One bar is the shortest following distance setting. Two bars are the medium setting. Three bars are the longest setting.



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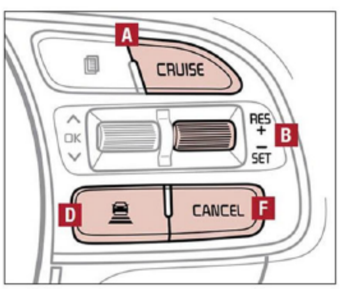
7

Adjusting the vehicle-to-vehicle distance

1. When Adaptive Cruise Control is activated, you can set **how closely your car will follow the car directly in front of you**.
2. To change the following distance setting, press the **button (D)** to adjust the distance between the vehicles.
3. It uses white bars to show the current distance setting. One bar is the shortest following distance setting. Two bars are the medium setting. Three bars are the longest setting.



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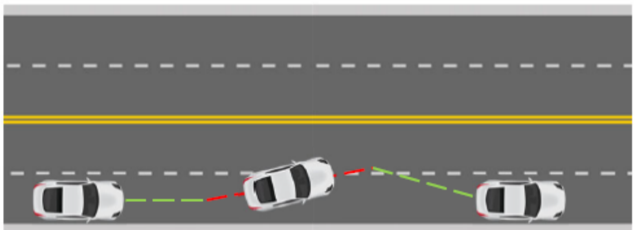
8

Lane Keeping Assistance (LKA)

- **Lane Keeping Assistance** uses lane detection to alert and gently steers vehicle back into its lane when the driver ***drifts out of the lane line***.
- This system functions only when both lane lines can be detected.



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Activating/Deactivating Lane Keeping Assistance

1. To turn on and off the Lane Keeping Assistance feature, **press the button (A)**.
2. Lane lines should appear on the dashboard when Lane Keeping Assistance is on. When lane lines are not detected, a white icon appears and when lane lines are detected the icon turns to green.

Lane lines undetected

Lane lines detected

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Lane Centering

- **Lane Centering** helps drivers stay in the ***center of their lane lines*** while driving by providing automatic steering to continually center the vehicle in its lane.

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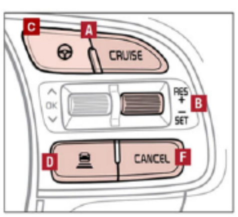
Activating/Deactivating Lane Centering

- To turn on and off, press the **Lane Centering button (C)** located on the steering wheel.
- Once the system is enabled, you will see the white lane centering icon display on your dashboard.
- When **both lane lines are detected** the lane centering icon will change from **white to green** to indicate the system is now active.
- If you take your hands off the steering wheel for several seconds while Lane Centering is active, you will receive a visual alert on your dashboard.



Lane lines undetected

Lane lines detected

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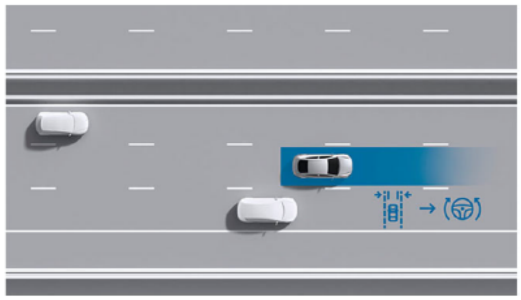
12

Partial Automation (LC + ACC)

- **Partial Automation** is a combination of **Lane Centering and Adaptive Cruise Control**
- It assists you in keeping a safe distance from the vehicle ahead and staying in the center of your lane



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Technology Limitations

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Things to know

- **Limited Environmental Perception:**
  These technologies primarily monitor lane lines and the vehicle directly ahead. They are not designed to detect or respond effectively to pedestrians, cyclists, animals, or unexpected objects on the road.

- **Dependence on Visibility for Lane Detection:**
  Systems like Lane Keeping Assistance and Lane Centering depend heavily on camera-based sensors to detect lane markings. In conditions where the lane lines are difficult to detect clearly, it can significantly impair the system's ability to function correctly.

- **No Replacement for Human Judgment:**
  ADAS systems are designed to assist, not replace, the drivers. They might not correctly interpret complex or unpredictable traffic situations as well as a human can.

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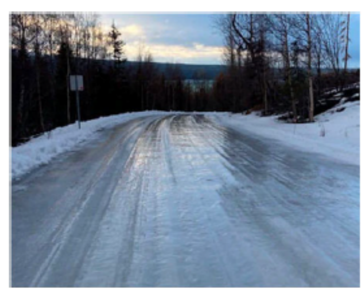
15

Adaptive Cruise Control/Lane Keeping Assistance/Lane Centering should not be used in severe weather conditions (rainy, snowy, etc.)

Snow

Heavy rain



Icy road

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Adaptive Cruise Control/Lane Keeping Assistance/Lane Centering does not work well in curvy, narrow lanes or lane closure

Curvy lane

Lane closure

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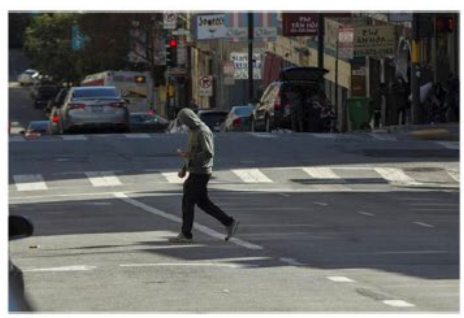
17

Adaptive Cruise Control/Lane Keeping Assistance/Lane Centering does not track pedestrians and objects on the road

Objects on the road



Pedestrians on the road

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Adaptive Cruise Control/Lane Keeping Assistance/Lane Centering works best with good lighting (not in shadows, tunnels, extremely bright sunlight)

Extremely bright sunlight

Shadows

Tunnels

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Lane Keeping Assistance/Lane Centering can only be used when both lane lines are clearly visible

Faded lane line

Clear lane line

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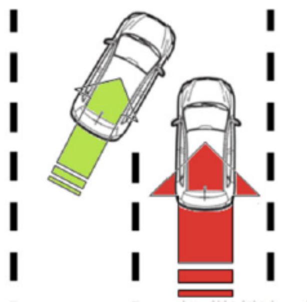
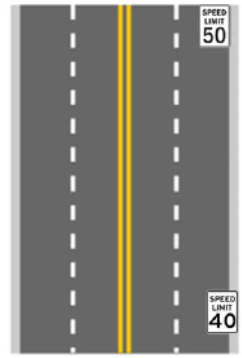
Adaptive Cruise Control doesn’t work well when there’s rapid speed change (sudden braking, speed limit increase/decrease, etc)



Vehicle cuts in front of your vehicle



Speed limit change

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Summary

- ADAS technology has benefits but also limitations.
- Use ADAS technology as a tool to support safe driving, not rely on it completely.
- ADAS technology is designed to assist drivers, not replace them.
- Drivers must make responsible choices and prioritize safe driving practices.
- Always drive responsibly and prioritize safety on the road.

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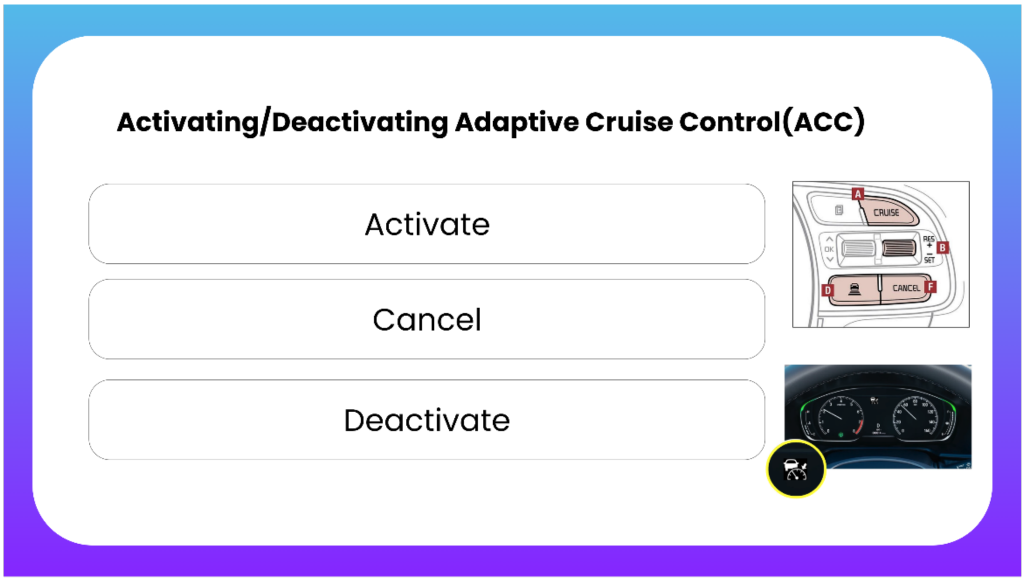
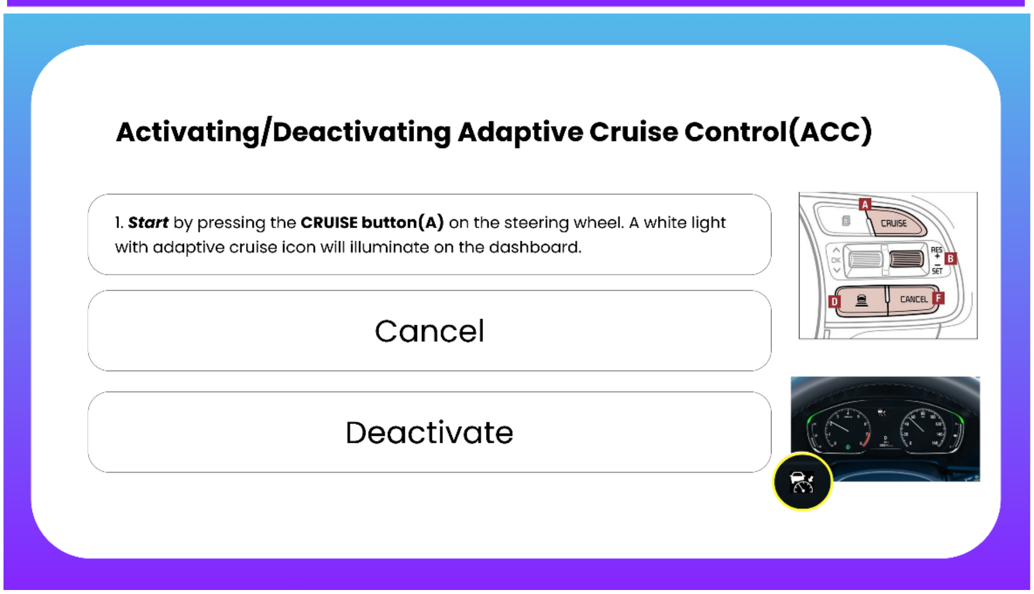
Appendix F: Video Practice Training for Experiment 2

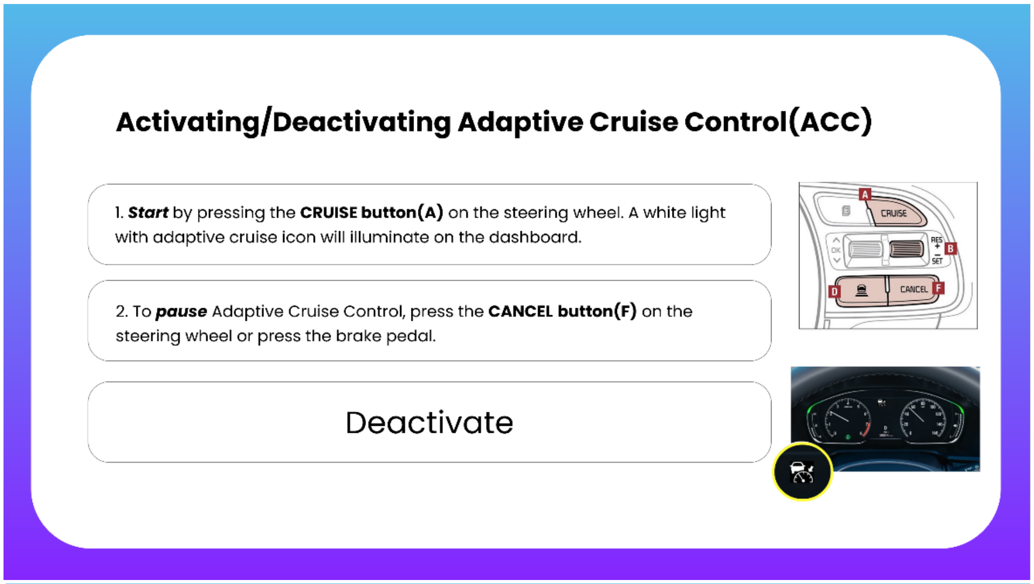
[Link to the interactive video](https://xd.adobe.com/view/f98673d1-9af9-4a5b-8197-a2552480e69c-acd5/?fullscreen&hints=off)

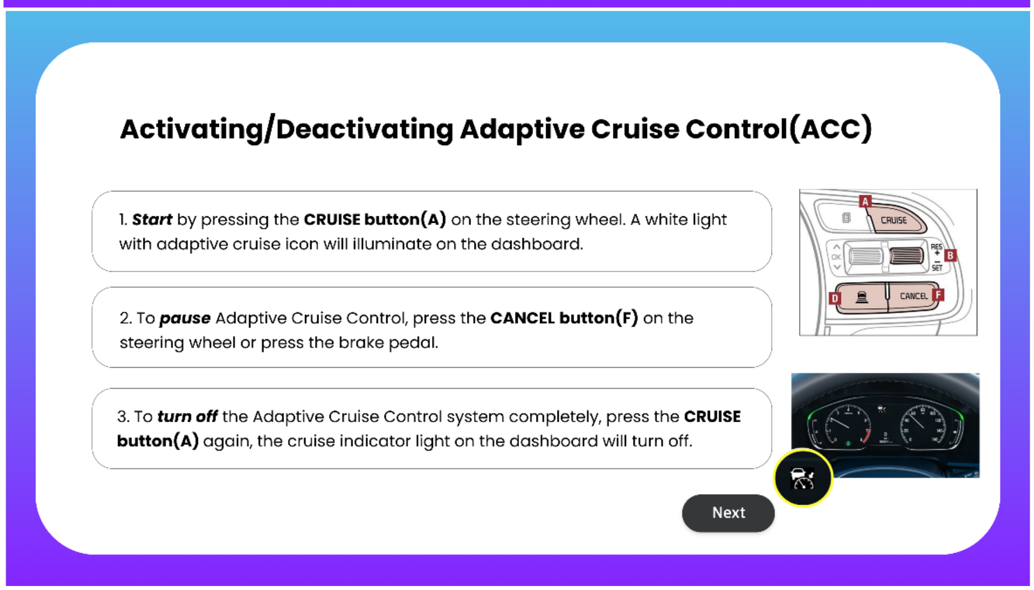
https://xd.adobe.com/view/f98673d1-9af9-4a5b-8197-a2552480e69c-acd5/?fullscreen&hints=off

Sample interactive content – activating and deactivating ACC:

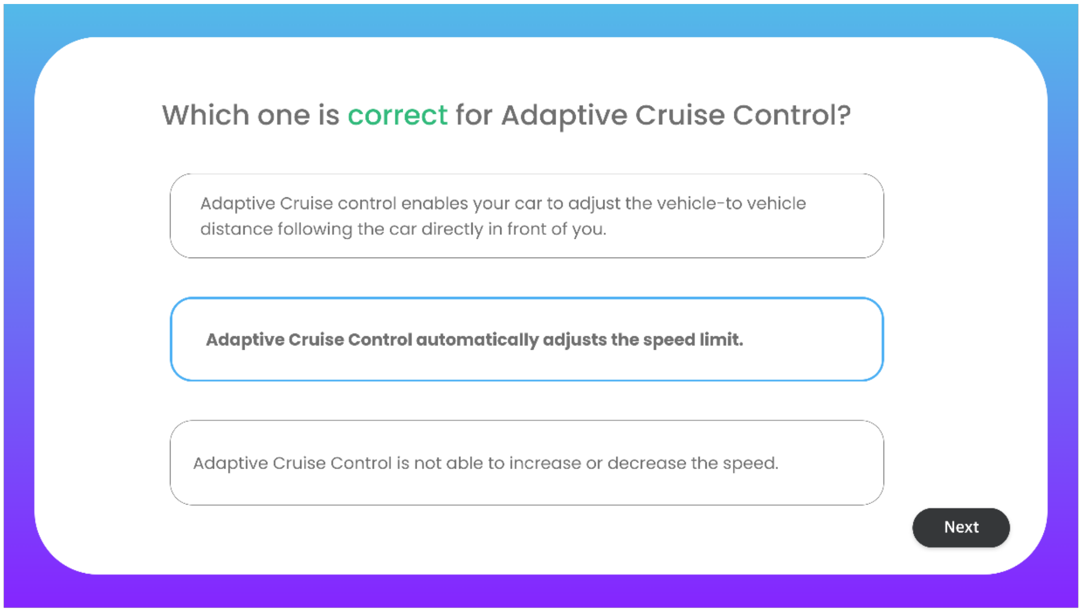


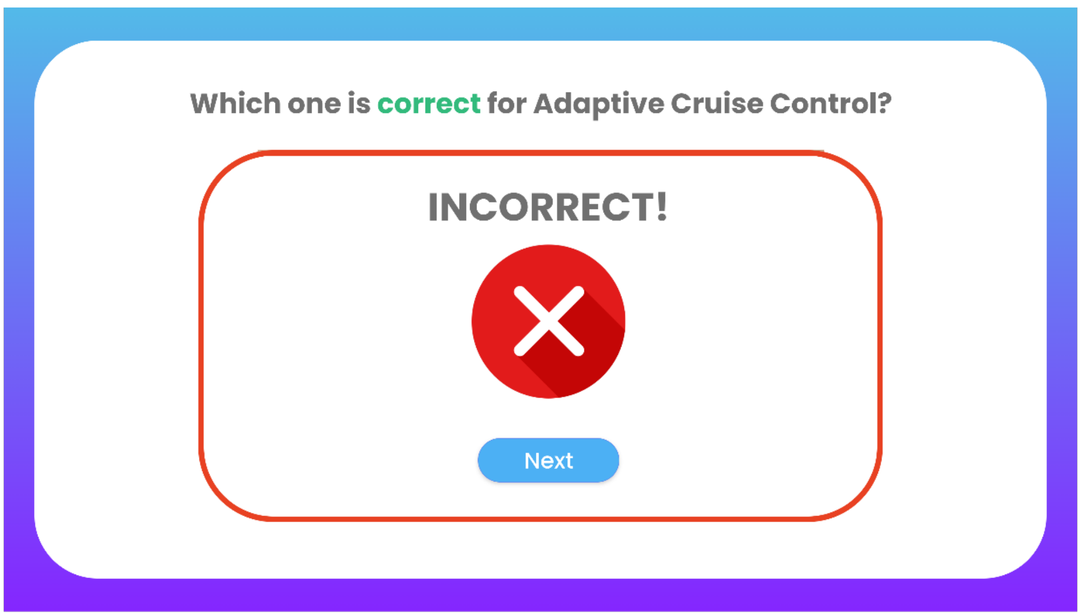



Activating/Deactivating Adaptive Cruise Control(ACC)
1. Start by pressing the CRUISE button(A) on the steering wheel. A white light with adaptive cruise icon will illuminate on the dashboard.
2. To pause Adaptive Cruise Control, press the CANCEL button(F) on the steering wheel or press the brake pedal.
Deactivate
CRUISE
CANCEL
RES
SET
A
B
D
F


Activating/Deactivating Adaptive Cruise Control(ACC)
1. Start by pressing the CRUISE button(A) on the steering wheel. A white light with adaptive cruise icon will illuminate on the dashboard.
2. To pause Adaptive Cruise Control, press the CANCEL button(F) on the steering wheel or press the brake pedal.
3. To turn off the Adaptive Cruise Control system completely, press the CRUISE button(A) again, the cruise indicator light on the dashboard will turn off.
Next
CRUISE
CANCEL
RES
SET
A
B
D
F

Sample interactive content – checking for understanding and providing feedback:





Appendix G: In-Vehicle Training Script for Experiment 2

Advanced Driver Assistance Systems or (ADAS) is used to assist drivers in many ways.

These features rely on sensors and cameras to provide information about the vehicles surrounding to assist with driving.

Adaptive Cruise Control (ACC)

- ACC varies slightly from regular cruise control.
- Adaptive cruise control keeps the vehicle at your preferred speed as well as relying on sensors to automatically decelerate or accelerate your vehicle to a safe distance following the vehicle in front of you.
- To activate adaptive cruise control, first press Cruise Control button (A) on the steering wheel.
  - A white light will illuminate on the dashboard indicating that adaptive cruise control is active.
  - To pause, you can either press the cancel button on the steering wheel or simply press the brake pedal.
  - To turn off adaptive cruise control, press the Cruise Control button (A) again and the white icon on the dashboard will turn off.
  - In order to set the speed,
    - First accelerate or decelerate to your desired speed.
    - Then press the "SET" button (B) on your steering wheel to set the speed.
      - The cruise control icon which was once white, will now change to green.
    - Once the speed is set, you can remove your foot from the accelerator.
    - To adjust the speed, press + or – on the steering wheel.
  - To adjust the following distance of the vehicle in front of you:
    - Ensure that Adaptive Cruise Control is activated
    - Press Adaptive Cruise control, which is the following distance icon.
      - The following distance indicator will now appear on the dashboard.
        - 1 white bar means the shortest following distance
        - 3 white bars mean the longest following distance.

Lane Keeping Assistance (LKA)

- **Lane Keeping Assistance** uses lane detection to alert and gently steers vehicle back into its lane when the driver ***drifts out of the lane line***.
- This system functions only when both lane lines can be detected. Alerts can be audio or visual signals on the dashboard.
  - Lane Keeping Assist can apply some corrective steering to move the vehicle back into the lane.
- This is a beneficial feature when the driver is not paying attention or even when driving on long straight road.
- Lane Keeping Assist will only work when BOTH lane lines can be detected through cameras and sensors.
    - If the lane lines are faded or missing, the system will not be able to assist you.
- To turn on Lane Keeping assist, press Lane Keeping Assistance feature (Button A)
  - Lane lines will appear on your dashboard indicating Lane Keeping Assistance is turned on.

- White lane lines on the dashboard indicate lane lanes are NOT detected.
    - Green lane lines on the dashboard indicate lane lanes are detected.
- To turn off Lane Keeping Assist, press the Lane Keeping Assistance feature (Button A) again.

Partial Automation

Partial Automation is a combination of Lane Centering and Adaptive Cruise Control

It assists you in keeping a safe distance from the vehicle ahead and staying in the center of your lane.

Lane Centering

- Lane centering is a feature of advanced driver assistance systems that helps keep your vehicle centered within its lane while driving by providing automatic steering to continually center the vehicle in its lane.
    - When engaged, lane centering can help reduce driver fatigue and increase safety by providing gentle steering inputs to keep the vehicle centered within the lane.
- To activate Lane Centering, press Lane Centering button on the steering wheel.
    - A white lane centering icon displays on the dashboard.
    - When BOTH lane lines are detected, the lane centering icon is green, indicating lane centering is active.
    - It is important to keep your hands on the steering wheel.
        - If your hands are off for several seconds, you will receive a visual alert on your dashboard to remind you to put your hands back on the steering wheel.

Partial Automation

- Limited Environmental Perception:

These technologies primarily monitor lane lines and the vehicle directly ahead. They are not designed to detect or respond effectively to pedestrians, cyclists, animals, or unexpected objects on the road.

- Dependence on Visibility for Lane Detection:

Systems like Lane Keeping Assistance and Lane Centering depend heavily on camera-based sensors to detect lane markings. In conditions where the lane lines are difficult to detect clearly, it can significantly impair the system's ability to function correctly.

- No Replacement for Human Judgment:

ADAS systems are designed to assist, not replace, the drivers. They might not correctly interpret complex or unpredictable traffic situations as well as a human can.

Key Limitations to Advanced Driving Assistance Systems:

- First, Adaptive Cruise Control, Lane Keeping Assistance and Lane Centering:
    - Should not be used in severe weather conditions such as rain, snow, icy roads.
    - These features do not work well in curvy, narrow lanes or lane closures.
    - ACC and LKA do not track pedestrians or objects on the road.

- Adaptive Cruise Control and Lane Keeping Assist works WELL in good lighting
    - If there is extremely bright sunlight, shadows, or tunnels the features will not work properly.
- Lane Keeping Assistance
  - Should only be used when both lane lines are clearly visible.
    - If faded lane lines exist, the feature will not perform properly.
- Adaptive Cruise Control:
  - Does not work well when there are rapid speed changes such as sudden braking due to a vehicle cutting in front of you, and speed limit increase/decrease.

In Summary:

Advanced Driving Assistance Systems have many benefits but it is also important to understand that the features have imitations.

ADAS is a tool to support safe driving, you should not rely on the features completely.

ADAS is designed to assist, not to replace you as a diver.

Always drive responsibly and prioritize safety on the road.

Appendix H: Knowledge Test for Partial Automation

Using your knowledge about the Partial Automation feature which is a combination of Lane Centering and Adaptive Cruise Control, please respond to the questions.

Q1 Partial Automation helps you stay centered within your lane lines

- True (1)
- False (2)

How confident are you with your answer?

	No Confidence (1)	Slight Confidence (2)	Moderate Confidence (4)	High Confidence (5)
Answer (1)	○	○	○	○

Q2 Partial Automation can be activated with any vehicle speed

- True (1)
- False (2)

How confident are you with your answer?

	No Confidence (1)	Slight Confidence (2)	Moderate Confidence (3)	High Confidence (4)
Answer (1)	○	○	○	○

Q3 Partial Automation is a combination of Adaptive Cruise Control and Lane Centering

- True (1)
- False (2)

How confident are you with your answer?

	No Confidence (1)	Slight Confidence (2)	Moderate Confidence (3)	High Confidence (4)
Answer (1)	○	○	○	○

Q4 Partial Automation does not require you to keep your hands on the steering wheel

○ True (1)

○ False (2)

How confident are you with your answer?

	No Confidence (1)	Slight Confidence (2)	Moderate Confidence (3)	High Confidence (4)
Answer (1)	○	○	○	○

Q5 Partial Automation works well in the sharp curve

○ True (1)

○ False (2)

How confident are you with your answer?

	No Confidence (1)	Slight Confidence (2)	Moderate Confidence (3)	High Confidence (4)
Answer (1)	○	○	○	○

Q6 Partial Automation automatically changes the speed according to the speed limit

○ True (1)

○ False (2)

How confident are you with your answer?

	No Confidence (1)	Slight Confidence (2)	Moderate Confidence (3)	High Confidence (4)
Answer (1)	○	○	○	○

End of Block: Knowledge test