Training to Support Appropriate Reliance on Advanced Driver Assistance Systems

by

Chelsea Ann DeGuzman

A thesis submitted in conformity with the requirements
for the degree of Doctor of Philosophy

Department of Mechanical and Industrial Engineering
University of Toronto

Training to Support Appropriate Reliance on Advanced Driver Assistance Systems

Chelsea Ann DeGuzman

Doctor of Philosophy

Mechanical and Industrial Engineering
University of Toronto

2023

Abstract

Advanced driver assistance systems (ADAS) are becoming more widely available to consumers. While these systems have potential safety benefits, overreliance on ADAS has contributed to several fatal collisions. Training has been identified as one way to address overreliance and support safe use of driving automation. Currently, existing training and related research generally focuses on teaching drivers various system limitations, but there are mixed results regarding the relationship between knowledge of limitations and trust in and reliance on ADAS. Further, this limitation-focused training approach may not be practical (e.g., due to the large number of limitations to learn and remember). This dissertation aims to understand the relationship between knowledge of ADAS limitations, trust, and reliance, and investigate an alternative to limitation-focused training.

First, a survey study was conducted and the results suggested that, in addition to impracticalities associated with limitation-focused training, it may not be an ideal approach if targeting a wide range of drivers, as knowledge did not significantly impact trust or reliance intention for drivers who had ADAS experience. Subsequently, training videos were developed to compare limitation-focused training to a novel training approach which highlighted the drivers' responsibility when using ADAS (i.e., responsibility-focused training). An online study revealed limited differences between the limitation-focused and responsibility-focused approach. Where significant differences were found for quantitative measures, they indicated potential drawbacks of the limitation-focused approach. Further, results of semi-structured interviews with participants suggest that limitation-focused training may have the unintended consequence of decreased interest in using ADAS among drivers without ADAS experience. Further investigation with a simulator study showed that even when an attention monitoring system was implemented to remind participants to keep their eyes on the road, there was a benefit of the responsibility-focused training, but not limitation-focused training, on reliance (e.g., lower rate of long glances to a secondary task and taking over control of the vehicle sooner when a potential conflict occurred).

Overall, this dissertation adds to the existing literature on the relationships between ADAS knowledge, trust, and reliance. Further, it expands the limited literature on alternatives to limitation-focused training and provides preliminary support to the responsibility-focused training approach.

Acknowledgments

First and foremost, I would like to thank my supervisor, Birsen Donmez, for her guidance and advice over the years. Birsen, I am extremely grateful to have had a supervisor as knowledgeable, supportive, and kind as you.

I would like to thank my committee members, Greg Jamieson and Keisuke Fukuda, for their continued support and feedback that helped shape my research. I would also like to thank Peter Burns and Benjamin Wolfe for being a part of my defense committee and for their valuable feedback.

I was fortunate to have help from many people in the Human Factors and Applied Statistics Lab along the way. Thank you for all the discussions, both work and non-work related, that helped me immensely. In particular, I would like to thank Dengbo He for always being available to share his knowledge, especially of the driving simulator. Thank you also to Dina Kanaan and Suzan Ayas for sharing your expertise and collaborating on some of the work in this dissertation.

There are so many others, more than I could name in these acknowledgements, who have also helped me throughout this process. I would like to express my sincere appreciation to anyone who has taken the time to talk with me about my research, provide advice, or share words of encouragement.

Finally, I would like to thank my family for their love and support throughout this journey. Thank you for your patience and for always cheering me on.

Table of Contents

List of Tables

List of Figures

List of Appendices

Chapter 1
Introduction

1.1. The Need for ADAS Training

Many consumer vehicles now have advanced driver assistance systems (ADAS) like adaptive cruise control (ACC) and lane keeping assist (LKA). ACC can control a vehicle's acceleration and braking, while LKA can steer the vehicle to keep it within the current lane. As of 2021, ACC was available on 92% of new vehicle models in the U.S., while 50% of new vehicles had both ACC and LKA as available options (Consumer Reports, 2021). When used together, these systems take over physical control of the vehicle, and are classified as Level 2 driving automation under the Society of Automotive Engineers (SAE) taxonomy (SAE International, 2021). However, these systems are only driver support features (i.e., they do not make the car self-driving) and they have many limitations. Thus, drivers still need to be paying attention to the roadway and be ready to take over full control of the vehicle when necessary (SAE International, 2021). This dissertation will focus on these ADAS that are currently available to consumers.

While ADAS have the potential to reduce the number and severity of collisions (e.g., Benson, Tefft, Svancara, & Horrey, 2018; Highway Loss Data Institute, 2019) and drivers perceive ADAS to be beneficial for their safety (e.g., Eby et al., 2018; Hagl & Kouabenan, 2020), they do not eliminate the possibility of collisions. According to statistics from the U.S. National Highway Traffic Safety Administration (NHTSA), 367 crashes involving a vehicle using ACC and LKA were reported from July 2021 to May 2022 (NHTSA, 2022). Injury severity was known for 98 of these crashes, of which five resulted in serious injuries and six resulted in fatalities. Safety benefits of ADAS depend on drivers using (or relying on) the systems appropriately (i.e., not overrelying or underrelying on them) to perform the dynamic driving task, or parts thereof. Measures of reliance on ADAS include driving performance metrics (e.g., when drivers choose to engage the automation and when they choose to take over manual control of the vehicle) and visual attention metrics (e.g., how much time drivers spend monitoring the roadway or looking at non-driving related areas). Thus, reliance can refer to usage (i.e., whether or not ADAS is engaged) or the extent to which drivers depend on ADAS to perform the dynamic driving task. Underreliance can take the form of drivers not using automation even when it would be appropriate to do so (Parasuraman & Riley, 1997), which could result in drivers missing out on potential safety benefits of ADAS. Examples of overreliance include using automation when it should not be used or not appropriately monitoring the system, which can lead to a failure to respond in critical scenarios (Parasuraman & Riley, 1997). Drivers failing to take over control of the vehicle in situations that ADAS is not designed to handle is one example of overreliance on ADAS. However, reliance is often a graded rather than discrete process (e.g., Lee & See, 2004), whereby drivers can have higher or lower levels of reliance. With regards to visual attention metrics, spending more time looking away from the road and engaging in non-driving activities indicates increased reliance on automation. Naturalistic driving data shows that while using ACC and LKA together, drivers spend more time looking away from the road and are five times as likely to browse on their cell phones compared to when ACC and LKA are not active (Noble, Miles, Perez, Guo, & Klauer, 2021). Further, the National Transportation Safety Board (NTSB) has identified that a contributing factor in several fatal collisions was that drivers were not paying enough attention to the roadway and thus failed to take over from ADAS in a critical situation (NTSB, 2020). Such overreliance on ADAS may be influenced by drivers' trust in the system (Körber, Baseler, & Bengler, 2018; Victor et al., 2018) or a lack of knowledge of the ADAS limitations (Dickie & Boyle, 2009).

A commonly used definition of trust in automation is, "the attitude that an agent will help achieve an individual's goals in a situation characterized by uncertainty and vulnerability" (Lee & See, 2004, p. 51). It is established in the literature that trust has a close relationship with reliance on automation, with higher trust being associated with increased reliance (e.g., Hoff & Bashir, 2015; Körber et al., 2018; Lee & See, 2004). Understanding what drivers know about the state-of-the-art ADAS that is available to consumers (and their expectations about how it will perform) is also important because such knowledge can influence their trust in and reliance on the automation (Hoff & Bashir, 2015; Khastgir, Birrell, Dhadyalla, & Jennings, 2018; Lee & See, 2004). Research indicates that drivers generally do not have a good understanding of ADAS. Jenness, Lerner, Mazor, Osberg, and Tefft (2008) found that 72% of drivers were unaware of the limitations of the ACC in their vehicle. In a more recent survey, drivers (both those who owned vehicles with ADAS and those who did not) were asked various questions to assess their understanding of different ADAS systems. Only 17% of respondents correctly answered the question to assess their understanding of ACC (McDonald et al., 2016).

In a survey study, drivers who were unaware or unsure of ACC limitations reported being more willing to use the automation in situations that were beyond the system's capabilities (Dickie & Boyle, 2009). Victor et al. (2018) found that when driving a vehicle with both ACC and LKA on a test track, 30% of drivers did not take over in time to avoid a collision due to an ACC limitation (an inflatable stationary vehicle ahead), despite receiving classroom training on the automation's limitations and in-vehicle reminders to keep their hands on the wheel and eyes on the road. Through semi-structured interviews after the test drive, the authors determined that many of the participants who did not avoid the collision trusted or expected that the system could handle the situation. In a simulator study, Körber et al. (2018) found that training that minimized the limitations of an automated driving system (i.e., making takeovers seem less likely to occur and less critical) was associated with higher self-reported trust in the system, compared to training that included more emphasis on the system limitations. Further, trust affected how drivers relied on the automation. Drivers with higher self-reported trust looked more at a secondary task display and less at the roadway. When a takeover was required (due to a stationary vehicle ahead), participants who received training that minimized system limitations (and had higher resulting trust) took longer to take over. Overall, these results suggest a relationship between knowledge of ADAS limitations, trust, and reliance. However, it is unclear whether knowledge directly impacts reliance behaviour, or whether it has an indirect impact through its effect on trust. Understanding this relationship can inform future research on interventions to support appropriate reliance on ADAS. For example, if knowledge of ADAS limitations is found to have an indirect impact on reliance, interventions that aim to support appropriate reliance by improving driver knowledge of limitations would also benefit from assessing trust and considering its other influencing factors.

There are several types of interventions that could be used to support drivers' interactions with ADAS, including driver monitoring, in-vehicle displays, and training. Some consumer vehicles already have ADAS with driver monitoring systems (e.g., GM Super Cruise, Subaru DriverFocus). Using driver-facing cameras, these systems monitor the driver and alert them if the system determines they are inattentive to the roadway. However, while driver monitoring systems may help keep drivers' eyes on the road, they do not necessarily ensure that drivers will correctly determine when they should take over control of the vehicle (Victor et al., 2018). Other research has investigated in-vehicle displays that provide drivers with continuous information related to the automation or surrounding environment to support drivers using ADAS. For example, research shows that displays conveying information about automation reliability (e.g., Helldin, Falkman, Riveiro, & Davidsson, 2013) or the system state relative to operating limits (e.g., the ability of ACC to maintain a gap with a vehicle ahead based on the lead vehicle's velocity and ACC's maximum braking force; Seppelt & Lee, 2019) were associated with faster takeovers when automation limits were reached. He, Kanaan, and Donmez (2021) found that providing drivers with information about the surrounding traffic paired with automation capability information and a takeover request (TOR; which alerted the driver of the need to resume control of the vehicle) resulted in larger minimum gap times compared to a display that had only a TOR and automation capability information and a baseline display that only showed whether or not the ADAS was engaged. While system design interventions can play an important role in providing ongoing support to drivers using ADAS, these interfaces are not yet available to drivers and some would require additional technology to implement (e.g., connected vehicle technology to provide accurate surrounding traffic information). Training is another intervention that could be used to support appropriate reliance on ADAS. Training was chosen as the focus of this dissertation as it can be implemented for drivers who currently use these systems while other interventions are being researched and developed. In addition, effective training could potentially be used in combination with in-vehicle interventions to provide additional support.

While training is important to teach new and potential users how to use ADAS, the real-world collisions associated with overreliance on these systems also indicate a potential benefit of training drivers who already have experience using ADAS. Research shows that the most common methods drivers use to learn about the ADAS in their vehicle are trial-and-error (i.e., experience using the vehicle) and reading the owner's manual (Abraham, Reimer, & Mehler, 2018; Nandavar, Kaye, Senserrick, & Oviedo-Trespalacios, 2023; Pradhan, Hungund, & Sullivan, 2022). Experience with ADAS has been found to affect ADAS reliance, trust, and knowledge. In an on-road study, drivers who had experience with ACC and LKA spent more time looking at a secondary task while using these systems in a test vehicle compared to those who had never used these systems (Solís-Marcos, Ahlström, & Kircher, 2018). However, another study found that, compared with drivers who had never used ACC, drivers with ACC experience were found to take over sooner when an event occurred that affected the ACC performance (Larsson, Kircher, & Hultgren, 2014). Participants' self-reported knowledge of ACC and their trust in the system has been shown to increase with ACC experience (Beggiato, Pereira, Petzoldt, & Krems, 2015). Further, Carney, Gaspar, and Horrey (2022) recruited participants who recently purchased a vehicle with ACC and found that after 6 months of using ACC, participants' confidence in their knowledge of ACC limitations was significantly higher than when they first purchased the vehicle. Their actual scores on the knowledge questionnaire were also higher, but the difference was only marginally significant. When compared to participants without ACC experience who either received no training or training based on an owner's manual, the experience group had better knowledge scores after 6 months than the no training group, but lower scores than the training group. Further, all three groups drove in a simulator using ACC and encountered several events which required them to take over control of the speed. Results showed that the training group had the fastest takeover time, followed by the experience group and no training group. Thus, learning through trial-and-error may result in improvements in knowledge and takeover performance compared with no training, but training (in this case based on an owner's manual) may lead to improvements over experience alone.

1.2. Existing Training Research

Research on training to reduce overreliance on automation is not unique to the driving domain. Casner and Hutchins (2019) describe the parallels between human-automation interaction research in airplanes and automobiles and provide recommendations for driver training based on pilot training. They recommend that at a minimum, drivers receive training on 26 different elements that fall under three categories: the automation (e.g., the different features and how they work), the driver (e.g., driver limitations related to vigilance, their tendency to overestimate their abilities), and the driving task (e.g., the car is not self-driving, the driver is responsible for anything that happens while using the automation). However, pilots are highly skilled and receive extensive training as part of their job requirements. In contrast, there are currently no training requirements for drivers who want to use ADAS. Thus, while Casner and Hutchins' training recommendations may help drivers use ADAS more appropriately, they cannot be easily implemented within the current context of ADAS training. Even if governing bodies established driver training requirements for ADAS, development and implementation of more extensive training programs that cover the recommended material would take time. In the meantime, drivers are already using ADAS on the road (sometimes with fatal consequences; e.g., NTSB, 2020) and use will likely increase with the increasing availability of these systems. While more intensive training may be ideal, the focus of this dissertation is on relatively short, easy-to-distribute training (i.e., videos) that can be implemented in the near future to help support drivers in using ADAS safely. Although the full set of training recommendations cannot be incorporated into such short training, they were used as a starting point in considering what should be included in the training for this dissertation.

Evidence from education research suggests that videos can be an effective training tool, but that to maximize effectiveness, designers should consider cognitive load, engagement, and active learning (Brame, 2016). Training in general should attempt not to overload the user with information as working memory has a limited capacity (e.g., Cowan, 2010). Based on cognitive load theory, instructional materials should be designed to reduce the cognitive load on the learner to maximize learning (Sweller, van Merriënboer, & Paas, 2019). Videos that provide large amounts of limitations in a short amount of time may result in high cognitive load, reducing learning and the transfer of the information to long-term memory. Training videos should also be short to maximize engagement. Based on data from massive open online courses, Guo, Kim, and Rubin (2014) recommend that educational videos should be a maximum of 6 minutes in length to maintain student engagement. Finally, research shows that active learning (e.g., encouraging more engagement/cognitive processing of the material) is more effective than passive learning (e.g., listening to lectures) (Deslauriers, McCarty, Miller, Callaghan, & Kestin, 2019; Freeman et al., 2014). While training videos can result in passive learning, methods can be used to encourage learners to think about the material (e.g., interactive quiz questions), resulting in a more active learning activity (Brame, 2016). While these findings come from an educational context, the concepts can be applied to the design of ADAS training research.

Much of the existing research on ADAS training focuses on training that is based on owner's manuals. In addition to providing information about the ADAS controls, owner's manuals typically contain lists of situations in which the ADAS may not work, so that drivers are able to recognize these situations and intervene if necessary. Studies have shown that awareness of specific limitations may affect how safely drivers use ADAS. In a survey study, drivers who were unaware or unsure of ACC limitations reported being more willing to use the automation in situations that were beyond the system's capabilities (Dickie & Boyle, 2009). In a simulator study, drivers who were aware of a specific limitation (e.g., ACC does not react to stationary vehicles), took over sooner when they encountered that limitation (Bianchi Piccinini, Rodrigues, Leitão, & Simões, 2015). However, Casner and Hutchins (2019) note that the first step for the airline industry to educate pilots about automation was also through additional text in operator manuals, but that this was not a practical method (e.g., because the amount of information would be difficult for pilots to learn and remember and they were unlikely to refer back to the manual frequently). The same is likely to be true in the driving domain, especially as drivers receive less (if any) training beyond the owner's manual. It is probably impractical to expect drivers to read and memorize the wide range of system limitations in an owner's manual, and even if they were able to memorize them all, research shows that over time, drivers forget limitations if they do not experience them (Beggiato et al., 2015). Thus, while learning various system limitations through an owner's manual may be beneficial to support drivers' initial interactions with ADAS, it may not have a lasting effect on how they use the systems.

Research into the design of ADAS training has generally focused on teaching drivers this limitation-focused content via different delivery methods (e.g., written manual compared to videos or demonstrations). However, limited differences in driver knowledge and behaviour have been found across delivery methods. One study found that multimedia training (videos based on an owner's manual presented on an in-car infotainment system) was not significantly different from an owner's manual in terms of driver knowledge of system limitations and time spent looking away from the road when driving the vehicle (Noble, Klauer, Doerzaph, & Manser, 2019). Singer and Jenness (2020) also trained drivers using an owner's manual, an instructional video, or an on-road demonstration (the video and demonstration training were based on the same content from the owner's manual). Participants who received the on-road demonstration training reported the training to be more useful than the other conditions, but overall, there was no clear benefit of one training method in improving drivers' knowledge of the ADAS limitations. In addition, when participants then drove the vehicle, results indicated no significant difference in reliance behaviours (e.g., time spent with their hands off the wheel) between the owner's manual and video groups. However, the on-road demonstration group spent more time with their foot away from the pedals and hands away from the wheel. Research suggests potential benefits of interactive simulator-based training. Compared to reading an owner's manual, training that combined an owner's manual with video and interactive simulator components that highlighted different system limitations reduced drivers' overestimation of their own knowledge of ADAS limitations and was associated with a higher self-reported inclination to take over control in scenarios that required driver intervention (Krampell, Solís-Marcos, & Hjälmdahl, 2020). However, drivers' actual behaviour in these scenarios was not assessed.

Other research has shown that training on specific limitations may not be sufficient for safe use of driving automation. In the test track study described previously, Victor et al. (2018) provided explicit classroom training on the limitations of a system that could control speed and steering; participants also received reminders to keep their hands on the wheel and eyes on the road while they drove. Still, 30% of drivers crashed into a hazard on a test track, primarily because they trusted the system to avoid the crash.

Relatively few studies have investigated the effect of changing the training content. In the Singer and Jenness (2020) study described above, the emphasis of the training was also modified. Although all training materials contained information about system limitations, some participants received training that had an optimistic view of the ADAS capabilities (e.g., it was called "AutonoDrive") and others received training that was more realistic (e.g., calling the system "DriveAssist"). While there were limited differences between delivery methods (written information, video, on-road demonstration) as described above, the way the information was presented had a significant impact on drivers' perceptions of the ADAS and how they used the system. Compared to those in the DriveAssist group, participants in the AutonoDrive group were more likely to think the ADAS would successfully control the vehicle in situations that were beyond its capabilities and spent more time with their hands off the wheel.

As an alternative to limitation-focused training, one study investigated whether providing drivers (who had no ADAS experience) with structural system information (e.g., explanations about how the different sensors work and their ranges) improved their ability to decide when they would need to take over from ADAS (Boelhouwer, van den Beukel, van der Voort, & Martens, 2019). Results showed no significant difference between participants who received structural system information and those who received no system information, likely due to participants' difficulty in remembering and applying structural information during rapidly changing driving scenarios (Boelhouwer et al., 2019). Another potential training approach (and the one that will be the focus of this dissertation) is to highlight the overall fallibility of ADAS and reinforce how drivers should be using these systems (i.e., emphasizing that they should always be paying attention and should not rely on the ADAS to make any evasive maneuvers). A recent study investigated the effect of adding information about the driver's role and responsibility while using ACC to basic training that covered ACC functionality, interface and operation, and system limitations (Zheng, Mason, Classen, & Giang, 2023). The training that included roles and responsibility information was associated with a higher percentage of ACC use compared to basic training alone. However, research has not investigated whether training using the responsibility-focused approach is effective without also providing training on system limitations.

It would be advantageous for ADAS training to be relatively short given that training is not currently required for drivers and is therefore self-initiated. If presented with long training modules, drivers may not finish the training or may not want to begin the training at all. Thus, the focus of this dissertation will be to compare limitation-focused training to responsibility-focused training that does not include an extensive list of system limitations. It is expected that the responsibility-focused approach may be beneficial in two ways. First, by reducing the amount of information provided to drivers, it can improve knowledge retention over time and make drivers more likely to complete the training. Second, even if drivers do not know all the limitations, by emphasizing that ultimately the driver is responsible, and that the system will not help them avoid collisions, they may be more likely to stay attentive to the roadway in order to identify situations where they may need to take evasive action themselves.

1.3. Research Gaps and Dissertation Goals

This dissertation aims to address two main research gaps:

1. The relationships between knowledge of ADAS capabilities and limitations and trust and reliance are unclear. Although there is evidence that knowledge of ADAS limitations may lead to more appropriate reliance (e.g., Bianchi Piccinini et al., 2015; Dickie & Boyle, 2009), other research suggests that learning about system limitations is not sufficient for safe use of driving automation (Victor et al., 2018). Further, it is unclear whether potential effects of knowledge on reliance are direct or indirect (through the impact of knowledge on trust). A better understanding of these relationships can help inform training to support appropriate reliance on ADAS.

2. Most existing ADAS training research has focused on teaching drivers various system limitations and studies on the design of ADAS training have generally focused on

varying the training delivery method (e.g., written manuals compared with videos or interactive tutorials). Limited research has investigated different training approaches, including the responsibility-focused approach, which is the focus of this dissertation.

Related to the two research gaps identified above, there are two overall objectives of this research. The first objective is to assess driver knowledge of ADAS (specifically ACC and LKA which can temporarily relieve the driver from physically controlling the vehicle) and investigate how this knowledge is related to trust in and reliance on these systems. The second objective is to use these findings to develop training to support the safe use of ADAS. The responsibility-focused approach was chosen as a promising training strategy to compare with the current most common training approach (limitation-focused). These objectives were addressed over the course of three studies (an overview of the three studies can be found in Figure 1).

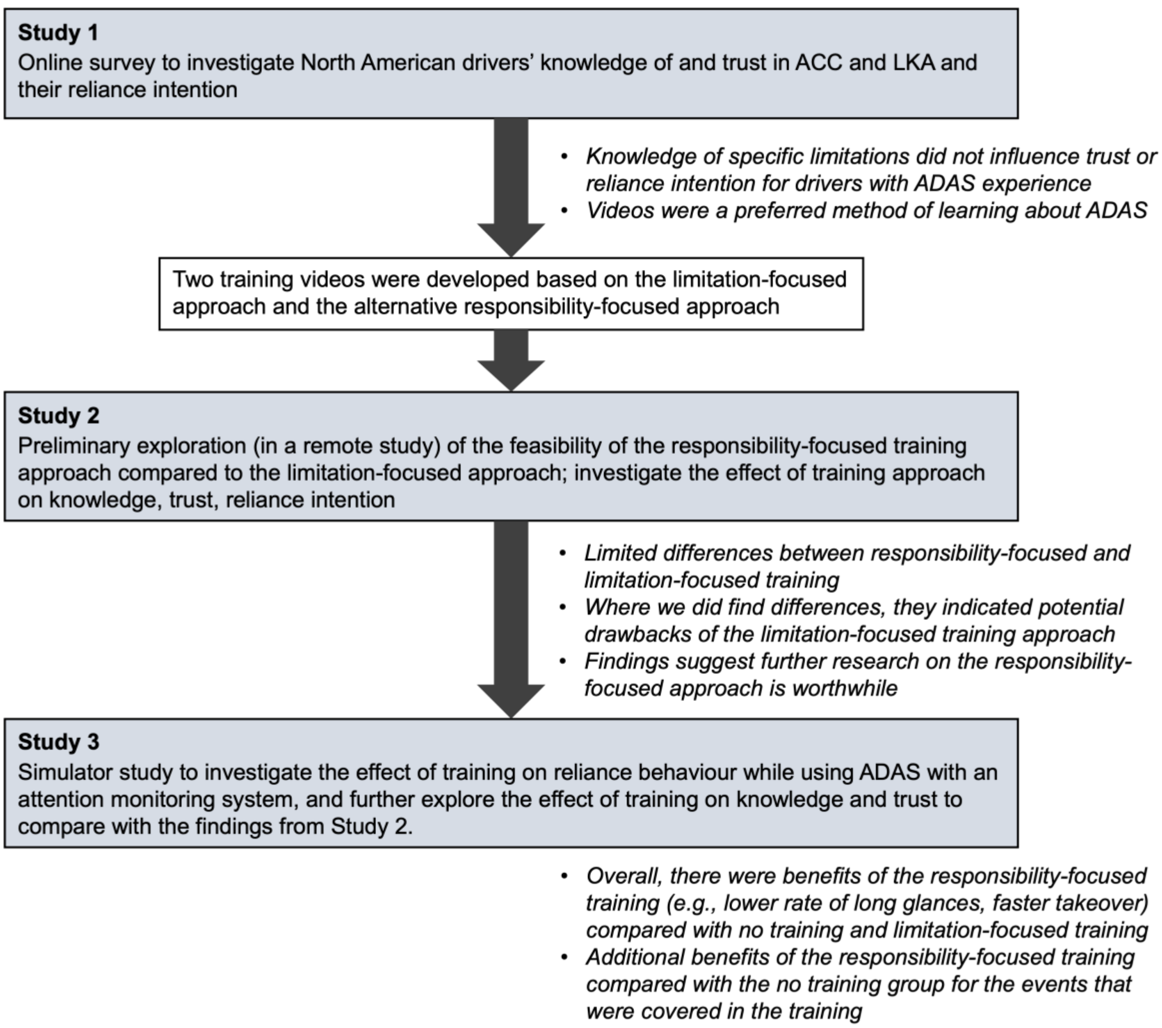


Figure 1. Research overview

Study 1 was a survey study that investigated drivers' knowledge of ACC and LKA capabilities/limitations and how that knowledge was related to trust and reliance intention (their likelihood to engage in non-driving tasks while using ACC and/or LKA). Before developing training, we wanted to assess how much drivers currently know about the capabilities and limitations that are commonly found in vehicle owner's manuals and how this knowledge (or lack of knowledge) might affect their trust in and reliance on ADAS. We conducted an online survey of Canadian and U.S. drivers with the primary objective of investigating drivers' current level of knowledge of ACC and LKA, their self-reported trust in these systems, and the relationship between knowledge and trust. A secondary objective was to explore how knowledge and trust affect reliance intention. We recruited participants from two groups: ADAS owners who had experience using ACC and LKA and non-owners who had never used either system. The Study 1 findings were used to inform the design of the ADAS training videos for Study 2.

Study 2 investigated the effect of responsibility- and limitation-focused training videos on drivers' knowledge of ADAS limitations, trust, and reliance intention. Due to COVID-19 shutdowns, the study had to be conducted online and was a preliminary exploration of the feasibility of the responsibility-focused approach. Videos were chosen as the training method for Study 2 based on our Study 1 results (Figure 5) and previous research indicating that they are a preferred method of learning about ADAS among drivers (Abraham et al., 2017). The findings from Study 2 suggested that it was worthwhile to investigate the responsibility-focused approach further with behavioural data.

Thus, Study 3 was a simulator study to explore the effects of responsibility- and limitation-focused training on driver behaviour (e.g., driving performance and visual attention). While we wanted to investigate whether training would affect drivers' monitoring the roadway while using ADAS (and whether there were differences between training approaches), driver attention monitoring systems that serve a similar purpose (i.e., ensuring drivers are paying visual attention to the roadway by alerting them when their eyes have been off the road for too long) are already available in consumer vehicles (e.g., GM's Super Cruise, Subaru's DriverFocus). Thus, an attention monitoring system was implemented for all participants, and a baseline group (with no training) was included to investigate whether training had any additional benefit on top of having an attention monitoring system.

1.4. Overview of Findings

Overall, the results of Study 1 suggested that experience with ACC and LKA does not result in better knowledge of system capabilities and limitations. Further, the relationship between knowledge, trust, and reliance appeared to differ depending on ADAS experience. For drivers who had never used ADAS, knowledge of ADAS capabilities and limitations was a significant predictor of trust in ADAS, which in turn predicted reliance intention (i.e., self-reported likelihood to engage in secondary tasks while using ADAS). For drivers with ADAS experience, trust was a significant predictor of reliance intention, but knowledge did not have a significant impact on trust or reliance intention. The findings of Study 1 were disseminated through two presentations and two journal publications (see Table 1).

Based on the findings of Study 1, Study 2 explored the effect of limitation-focused and responsibility-focused training for drivers with and without ADAS experience. Based on measures we collected remotely, we found limited differences between the limitation-focused and responsibility-focused approach. Where significant differences were found for quantitative measures we collected, they indicated potential drawbacks of the limitation-focused approach. Further, through semi-structured interviews with participants, we found that limitation-focused training may have the unintended consequence of decreased interest in using ADAS among drivers without ADAS experience who may be potential users. The findings of Study 2 were disseminated through three presentations and two journal publications (see Table 1).

The findings of Study 2 confirmed that the responsibility-focused approach warranted further investigation with a simulator study (Study 3) to collect behavioural data. Results showed that even when an attention monitoring system was implemented for all participants, there was a benefit of the responsibility-focused training, but not limitation-focused training, on reliance (e.g., lower rate of long glances to a secondary task and taking over control of the vehicle sooner when a potential conflict occurred).

Table 1. Presentations and journal publications produced from this dissertation research

Study 1

Presentations

1. DeGuzman, C. A. & Donmez, B. (September 30, 2020). Automated vehicles: Driver response to failures and implications of system knowledge for driver training and safe use of automation. *University of Waterloo Centre of Research Expertise for the Prevention of MSD and Association of Canadian Ergonomists Webinar Series*, Online.
2. DeGuzman, C. A., & Donmez, B. (2021). How much drivers know about adaptive cruise control: A survey of owners and non-owners. *Transportation Research Board 100th Annual Meeting*. (Paper reviewed, abstract published; virtual conference).

Journal Publications

1. DeGuzman, C. A. & Donmez, B. (2021). Knowledge of and trust in advanced driver assistance systems. *Accident Analysis and Prevention, 156,* 106121.
2. DeGuzman, C. A. & Donmez, B. (2021). Drivers still have limited knowledge about adaptive cruise control even when they own the system. *Transportation Research Record: Journal of the Transportation Research Board, 2675*(10), 328-339.

Study 2

Presentations

1. DeGuzman, C. A., & Donmez, B. (November 14, 2022). Training to Support Appropriate Reliance on Advanced Driver Assistance Systems. *Association for the Advancement of Automotive Medicine (AAAM) Webinar: "Vehicle Automation and Consumer Education: Recent Research Findings and Implications"*, Online.
2. DeGuzman, C. A., & Donmez, B. (2022). Do drivers need to know all ADAS limitations? A comparison of two training approaches for advanced driver assistance systems. *Human Factors and Ergonomics Society 66th Annual Meeting.* (Paper reviewed, abstract published)
3. DeGuzman, C. A., Ayas, S., & Donmez, B. (2023). Limitation-focused versus responsibility-focused advanced driver assistance system training: A thematic analysis of driver opinions. *Transportation Research Board 102nd Annual Meeting,* Washington, D. C. (Paper reviewed, abstract published)

Journal Publications

1. DeGuzman, C. A., Ayas, S., & Donmez, B. (2023). Limitation-focused versus responsibility-focused ADAS training: A thematic analysis of driver opinions. *Transportation Research Record: Journal of the Transportation Research Board, 2677*(7), 122-132.
2. 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 and Prevention, 178*, 106871.

Chapter 2
Study 1: Online Survey to Assess North American Drivers' Knowledge of and Trust in ADAS

This chapter presents the results of the first study, an online survey to investigate drivers' knowledge of and trust in ACC and LKA. The primary objective of the survey was to investigate drivers' knowledge of ACC and LKA capabilities and limitations, their self-reported trust in these systems, and the relationship between knowledge and trust, to better inform the design of ADAS training for the subsequent studies.

We surveyed owners (drivers who owned or leased a vehicle with ACC or LKA) and non-owners (drivers who did not own a vehicle with ACC or LKA and had never used either system). While it is important to understand the relationship between knowledge, trust, and reliance among owners, non-owners represent a population that will potentially use these systems in the future as they continue to emerge in the market. Thus, it is also important to understand how their knowledge may impact trust and how they intend to use these systems. An online survey was used so that we could capture a more realistic view of drivers' current understanding of ADAS and its impact on trust, compared to studies that have provided participants with training before assessing knowledge and/or trust (e.g., Singer & Jenness, 2020; Victor et al., 2018).

Although there was existing survey research related to drivers' knowledge of ACC (Dickie & Boyle, 2009; Jenness et al., 2008; McDonald et al., 2016), the studies were conducted 6+ years prior to data collection for Study 1. ACC is now more widely available and the technology has matured (e.g., many systems are now able to slow the vehicle to a stop in stop-and-go traffic). Thus, we first conducted a preliminary analysis of the ACC data from the online survey to explore drivers' knowledge of ACC systems now that they are more widely available, and what factors may influence ACC knowledge. We then conducted a full analysis of the ADAS knowledge and trust data. A secondary objective of the survey was to investigate how knowledge of and trust in ADAS impact drivers' reliance intention. Since we could not observe reliance behaviour, we asked drivers how likely they would be to engage in various secondary tasks while using no ADAS, ACC only, LKA only, and ACC and LKA combined. These responses were used as a measure of reliance intention (i.e., to what extent drivers think they would rely on the system and disengage from the driving task).

The contents of this chapter have been published in *Transportation Research Record* (DeGuzman & Donmez, 2021a) and *Accident Analysis and Prevention* (DeGuzman & Donmez, 2021b).

2.1. Materials and Methods

The survey was conducted in two parts: a main survey (approximately 20-25 minutes) and an optional follow-up survey (approximately 10 minutes); the second part was optional to avoid lengthening the survey. As our main focus was investigating drivers' understanding of and trust in ACC and LKA, the main survey consisted of demographics, ACC and LKA knowledge questionnaires, and ACC and LKA trust ratings (see Appendix A). Participants were also asked to report the methods they used to learn about ADAS in the past and their experience with ADAS (for owners only) to explore whether these factors may also influence knowledge and trust. The follow-up survey contained the reliance intention ratings (see Appendix B). The surveys contained brief descriptions of ACC and LKA so that participants knew what systems they were being asked to consider, as the names may differ across manufacturers.

2.1.1. Participants

Participants were recruited through Mechanical Turk, online postings (e.g., Facebook; Kijiji, a website similar to Craigslist), and emails to our lab contact list (consisting of individuals who previously indicated that they would like to be contacted for research studies). Mechanical Turk is an online crowdsourcing platform that is commonly used for survey studies (e.g., Ayoub, Yang, & Zhou, 2021; Rahman et al., 2018). Data from Mechanical Turk has been shown to be of similar quality to that of traditional data collection methods and represent a more diverse sample than might typically be obtained through recruiting on university campuses (e.g., Casler, Bickel, & Hackett, 2013; Thomas & Clifford, 2017; Walter, Seibert, Goering, & O'Boyle, 2019). However, researchers often use attention checks and monitor survey completion time to screen out potentially unreliable responses and ensure quality data (e.g., Ayoub et al., 2021; Rahman et al., 2018). Attention checks were implemented for all participants in our survey. These items asked participants to provide a specific response (e.g., an item stating "Please answer yes and full confidence" in a list of items in the knowledge questionnaire; see Section 2.1.2.1).

Participants who were recruited through Mechanical Turk were compensated $4 for the main survey and $2 for the follow-up survey (all currency in this chapter is reported in USD). Participants recruited through online postings or emails were entered into a raffle to win a $100 gift card for completing the main survey and received an additional entry into the raffle for completing the follow-up survey. Participants were informed that their chance of winning was approximately 1 in 25 (one gift card was purchased for approximately every 25 participants).

Participants were required to live in the United States or Canada and have a valid driver's license, so that they were a potential user of ADAS. Initially, participants with all levels of experience with ACC and LKA were recruited. However, initial inspection of the data partway through data collection showed that only 14% of respondents (20 of 138) did not own or lease a vehicle with ACC or LKA but had used at least one of these systems before. Because we did not think we would get a large enough sample for this group, we excluded these participants and continued data collection with the additional inclusion criteria that participants either had to: (1) own or lease a vehicle with ACC and/or LKA (owners), or (2) have never used ACC or LKA (non-owners).

After excluding the previously mentioned 20 participants, 479 participants completed the main survey. Our final sample used in analysis consisted of 102 owners and 262 non-owners. A total of 309 participants completed the follow-up survey. The final sample for the follow-up survey consisted of 43 owners and 150 non-owners. The screening process to obtain our final samples can be found in Figure 2 and descriptive statistics for the owner and non-owner samples can be found in Table 2.

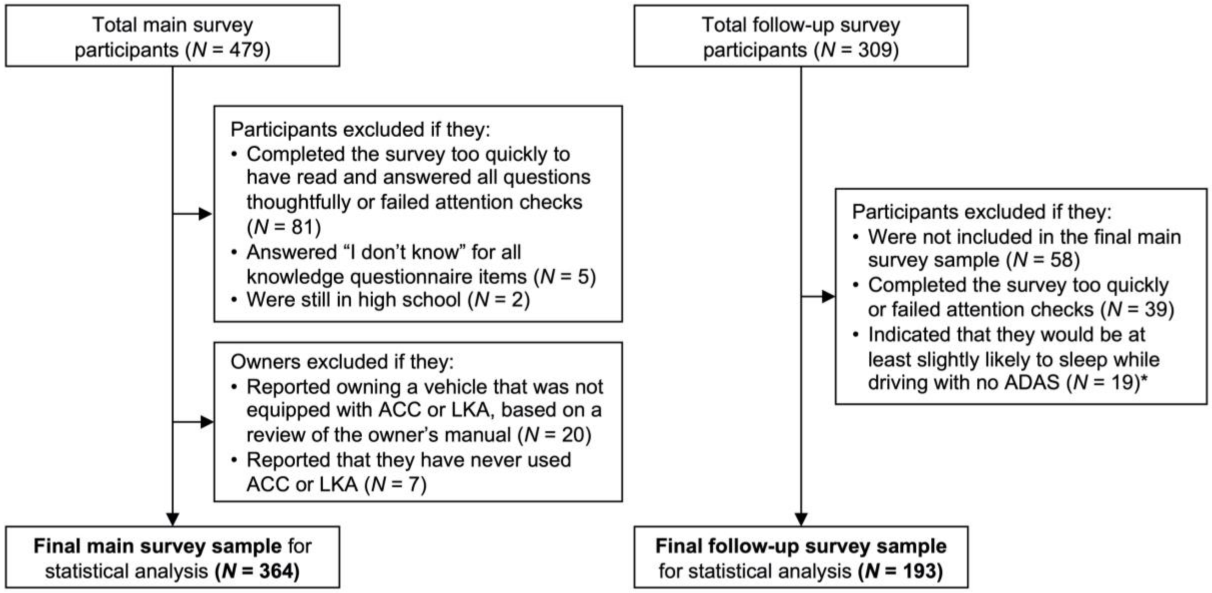


Figure 2. Screening process to obtain final samples for the main survey and follow-up survey in Study 1. *We were unable to identify whether these responses were due to misunderstanding the item or not paying attention to the items, thus these participants were removed to be conservative.

Table 2. Descriptive statistics by ownership in Study 1

	ADAS non-owner	ADAS owner
Main Survey		
N	262 (123 F, 139 M)	102 (48 F, 54 M)
Age (*M*, *SD*)	35.3, 13.4	35.2, 11.5
Number of ADAS Learning Methods (*N*)		
0	101	0
1	58	26
2	52	30
3+	51	46
Technology Familiarity (*M*, *SD*)	7.7, 1.4	8.1, 1.4
Education (*N*)		
High school, some postsecondary, or college degree	102	26
Bachelor's degree	111	41
Graduate or professional degree	47	35
Income (*N*)		
Less than $40,000 USD	88	13
$40,000 to $74,999 USD	100	43
More than $75,000 USD	74	46
% Recruited through Mechanical Turk	54	48
Follow-up Survey		
N	150 (71 F, 77 M)	43 (18 F, 25 M)
Age (*M*, *SD*)	37.0, 14.4	36.9, 13.0
Number of ADAS Learning Methods (*N*)		
0	50	0
1	32	12
2	32	13
3+	36	18
Technology Familiarity (*M*, *SD*)	7.8, 1.4	7.8, 1.7
Education (*N*)		
High school, some postsecondary, or college degree	65	14
Bachelor's degree	57	15
Graduate or professional degree	28	14
Income (*N*)		
Less than $40,000 USD	50	5
$40,000 to $74,999 USD	63	15
More than $75,000 USD	37	23
% Recruited through Mechanical Turk	54	42

2.1.2. Survey Design and Procedure

2.1.2.1. Main Survey: Demographics, Knowledge, Learning Methods, and Trust

Participants first completed a short screening questionnaire to ensure that they met the inclusion criteria, and then were given information about the study and provided informed consent. In the first section of the survey, participants reported demographic information, driving habits, what methods (if any) they had used to learn about ADAS, and how they would prefer to learn about

ADAS. Methods of learning about ADAS (past and preferred) were one question each for which participants were asked to consider both ACC and LKA. ACC owners and LKA owners were also asked how often they used the ACC and/or LKA in their vehicle. The questions in this section were developed based on a review of previous surveys about ADAS (Abraham et al., 2017; McDonald, Carney, & McGehee, 2018; Seppelt, 2009). Data collection began in April 2020, at which point many people were spending more time at home due to the COVID-19 pandemic. Thus, participants were asked to report their driving habits before the pandemic and their yearly income from 2019 as their current income may also have been affected by the COVID-19 pandemic. Data collection concluded in January 2021.

The second section of the main survey contained ACC and LKA knowledge questionnaires which were developed based on a review of previous questionnaires assessing knowledge of ACC (Beggiato et al., 2015; Seppelt, 2009) and a review of owner's manuals from various manufacturers to identify the functionality and limitations of each system. Each questionnaire had two parts (ACC total items = 51, LKA total items = 38). In part one, participants were presented with a series of statements about ACC or LKA and were asked whether each statement was true (response options were "Yes", "No", or "I don't know"). In part two, participants were presented with a list of situations and were asked whether the ACC or LKA would have difficulty in each situation (response options: "Yes", "No", or "I don't know"). The items were the same for owners and non-owners, but owners were asked to consider their own system, and non-owners were asked whether the statements were true for any ACC or LKA system (part one) and whether any system would have difficulty in a given situation (part two). For all items, participants were also asked to rate their confidence in their answer from 1 (very low confidence) to 7 (full confidence). If participants answered "I don't know", they did not need to rate their confidence, but they were encouraged to do so only if they were completely unsure. In this section, participants also rated their trust in ACC and LKA, using five items from Jian, Bisantz, and Drury (2000): "I can trust the system", "The system is reliable", "I am confident in the system", "I am familiar with the system", and "The system is dependable". Participants were asked to rate their overall agreement with these statements on a Likert scale from Strongly Disagree to Strongly Agree, and rated their trust separately for ACC and LKA. The presentation order of the ACC and LKA questionnaires was randomized, and within the knowledge questionnaires, the order of parts one and two were randomized (but consistent across the ACC and LKA questionnaires). Approximately half of the participants rated trust first and the other half rated trust after the knowledge questionnaires.

2.1.2.2. Follow-up Survey: Reliance Intention

At the end of the main survey, participants were informed that there was an optional follow-up survey. Follow-up survey responses were matched to the main survey data using a Mechanical Turk Worker ID (for Mechanical Turk participants) or a unique code provided at the end of the main survey (for participants who were recruited through emails or online postings). After consenting to participating in the follow-up survey, participants were asked to rate how likely they would be to engage in various secondary tasks while using (1) no ADAS, (2) ACC only, (3) LKA only, and (4) both ACC and LKA (the list of secondary tasks can be seen in Figure 13). Likelihood was rated on a 5-point scale from “not at all likely” to “extremely likely”.

2.1.3. Analysis

2.1.3.1. Main Survey

We analyzed the main survey data separately for owners and non-owners because owners were asked to consider the capabilities of the ACC and/or LKA in their own vehicle and non-owners were asked to consider the capabilities of currently available ACC and LKA. Further, we analyzed the data for ACC and LKA separately because it was possible to own (or be aware of owning) only one system. For example, a participant could be considered an ACC owner, but an LKA non-owner (i.e., own a vehicle equipped with ACC but not LKA). Thus, we split the ACC data into two groups (ACC non-owners and ACC owners), and the LKA data into two groups (LKA non-owners and LKA owners). We scored owners’ responses on the knowledge questionnaire based on a review of the manual for their vehicle to assess the features (e.g., could it slow down to a stop). Because owner’s manuals do not always list all of the limitations of current ADAS technology, if any common limitations were not listed in the owner’s manual (e.g., difficulty detecting stopped vehicles), those were still considered to be limitations for the given vehicle. ADAS owners owned vehicles from 21 manufacturers, the most common being Toyota (33%) and Honda (14%). Vehicles from all other manufacturers accounted for less than 10% of vehicles owned by the ADAS owners in our sample (the percentage of vehicles by manufacturer is provided in Appendix C).

As part of our preliminary analysis of the ACC knowledge data, we calculated the percentage of items participants answered correctly (percent correct). For both owners and non-owners, we used a median split on the percent correct data to compare whether participants with a higher percent correct used different methods to learn about ADAS than those with a lower percent correct. Chi-square tests were conducted for each learning method (separately for owners and non-owners) to test whether there was an association between using that learning method (yes or no) and percent of correct answers (higher or lower). When expected values were less than 5 in any cells, Fisher's exact test was used. To investigate the potential factors that are related to knowledge about ACC, we then built regression models (one for owners and one for non-owners) with percent correct as the outcome variable and predictor variables related to demographics, methods used to learn about ACC, and experience with ACC and technology in general (see Table 3 for descriptions of each predictor).

For the full dataset, we then calculated a confidence weighted knowledge score for ACC and LKA as a further investigation of participants' performance on the knowledge questionnaires. First, correct responses were given a score of 1, incorrect responses were given a score of -1, and "I don't know" responses were given a score of 0. Then, the scores were multiplied by the confidence rating for each item (from 1 to 7). Thus, final scores for each item could range from -7 to 7. The responses were scored this way to penalize drivers more for incorrect knowledge than not knowing the answer to an item, and to give more weight to items that participants were more confident that they knew, compared to those they were not sure about. In order to make the scores easier to interpret, after summing the scores for all items in each questionnaire, we turned the final scores into a percentage out of the total available points for each questionnaire. For example, on the ACC questionnaire (51 items) the maximum score was 357 (every item answered correctly with a confidence rating of 7); the minimum score was -357 (every item answered incorrectly with a confidence rating of 7). The ACC scores were then transformed so that 0 was the minimum and 714 was the maximum and the confidence weighted percentage reflected participants' score out of 714.

To explore the factors that influenced trust in ACC and LKA, we then built four regression models with trust as the dependent variable (two ACC models: owners and non-owners, and two LKA models: owners and non-owners). Principal components analysis indicated that all trust items loaded onto the same factor except for "I am familiar with the system". Thus, the item related to familiarity was removed and scores for ACC and LKA trust were calculated by averaging the ratings for the other four items. The predictor variables are described in Table 3. For both the knowledge and trust models, all predictors were entered simultaneously and the full models are reported. The models were built with the ‘lm’ function in R. For the trust models, we were mainly interested in the relationship between knowledge and trust; the other variables were included as covariates to explore whether they also influenced trust.

As presented in Table 3, we used signal detection theory constructs of sensitivity and response bias to isolate the effect of knowledge (e.g., Macmillan & Creelman, 2005; Stanislaw & Todorov, 1999). Bias is a participants’ inclination towards a certain response (e.g., a bias towards answering “Yes” that a signal is present regardless of actual signal presence). Sensitivity is the ability to detect a signal among all items and is independent of bias. All knowledge items were recoded so that they reflected the capabilities of ACC and LKA. Thus, the signal to be detected was whether an item reflected a true capability of ACC or LKA, and the sensitivity represented the participant’s ability to detect actual system capabilities, which is an unbiased measure of knowledge. A response bias towards “Yes” indicated that a participant was inclined to respond that the system was capable regardless of whether the item was true or false (i.e., they had a favourable view of the system). Sensitivity was measured using the area under the receiver operating characteristic curve (AUC), and criterion location (c) was used to measure response bias (for a description of how to obtain the AUC and c from confidence rating scale data, see Macmillan & Creelman, 2005; Stanislaw & Todorov, 1999).

To explore the effect of learning methods on trust, we first conducted t-tests to analyze whether trust differed based on whether or not participants used a given learning method. Given the large number of t-tests (one for each learning method), alpha was adjusted according to the Benjamini-Hochberg method (Benjamini & Hochberg, 1995). For ACC non-owners, three learning methods were associated with higher trust in ACC: reading an owner’s manual, asking friends for information, and searching for information on websites. For LKA non-owners, reading an owner’s manual, asking friends for information, and getting information from dealership or car rental staff were all associated with higher trust in LKA. ACC owners who asked staff for information had significantly higher trust in ACC than those who did not ask staff for information. LKA owners who learned by trial-and-error had significantly lower trust in LKA than owners who did not learn by trial-and-error.

Table 3. Explanatory variables for main survey analyses in Study 1

Predictor	**Description**	**In ACC Knowledge Model**	**In Trust Model**
Sensitivity*	Participants' ability to identify true capabilities of ACC and LKA among items in the knowledge questionnaires, independent of response bias. Measured using area under the receiver operating characteristic curve (AUC). Values range from 0 to 1. A value of 1 indicates perfect performance (i.e., participants correctly answered all items); a value of 0.5 represents chance performance (Stanislaw & Todorov, 1999).	No	Yes
Bias*	A measure of participants' inclination towards a certain response, independent of sensitivity (Stanislaw & Todorov, 1999). Measured using criterion location (*c*). Negative values indicate that participants had a response bias towards "Yes", in other words, they had an inclination to respond that the system was capable regardless of whether the item was true or false.	No	Yes
Number of learning methods used	The number of methods the participant used to learn about ADAS in the past. Participants were asked to select all methods they used from the following: Read the vehicle manual; Asked sales staff at the dealership for information; Staff at the dealership offered information (you did not specifically ask); Asked a friend or family member for information; Friends or family were talking about advanced driver assistance systems (you did not specifically ask); Looked for information on the internet; Searched for online videos; Saw a video or commercial by chance; Drove the vehicle to learn by trial-and-error; Observed the advanced driver assistance systems as a passenger; Other - please specify. This variable was split into two levels for analysis. For non-owners the levels were 0-1 and 2+; for owners the levels were 1-2 and 3+ (there were no owners who used 0 learning methods).	Yes	Yes
Technology familiarity	An average of three items asking about level of experience with technology, the degree to which participants consider themselves early adopters of technology, and how easy they find it to learn new technology. The first two items were taken from (Chen & Donmez, 2016; Reimer, Mehler, Dobres, & Coughlin, 2013).	Yes	Yes
Education	Highest level of education completed. This predictor had three levels: high school, some postsecondary, or college degree; bachelor's degree; and graduate or professional degree.	Yes	Yes
Age	Self-reported age at the time that the survey was completed	Yes	Yes
Sex	Self-reported sex. This predictor had two levels: male, female.	Yes	No
Income	The participant's yearly household income for 2019, reported by selecting from nine income ranges. The median income in the U.S. for 2018 was $63,000 (Rothbaum & Edwards, 2019), which was contained within the "$50,000 to $74,999" range in our survey, and Pew Research Center (2016) considers lower income households to be those with an income less than 67% of the median income ($42,000 for 2018). Thus, we split income into three levels: less than $40,000, $40,000 to $74,999, and $75,000 or greater. For owners, due to a small proportion of participants who reported earning less than $40,000, income was split into two levels: less than $75,000 and $75,000 or greater.	Yes	Yes
Experience (for owners only)	Level of experience, rated separately for ACC and LKA. This predictor had two levels: lower (reported using ACC or LKA rarely or sometimes) and higher (reported using ACC or LKA most of the time or almost every time they drove)	Yes	Yes

Note: Full items can be found in Appendix A.
* To calculate sensitivity and bias, items were recoded so that they reflected a system capability.

Given that there was not a consistent effect of any given learning method across our sample, we then explored whether the number of learning methods used influenced trust, as drivers may trust the system more if they got information from multiple sources. A t-test showed that non-owners who used two or more learning methods had significantly higher trust than those who used fewer than two learning methods. There was a relatively small proportion of owners (25%) who used fewer than 2 learning methods (see Table 2), thus for owners, number of learning methods was split into two levels (1-2 and 3+) to obtain more balanced groups. There was no significant effect of number of learning methods on trust for owners. To simplify the regression models, number of learning methods was chosen as the relevant predictor over type of method and included in the analysis for non-owners and owners to investigate whether it had an effect on trust when controlling for the other variables in the model.

2.1.3.2. Follow-up Survey

Mixed linear models were used for the reliance intention analysis to account for the repeated measures (participants rated likelihood to engage in secondary tasks four times, once for each ADAS condition). Models were built using the ‘nlme’ package in R, with participant listed as a random effect. Like with the main survey data, the follow-up survey data was analyzed separately for owners and non-owners. However, we could not further breakdown the sample based on ACC and LKA ownership given the smaller sample size. Thus, we created two models, one for ADAS owners (owned a vehicle with ACC and/or LKA) and one for ADAS non-owners (did not own a vehicle with either system). The dependent variable was average self-reported likelihood to engage in secondary tasks, which was calculated by averaging the likelihood ratings across the secondary tasks. The predictor variables are shown in Table 4. Trust was entered into the model before the sensitivity and bias measures given its known relationship with reliance (Lee & See, 2004). Sensitivity and bias were included in the model to assess whether either measure exerted any additional influence on reliance. Likelihood ratio tests were used for model selection. None of the first order or second order interactions significantly improved either model, so they were excluded from the analysis.

Table 4. Explanatory variables for mixed linear model predicting reliance intention in Study 1

Predictor	Description
ADAS condition (repeated measure)	A categorical variable with four levels: no ADAS, ACC only, LKA only, both ACC and LKA
Average trust score	An average of the ACC and LKA trust scores
Average sensitivity	An average of the AUC for ACC and LKA
Average bias	An average of *c* for ACC and LKA

Note: Full items can be found in Appendix B.

2.2. Results and Discussion

2.2.1. Preliminary Analysis: ACC Knowledge and Learning Methods

Owners, on average, answered 51% of all knowledge items correctly (*SD* = 13.5), with scores ranging from 4% to 80%. Figure 3 includes three items from the survey that related to the main purpose of ACC (top three items) and several items relating to limitations that are commonly considered in driving automation research (e.g., Beggiato & Krems, 2013; Dickie & Boyle, 2009; Larsson et al., 2014; Seppelt & Lee, 2007; Xiong, Boyle, Moeckli, Dow, & Brown, 2012). While 40-44% of owners correctly reported that their ACC system might have difficulty when driving on curvy roads or when approaching a stationary vehicle, 46-47% of owners incorrectly thought that their ACC system would not have difficulty in these situations. Non-owners, on average, answered 45% of the items correctly (*SD* = 15.0), with a range of 2% to 78%.

When looking at individual survey items, the responses were similar between owners and non-owners. Most owners and non-owners (68-78%) knew the main purpose of the system and that it might have difficulty if the sensors were blocked or dirty (the four items at the top of Figure 3). There were also some common misperceptions among owners and non-owners (Figure 3). Around half of owners and non-owners incorrectly thought that ACC had full braking power. Further, like the owners, around half of non-owners were unaware that ACC might have difficulty when approaching a stationary vehicle or when driving on curvy roads. In fact, the percentage of incorrect responses is similar for owners and non-owners (≤ 11% difference) for all items in Figure 3, except for “Might have difficulty when the vehicle ahead brakes suddenly”, which 63% of owners answered incorrectly, compared to only 40% of non-owners. These results indicate that even with experience using ACC, the owners do not seem to have a better understanding of their own ACC system compared to non-owners’ understanding of ACC systems generally.

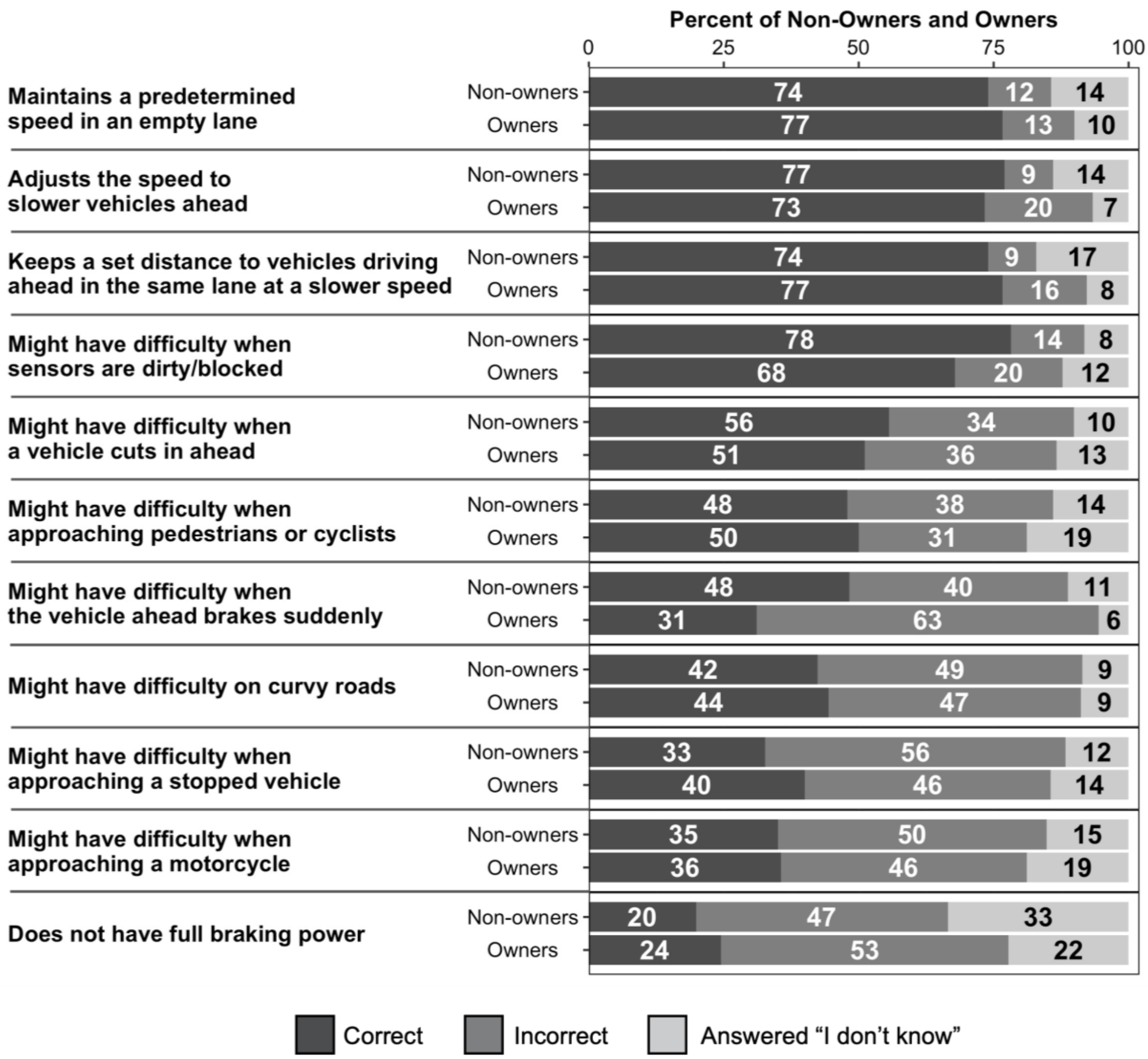


Figure 3. Percent of non-owners and owners who answered correctly, incorrectly, and “I don’t know” for a subset of ACC knowledge items in Study 1. For the figure, items were recoded to be true statements.

To statistically compare owners and non-owners, we calculated a revised percent correct based on just the items that had the same response for all vehicles (see Appendix A, underlined items were removed for this analysis). In other words, the correct answers for these items were the same for non-owners and owners, regardless of their vehicle. Overall, owners had a higher percent correct, $t(171.2) = 2.71$, $p = .007$, answering 52% correctly compared to non-owners who answered 47% correctly. However, when we examined the percent correct for items related specifically to ACC limitations, there was no significant difference between owners and non-owners, $t(159.1) = 0.49$, $p = .6$. On average, owners answered 47% of limitation-related items correctly and non-owners answered 46% correctly. The difference in the revised percent correct between owners and non-owners was driven by the other items which asked about the general purpose of ACC and how to operate it (e.g., how to engage/disengage it), $t(178.2) = 4.73$, $p < .001$, with owners answering 59% correctly and non-owners answering 49% correctly on average.

Our results suggest that owners today may have a better understanding of the ACC limitations that have been investigated in survey studies over the past 10+ years. Forty percent of owners correctly reported that their ACC system might have difficulty when approaching a stationary vehicle, and 44% were aware that their ACC system might have difficulty on roads with curves. These results are consistent with a 2009 study which found that 42% of the 55 surveyed owners were aware of these limitations (Dickie & Boyle, 2009). However, larger surveys conducted around the same time indicated that a lower percentage of drivers knew about these limitations. In a 2006 paper, only 1% of owners correctly identified that ACC would not detect a stopped vehicle ahead (Llaneras, 2006). Jenness et al. (2008) found that 34% of owners correctly identified that their ACC system would work “poorly” or “not at all” on a curvy road, and only 22% correctly reported that their ACC system would work “poorly” or “not at all” when approaching a stationary vehicle. These results, combined with our current findings, suggest that as ACC has been available for a longer period of time and become more common, more owners have become aware of these limitations. However, despite a larger percentage of owners being able to correctly identify these limitations in our study, there was still a large percentage of owners (over 40%) who incorrectly believed that their ACC system would not have difficulty in these situations. In addition, our results showed that while owners had a higher percentage of correct answers than non-owners for items that related to the purpose and features of ACC, there was no significant difference in their knowledge of ACC limitations. As this technology is becoming more common, even non-owners may be becoming aware of the limitations, and owning and using ACC does not seem to result in an increased awareness of system limitations.

2.2.1.1. Drivers’ Past and Preferred Learning Methods

All owners reported using at least one method to learn about the ADAS in their vehicle, with most owners (77%) using multiple methods. Owners most frequently reported learning by reading an owner’s manual, however, consistent with previous research (Abraham et al., 2018; McDonald et al., 2018) only about half of them reported doing so (see Figure 4). The next most common learning methods were learning from staff at the dealership and searching for videos. While around half of the owners surveyed by Abraham et al. (2018) reported learning about ADAS using trial and error, our results are more in line with those of McDonald et al. (2018), with only 31% of owners in our sample reporting to learn by trial and error (34% in McDonald et al.'s sample). For the methods drivers would prefer to use to learn about ADAS, videos were the most popular overall (Figure 5), consistent with previous research (Abraham et al., 2017).

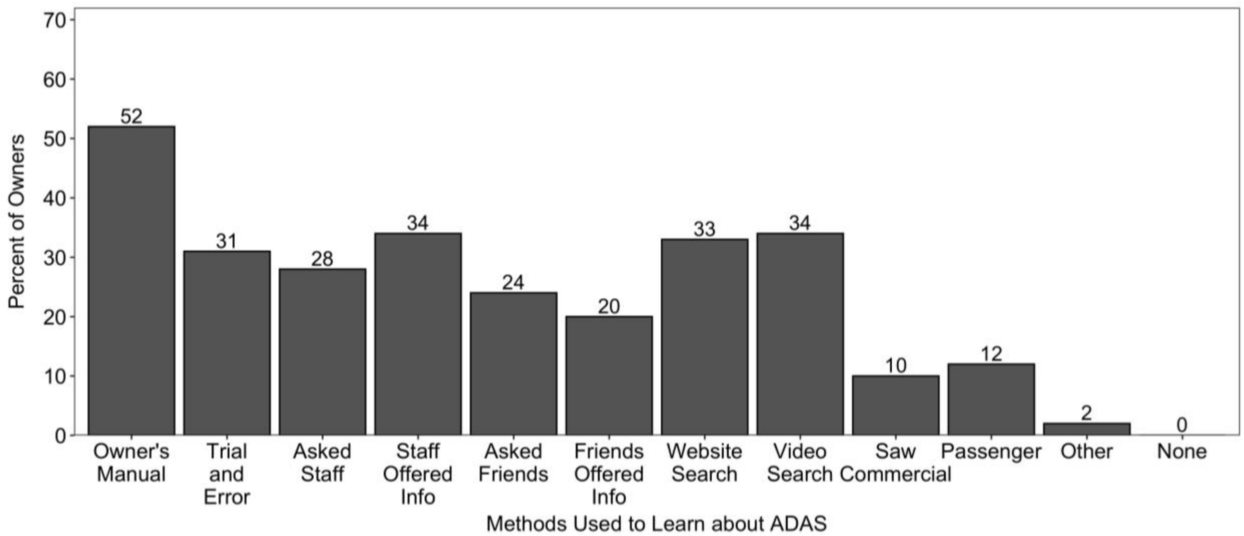


Figure 4. Learning methods used by owners in Study 1 (participants could select all that applied)

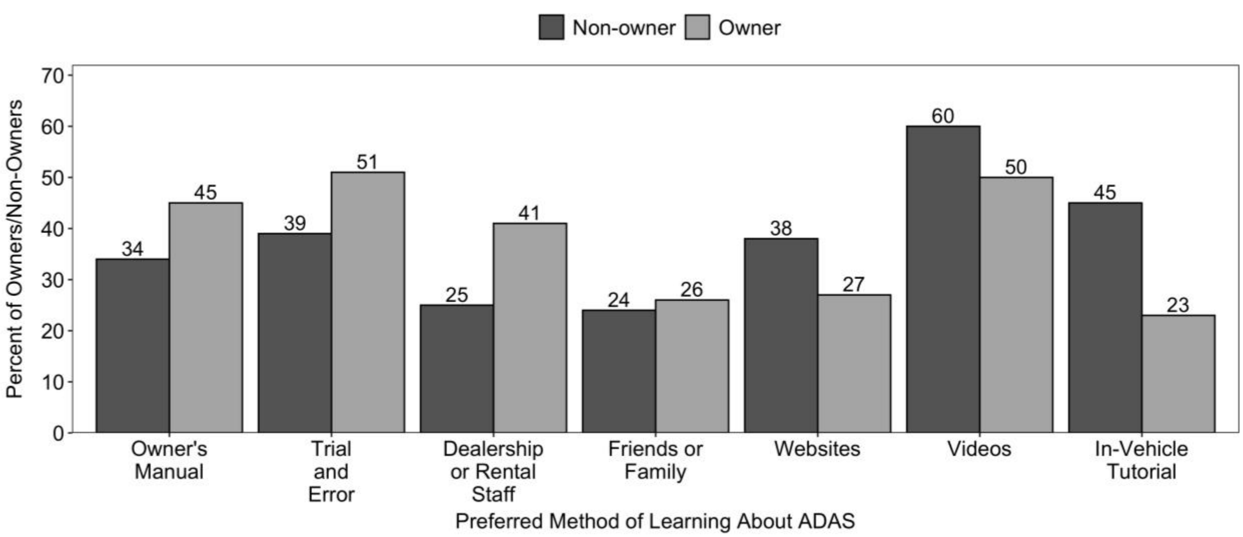


Figure 5. Preferred learning methods of non-owners and owners in Study 1

Although on average owners did not perform well on the ACC knowledge questionnaire, there was variance in their performance as reported earlier. We split the data to explore whether owners who had a better understanding of ACC differed from those with a worse understanding in terms of how they learned about ADAS. Owners were split into two groups based on total percent correct (Median = 49.0). The higher group consisted of owners who answered more than 50% correct (N = 44) and the lower group consisted of those who answered 50% or fewer items correctly (N = 46). The percentage of owners who used each learning method was plotted for the higher and lower group (see Figure 6). While various learning methods have slight differences between groups, chi-square tests revealed that trial and error was the only learning method that was significantly associated with having a higher percent correct, $\chi^2 = 5.85$, $p = .02$. Odds of being in the higher group were 3.12 times higher [95% CI: 1.22, 8.01] for owners who learned by trial and error. There was a marginally significant effect of searching for information on websites ($\chi^2 = 3.76$, $p = .053$), with the odds of being in the higher group being 2.42 times higher [95% CI: 0.98, 5.96] for owners who searched for information on websites.

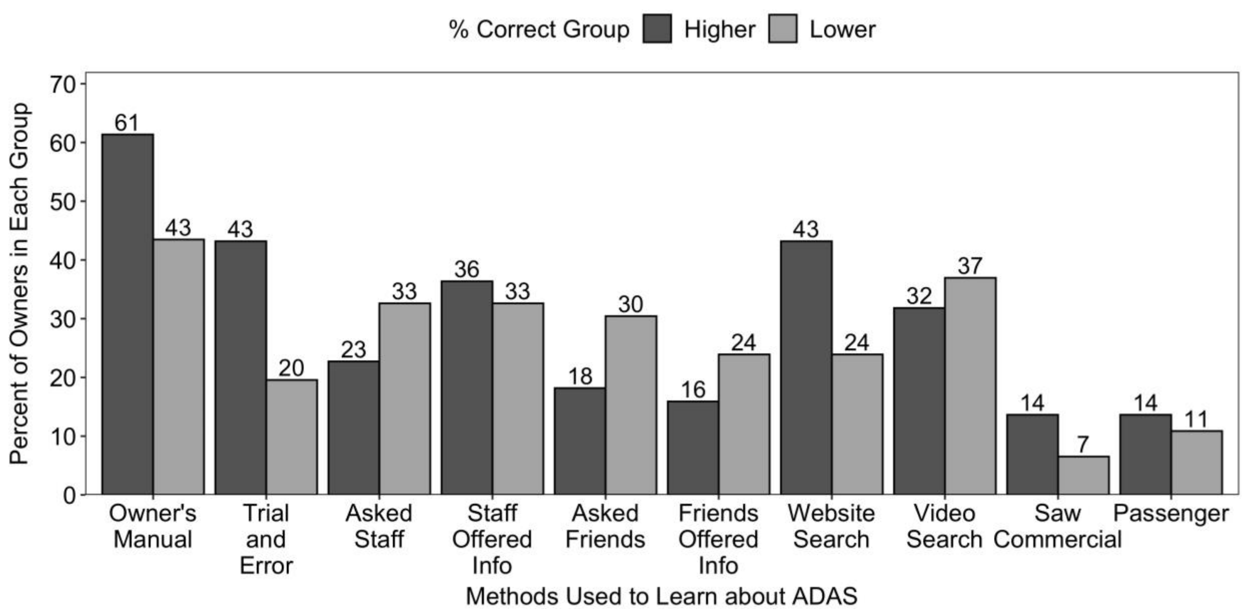


Figure 6. Percentage of owners in the higher and lower groups who used different methods to learn about the ADAS in their vehicle in Study 1. Higher and lower groups were created using a median split on the total percent of correct items among owners.

Thus, while an owner’s manual contains information about ACC features and limitations, reading a manual may not be sufficient to understand and remember all of the limitations. A higher percentage of owners in the higher percent correct group read their owner’s manual compared to those in the lower group. However, we did not find a significant association between reading an owner's manual and having a higher percentage of correct answers. Further, almost half of owners in the lower group also read an owner's manual, and thus simply reading a manual does not guarantee a better understanding of ACC. It may be that some owners reported reading a manual even if they only read small portions of it. Prior work on driving in general showed that drivers typically do not read an entire manual (Mehlenbacher, Wogalter, & Laughery, 2002). In the current study, we did not ask whether owners had read the whole section on ACC, and thus they may have gotten some information about ACC from a manual without thoroughly reading all relevant information. The quality of the information presented in an owner's manual could also be a factor. For example, only 24% of owners knew that ACC did not have full braking power. In the current study, owners had vehicles from 21 different manufacturers and the manuals for eight of these manufacturers did not mention that ACC had limited braking power. Thus, even if drivers read the entire ACC section of a manual, training materials may not contain all the relevant information to give drivers sufficient knowledge of the system. We did not control for this variation in information across different manuals, which is a limitation of our analysis.

Studies show that limitations are forgotten over time unless they are experienced (Beggiato & Krems, 2013; Beggiato et al., 2015), which may explain why trial and error was the only learning method among owners that had a significant association with having a higher percentage of correct responses. If drivers forget limitations they have learned (through reading an owner's manual or any other method) unless they experience them, drivers who experiment with their system through trial and error may encounter and thus remember more limitations of their ACC system. We also found a marginally significant association between searching for information on websites and answering a higher percentage of items correctly. Searching for information on the internet may return information from a wider range of sources that may be easier to understand than an owner's manual, or owners may be searching for specific information about their ACC system after using it to get a better understanding of how it works. However, further research would be needed to investigate what information drivers search for on the internet and whether they find it to be more informative than an owner's manual.

Thirty-nine percent of non-owners reported never learning about ACC or LKA. For those who did, the most common method of learning was from a commercial (reported by 36% of non-owners), followed by searching for information on websites and having friends offer information (reported by 24% and 20% of non-owners, respectively). Splitting non-owners into two groups (higher and lower) using a median split on percent correct (Median = 47.1), it was found that the higher (N = 127) and lower (N = 126) groups were similar in the learning methods that they used (see Figure 7). Results of chi-square tests indicated no significant associations between using a specific learning method and having a higher percent correct.

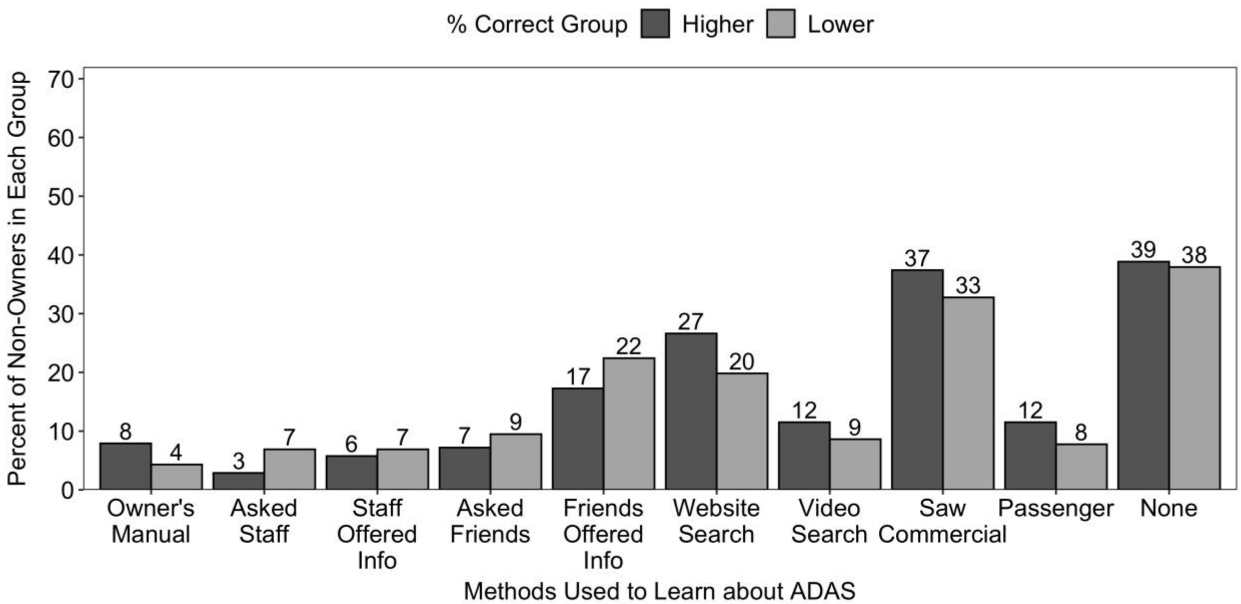


Figure 7. Percentage of non-owners in the higher and lower groups who used different methods to learn about ADAS in Study 1. Higher and lower groups were created using a median split on the percent of correct items among non-owners.

In general, our results do not indicate that one method of learning clearly results in a better understanding of ACC, which is consistent with training research showing that the way ADAS information was presented to drivers (owner's manual versus multimedia training) did not significantly affect driver knowledge of system limitations (Noble et al., 2019). However, an important limitation of this analysis is that we asked participants how they have learned about either ACC or LKA in the past – they did not separately report how they learned about ACC. It is possible that we did not find an association between learning methods and percentage of correct responses because some of the methods participants reported using may have been used to learn about LKA and not ACC. In addition, participants often learned using more than one method, and thus our comparisons do not reflect the isolated effect of each learning method. Due to sample size limitations, we were not able to assess the various combinations of learning methods for their effect on knowledge. Future research is needed to confirm our findings based on participants' past learning about ACC specifically and to investigate whether certain combinations of learning methods are more effective in improving drivers' knowledge of system limitations.

2.2.1.2. Factors Related to Knowledge About ACC

For owners, income and age were significant predictors of percent correct (Table 5). Owners with a yearly household income of $75,000 or greater answered more items correctly, while older owners answered fewer items correctly. However, there was also a marginally significant age by sex interaction, whereby there was only an effect of age for females (see Figure 8). Previous research suggests that males and younger people have a higher interest in automated vehicles (e.g., Hardman, Berliner, & Tal, 2019; Spurlock et al., 2019). Thus, males of all ages may be motivated to learn about ACC, whereas for females it may be primarily the younger owners who are interested in learning about and using ADAS. However, our results were only marginally significant and future research is needed to explore this potential age-sex interaction.

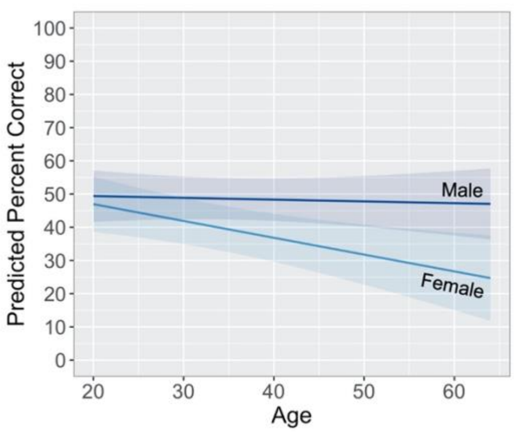


Figure 8. Predicted percent correct by age and sex, based on the regression model for owners in Study 1. Shaded bands represent 95% confidence interval.

Given that income was a significant predictor of percent correct, we explored whether owners with higher income were more likely to own luxury vehicles, as luxury vehicles may have more sophisticated interfaces that help convey more information about the ACC. Forty-four percent of owners in the higher income group owned a luxury vehicle, compared to 31% of owners in the lower income group. Chi-square analysis indicated no significant relationship between income and having a luxury vehicle (χ^2 = 0.59, p = .4), however we may not have had enough power with our sample size to detect a significant difference. Future research could investigate differences in owner understanding of ADAS for different vehicle manufacturers.

For non-owners, education and income were significant predictors (Table 5). Having a graduate or professional degree and a yearly household income of $40,000 or greater were associated with a higher percentage of correct responses. There was no difference in percent correct between non-owners in the $40,000 to $74,999 income group and those in the $75,000 or greater income group, $t(152.6) = 0.36$, $p = .7$.

Table 5. Results of regression models predicting percent correct for owners and non-owners in Study 1. Significant ($p < .05$) and marginally significant ($p < .1$) results are in bold.

	Estimate	Standard Error	*t*-value	*p*-value
Owners, $R^2 = .26$, $F(9, 80) = 3.16$, $p = .003$				
Intercept	**59.54**	**11.12**	**5.36**	**< .001**
Number of Learning Methods	0.27	0.87	0.31	.76
Technology Familiarity	-0.39	1.03	-0.38	.71
Education (High school, college, or some postsecondary degree)				
Bachelors, graduate, or professional degree	4.55	3.49	1.30	.20
Graduate or professional degree	4.94	3.68	1.34	.18
Income (less than $75,000)				
$75,000 or greater	**5.99**	**2.72**	**2.20**	**.03**
Age	**-0.28**	**0.12**	**-2.33**	**.02**
Sex (Female)				
Male	-6.63	8.94	-0.74	.46
Age x Sex	**0.45**	**0.24**	**1.91**	**.06**
Experience (Lower)				
Higher	1.42	3.16	0.45	.65
Non-owners, $R^2 = .09$, $F(8, 243) = 2.83$, $p = .005$				
Intercept	**38.34**	**6.18**	**6.21**	**< .001**
Number of Learning Methods	0.01	0.72	0.02	.99
Technology Familiarity	0.17	0.68	0.25	.80
Education (High school, college, or some postsecondary degree)				
Bachelor's degree	0.75	2.09	0.36	.72
Graduate, or professional degree	**7.76**	**2.62**	**2.97**	**.003**
Income (less than $40,000)				
$40,000 to $74,999	**7.25**	**2.24**	**3.23**	**.001**
$75,000 or greater	**5.95**	**2.43**	**2.45**	**.01**
Age	-0.04	0.07	-0.57	.57
Sex (Female)				
Male	1.09	1.91	.57	.57

Notes: For categorical variables, the reference level is shown in parentheses. Higher experience = used ACC most of the time or almost every time they drove, lower experience = used ACC rarely or sometimes.

Higher income and higher education have been found to be associated with greater interest in and more positive attitudes towards automated vehicles, respectively (Liljamo, Liimatainen, & Pöllänen, 2018; Spurlock et al., 2019). The better performance of higher income owners and higher income and higher education non-owners on the knowledge questionnaire may be due, in part, to an increased interest in ACC technology and subsequently seeking out more information about it. However, Spearman rank correlations showed that for owners, income was not related to number of learning methods used. For non-owners, higher income had a marginally significant ($\rho = 0.12$, $p = .054$) association with using more learning methods, but it was not a strong effect. In addition, there was not a significant relationship between education and number of learning methods. It is also possible that participants with higher education or income did not use more learning methods but sought out more information from a given source (e.g., read more of the details from an owner's manual), which resulted in a better understanding of the system. Alternatively, the better performance of higher income and higher education individuals may reflect that the available information about ACC is not accessible to all drivers. As ACC becomes more commonly available, the barrier of cost is reduced. However, if training or marketing materials are created such that only young drivers or drivers who are highly educated or have a high income can understand how to use ACC safely, the benefits of ACC may not be experienced by drivers who do not fit these demographics. Future research should focus on developing training materials to be easy to understand for all segments of the population, so that drivers do not need to be young, highly educated, or have a higher income to understand how ACC works and benefit from this technology.

2.2.2. ADAS Knowledge

2.2.2.1. Driver Misperceptions

As previously discussed (Section 2.2.1), non-owners and owners had similar misperceptions about ACC. While most participants knew what the purpose of the system is and that dirty or blocked sensors may cause a problem, a large percentage of both non-owners and owners did not correctly identify many of the other ACC limitations. Further, those who did not answer correctly often answered incorrectly (i.e., they thought ACC would not have difficulty in these situations or that ACC had full braking power) as opposed to answering "I don't know", indicating that many participants were overestimating the system's capabilities.

Figure 9 shows that responses from owners and non-owners were also similar for LKA items. Most participants knew the main function of LKA and that it had difficulty when sensors were blocked/dirty. Compared to ACC, more participants were aware of some of the LKA limitations, for example, that it has difficulty when the road is covered in snow/sand or that it has difficulty when lane markings are faded or missing. However, there were still some common misperceptions among a large portion of participants. For example, many participants thought that LKA would not have difficulty in the presence of glare, which is a limitation of LKA systems due to their use of cameras. In addition, 35% of non-owners and 37% of owners incorrectly thought that LKA executed evasive steering maneuvers, another example of participants overestimating ADAS capabilities.

Owners and non-owners also had a similar level of knowledge based on their confidence weighted scores. For ACC, non-owners and owners had an average score of 53.3% ($SD = 7.8$) and 55.7% ($SD = 9.3$), respectively. For LKA, non-owners had an average confidence weighted score of 54.5% ($SD = 9.0$), while owners had a confidence weighted score of 55.9% ($SD = 10.5$). We statistically compared owners and non-owners based on the confidence weighted scores for items that had the same correct response across all vehicles (thus responses would be the same for owners and non-owners). There was no significant difference between owners and non-owners for ACC, $t(139.8) = 1.38$, $p = .2$, or LKA, $t(87.7) = -0.21$, $p = .8$.

Overall, the survey results indicate that owners do not have a better understanding of system limitations compared to non-owners. Previous research showed that limitations that were learned from an owner's manual were forgotten over time if drivers did not encounter them (Beggiato et al., 2015). A survey of Tesla Autopilot users found that 62% of drivers experienced at least one "unexpected or unusual behaviour" while using Autopilot (Dikmen & Burns, 2016). However, only 14% reported experiencing two or more unexpected or unusual behaviours, suggesting that experiencing a system limitation or malfunction may be a relatively rare event. Thus, even if owners in our sample initially learned about ACC and LKA limitations, this knowledge may have been lost over time due to limited firsthand experience of limitations. Further, when drivers do experience unexpected system behaviour, they may not be aware of why the unexpected behaviour occurred enabling them to link the occurrence to a specific limitation. These findings highlight that experience with ACC and LKA does not appear to be sufficient for supporting drivers' knowledge of ADAS limitations.

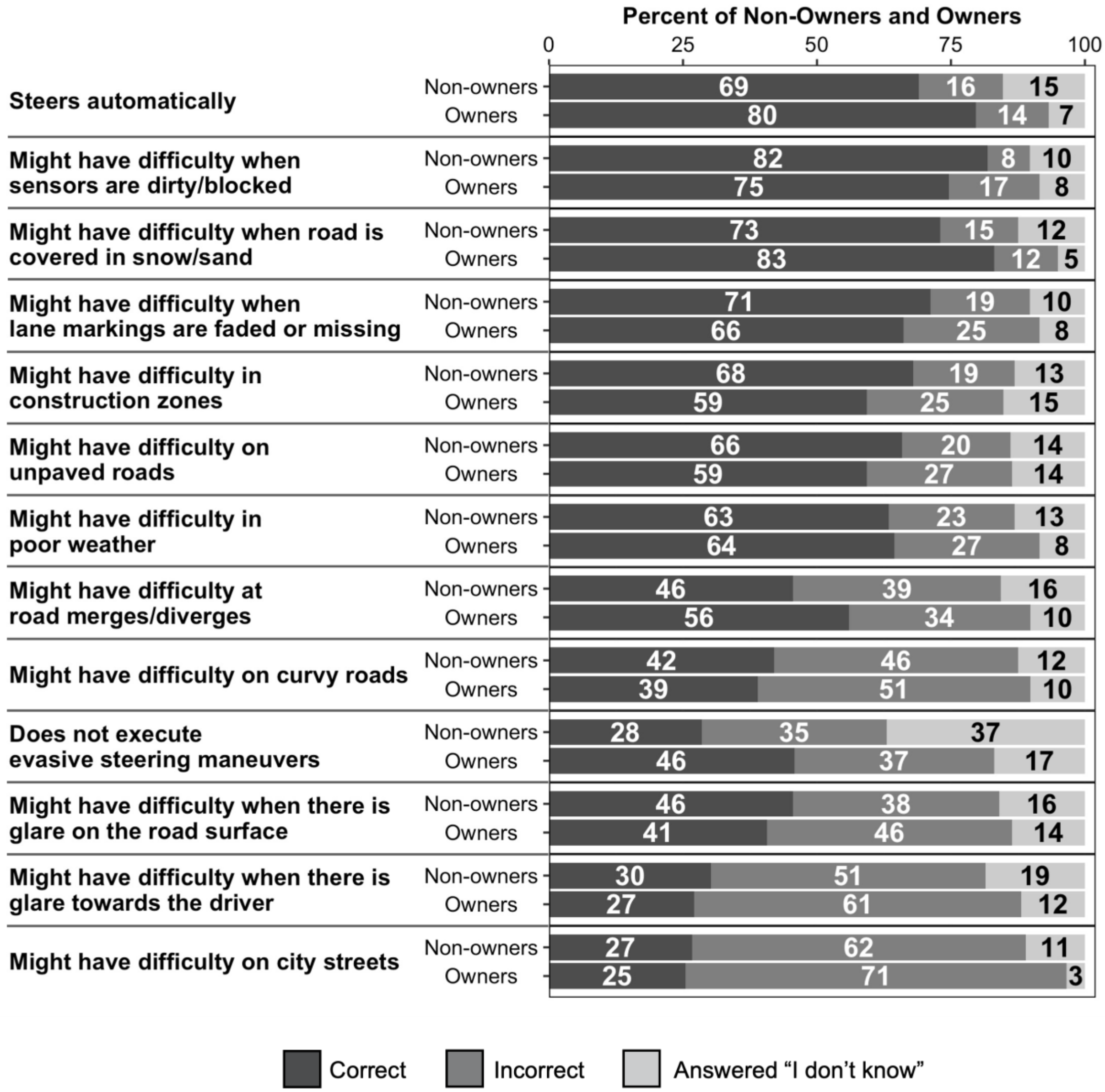


Figure 9. Percent of non-owners and owners who answered correctly, incorrectly, and “I don’t know” for a subset of LKA knowledge items in Study 1. For the figure, items were recoded to be true statements.

2.2.2.2. To What Extent Do Drivers Overestimate ADAS?

To further explore the extent to which participants were overestimating ACC and LKA, individual ACC and LKA knowledge items were also categorized as overestimate or underestimate items. Overestimate items were those for which an incorrect response would indicate an overestimation of the system (e.g., ACC does not have difficulty in poor weather), whereas underestimate items were those for which an incorrect response would indicate an underestimation of the system (e.g., ACC does not work on highways). Some of the feature items (e.g., relating to how to engage/disengage the system) were not considered overestimate or underestimate items and were left out of this analysis.

We calculated the percent of underestimate and overestimate items that each person answered incorrectly and the average confidence in these incorrect responses (see Figure 10). Participants were fairly confident in their incorrect responses, with average confidence ranging from 4.5 to 5.6 (with 7 corresponding to "full confidence"). Participants answered less than 25% of the underestimate items incorrectly, as opposed to 39-45% of the overestimate items, suggesting that participant misperceptions of ACC and LKA were more frequently overestimations. Overestimating system capabilities is of particular concern because it may lead to drivers over-relying on ADAS, which has been a contributing factor to several collisions that have occurred while ADAS was engaged (e.g., NTSB, 2020).

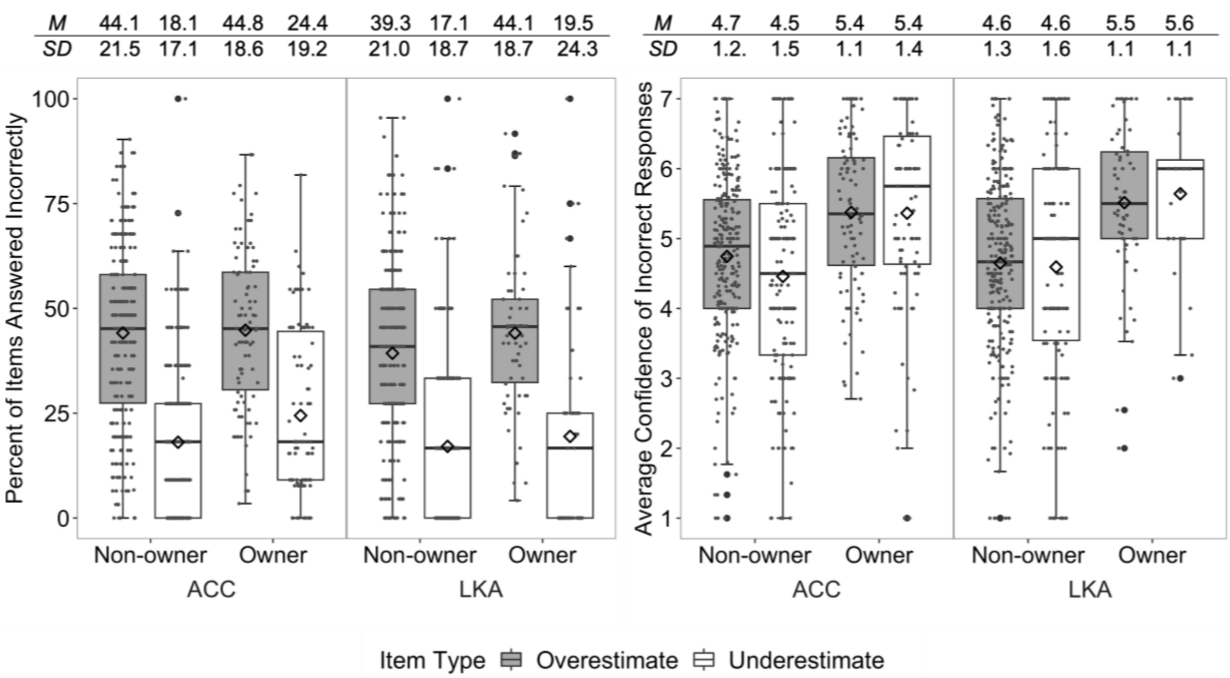


Figure 10. Proportion of incorrect overestimate and underestimate items (left) and average confidence for the incorrect overestimate and underestimate items (right) in Study 1. Boxplots represent the five-number summary, the diamond indicates the mean. At the top, mean (*M*) and standard deviation (*SD*) values are provided.

2.2.2.3. Signal Detection Theory Measures

Figure 11 shows the receiver operating characteristic curves (averaged across participants) and the corresponding AUCs. Inspection of the plots shows that participants' sensitivity was higher for LKA than ACC, which is consistent with our findings from the individual survey items showing that participants were more aware of some of the LKA limitations compared to ACC limitations (i.e., Figures 3 and 9). However, consistent with the findings for confidence weighted scores, owners and non-owners did not differ in their sensitivity (Table 6). In other words, owners were not better able to distinguish the actual ACC and LKA capabilities from other items in the knowledge questionnaire. However, ACC owners were significantly different from non-owners in their response bias (Table 6). Owners were biased towards saying "Yes" (indicated by the negative *c* value), indicating that they were more inclined to respond that ACC was capable for any given item regardless of whether it was true or not. Non-owners on the other hand, had a bias towards saying "No" (indicated by the positive *c* value), indicating that they had an overall inclination to report that the system was not capable. For LKA, both owners and non-owners had a response bias towards saying "Yes", but owners had a significantly larger bias (see Table 6). In combination with the earlier results, these results suggest that not only is experience insufficient for learning ADAS limitations, but it is also associated with having a positively biased view of the system. To the best of our knowledge, previous surveys on drivers' knowledge of system capabilities have not separated sensitivity from response bias. Given that these measures captured differences in our groups (i.e., owners and non-owners differed in their response bias but not in their sensitivity), it may be a valuable approach to explore for future surveys.

Table 6. Comparison of sensitivity and bias between owners and non-owners in Study 1. Significant ($p < .05$) results are in bold.

	***t*-value**	***DF***	***p*-value**	**Owner *M* (*SD*)**	**Non-owner *M* (*SD*)**
ACC Sensitivity (AUC)	-1.55	149.1	.12	0.62 (0.14)	0.59 (0.12)
LKA Sensitivity (AUC)	0.29	83.4	.77	0.64 (0.15)	0.64 (0.13)
ACC Bias (*c*)	**3.14**	**252.8**	**.002**	**-0.10 (0.47)**	**0.10 (0.72)**
LKA Bias (*c*)	**2.45**	**135.8**	**.02**	**-0.27 (0.58)**	**-0.05 (0.90)**

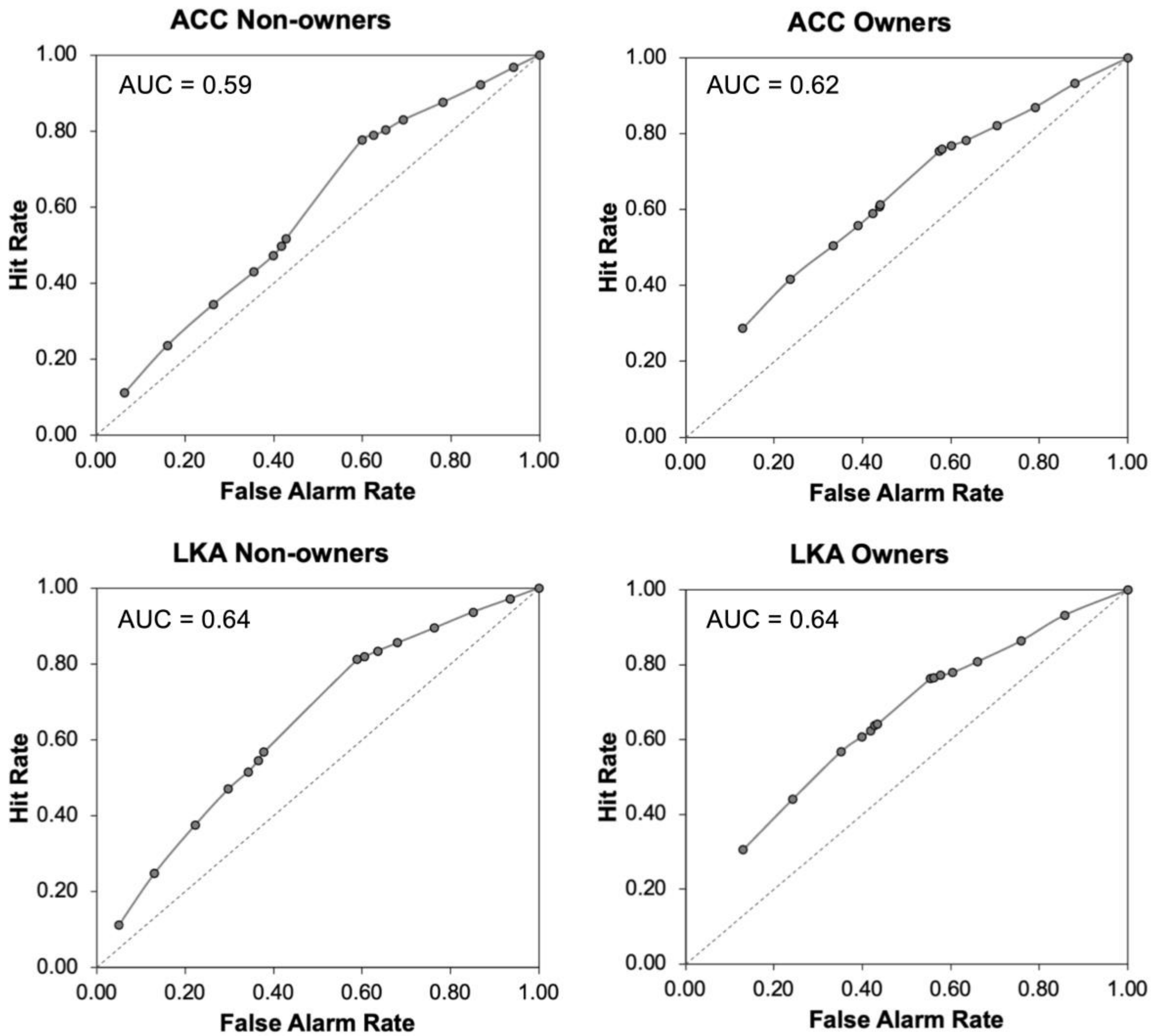


Figure 11. Receiver operating characteristic curves and AUCs, averaged across participants within each group (i.e., ACC non-owners, ACC owners, LKA non-owners, LKA owners) in Study 1. Dots represent hit-false alarm pairs at each possible response level. The leftmost point is the hit-false alarm pair for a response of "Yes" with a confidence rating of 7, the next 6 points are for "Yes" responses with confidence ratings from 6 to 1, followed by "I don't know", and then the hit-false alarm pairs for "No" responses with confidence ratings of 1 up to 7. For more detail about plotting receiver operating characteristic curves with confidence rating data, see Macmillan and Creelman (2005) and Stanislaw and Todorov (1999).

2.2.3. Trust

Trust items were rated on a scale from 1 (strongly disagree) to 5 (strongly agree), with 3 corresponding to "neither agree nor disagree". Inspection of the raw data (Figure 12) suggests that respondents tend to trust ACC and LKA, as the average trust was above 3. In addition, ACC and LKA owners had higher trust in ACC and LKA, respectively, compared to non-owners who had never used the system (ACC, $t(355) = 3.52$, $p < .001$; LKA, $t(347) = 5.47$, $p < .001$). These results are consistent with previous studies showing that experience with ACC and LKA, either as a driver (Beggiato et al., 2015) or passenger (Nylen, Reyes, Roe, & McGehee, 2019), was associated with higher trust in these systems.

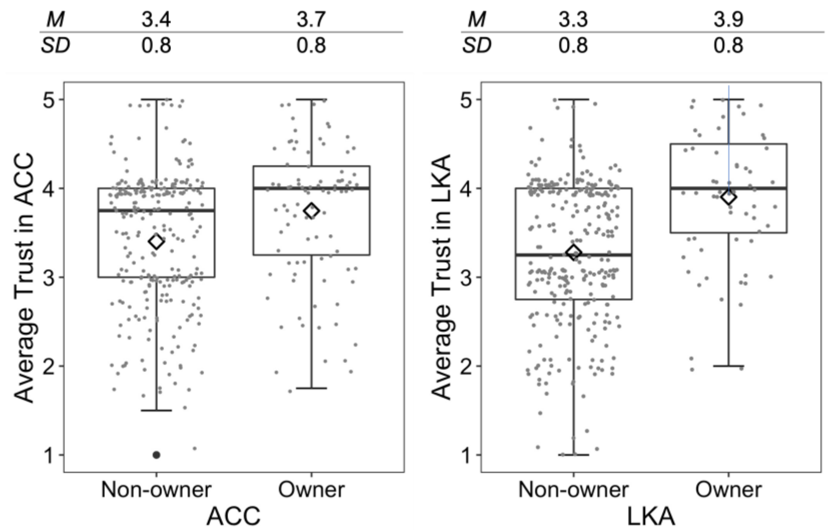


Figure 12. Average trust in ACC and LKA for owners and non-owners in Study 1. Trust items were rated on a scale from 1 (strongly disagree) to 5 (strongly agree), thus higher average values indicate higher trust. Boxplots represent the five number summary, the diamond indicates the mean. At the top, mean (*M*) and standard deviation (*SD*) values are provided.

2.2.3.1. What Factors Predict Trust in ACC and LKA?

For non-owners, sensitivity predicted trust in ACC and LKA (see Table 7). Higher sensitivity in detecting ACC and LKA capabilities was associated with lower trust in ACC and LKA, respectively. Conversely, lower sensitivity was associated with higher trust. Response bias also significantly influenced trust, with participants who were more biased towards responding “Yes” (i.e., endorsing the system capabilities) having higher trust. Thus, in the absence of firsthand experience with ACC and LKA, drivers’ trust in these systems is influenced by their knowledge of specific system capabilities and limitations and response bias that was captured in the knowledge questionnaire. Among the other predictors, the number of learning methods used and technology familiarity significantly predicted trust in ACC and LKA (see Table 7). Having used more learning methods and having higher technology familiarity were associated with higher trust in ACC. When non-owners who have never used ACC or LKA learned about ADAS, they may have learned basic information like the purpose of the systems and their capabilities. This initial knowledge may have served to increase their trust. Those with higher technology familiarity may have an overall higher propensity to trust technology, including ADAS. None of the other demographic variables (age, education, or income) had a significant impact on trust.

For owners, neither sensitivity nor bias were significantly associated with trust (Table 8). The correlation between AUC and trust for non-owners was -0.29 for ACC and -0.17 for LKA. Power analysis indicated that 26 participants would be needed to detect the ACC effect, and 74 participants would be needed to detect the LKA effect, based on 80% power and a significance level of .05. Thus, our sample size was large enough for 80% power for ACC and LKA non-owners and ACC owners, but not for LKA owners. For LKA owners, number of learning methods and technology familiarity were significant predictors of trust (Table 8). Similar to the results for non-owners, higher technology familiarity was associated with higher trust. However, in contrast to the non-owner findings, using more learning methods was associated with lower trust. This finding may be due to differences in the reason why owners search for information about ADAS. It may be the case that owners search for information about their system after experiencing unexpected system behaviour. In doing so, they may find out more about the system limitations, which in turn, lowers their trust. Further research could explore not only how drivers learn about ADAS but why they search for information and what information they search for to further investigate the relationship between learning methods and trust.

For ACC owners, age was a significant predictor of ACC trust and higher experience was marginally significant (Table 8). Older age was associated with higher trust and a higher experience level (using ACC most of the time or almost every time they drove) was associated with lower trust. Using ADAS more frequently may lead to drivers experiencing more unexpected system behaviour (even if they cannot attribute it to a specific capability/limitation in the questionnaire), which may increase their awareness that ADAS is not always reliable and impact their trust. It is possible that experience was marginally significant for ACC but not LKA due to participants' knowledge of system limitations. As discussed previously (Section 2.2.2.1, Figures 3 and 9) more participants were aware of some of the LKA limitations, such as its limited capability when lane markings are faded or missing. This awareness may have mediated the effect of experiencing system failures on LKA trust. Prior research has shown that if participants are aware of system limitations, their trust may be less negatively affected when they encounter these limitations (Beggiato & Krems, 2013). However, it should be noted that our sample size of owners (particularly LKA owners) was relatively small and thus we may not have had sufficient power to detect an effect of experience on trust for LKA owners. For ACC owners, the difference in trust between those with higher and lower experience was approximately 0.45 (on a scale of 1 to 5). Power analysis indicated that a sample size of 47 participants per group (higher and lower experience) would be needed to detect this effect with 80% power at $p < .05$. While our sample of ACC owners was overall large enough ($N = 94$), a group imbalance (higher experience = 27, lower experience = 67) resulted in a power of 71%. Future work with a larger sample of owners is needed to confirm our results and explore the reasons for the different influencing factors on ACC and LKA trust.

Table 7. Results for regression models predicting trust for non-owners in Study 1. Significant ($p < .05$) results are in bold. For categorical variables, the reference level is shown in square brackets.

	Estimate	**Standard Error**	***t*-value**	***p*-value**
ACC, Non-owners: $R^2 = .26$, $F(9, 250) = 9.64$, $p < .001$				
Intercept	**3.21**	**0.38**	**8.50**	**< .001**
Sensitivity (AUC)	**-1.58**	**0.37**	**-4.24**	**< .001**
Bias (*c*)	**-0.23**	**0.06**	**-3.61**	**< .001**
Number of Learning Methods [0-1]				
2+	**0.32**	**0.10**	**3.28**	**.001**
Technology Familiarity	**0.13**	**0.03**	**3.86**	**< .001**
Education [High school, some postsecondary, or college degree]				
Bachelor's degree	-0.06	0.10	-0.60	.55
Graduate or professional degree	0.02	0.13	0.18	.85
Age	0.00	0.00	0.37	.71
Income [less than $40,000]				
$40,000 to $74,999	0.08	0.11	0.78	.44
$75,000 or greater	-0.05	0.12	-0.46	.64
LKA, Non-owners: $R^2 = .18$, $F(9, 274) = 6.89$, $p < .001$				
Intercept	**3.24**	**0.38**	**8.45**	**< .001**
Sensitivity (AUC)	**-1.38**	**0.35**	**-3.97**	**< .001**
Bias (*c*)	**-0.21**	**0.05**	**-4.10**	**< .001**
Number of Learning Methods [0-1]				
2+	**0.30**	**0.10**	**3.03**	**.003**
Technology Familiarity	**0.11**	**0.03**	**3.44**	**< .001**
Education [High school, some postsecondary, or college degree]				
Bachelor's degree	0.05	0.10	0.55	.59
Graduate or professional degree	0.05	0.13	0.42	.67
Age	-0.00	0.00	-0.56	.58
Income [less than $40,000]				
$40,000 to $74,999	-0.01	0.11	-0.13	.89
$75,000 or greater	-0.12	0.12	-1.00	.32

Table 8. Results for regression models predicting trust for owners in Study 1. Significant ($p < .05$) and marginally significant ($p < .1$) results are in bold. For categorical variables, the reference level is shown in square brackets.

	Estimate	**Standard Error**	***t*-value**	***p*-value**
ACC, Owners: $R^2 = .19$, $F(9, 84) = 2.21$, $p = .03$				
Intercept	**3.35**	**0.83**	**4.02**	**< .001**
Sensitivity (AUC)	-0.89	0.62	-1.42	.16
Bias (*c*)	-0.29	0.18	-1.65	.10
Number of Learning Methods [1-2]				
3+	0.18	0.17	1.06	.29
Technology Familiarity	0.08	0.06	1.33	.19
Education [High school, some postsecondary, or college degree]				
Bachelor's degree	-0.19	0.22	-0.85	.40
Graduate or professional degree	-0.11	0.22	-0.53	.60
Age	**0.01**	**0.01**	**2.03**	**.046**
Income [less than $75,000]				
$75,000 or greater	0.03	0.17	0.20	.84
Experience [Lower]				
Higher	**-0.37**	**0.19**	**-1.95**	**.054**
LKA, Owners: $R^2 = .16$, $F(9, 52) = 1.08$, $p = .39$				
Intercept	**2.70**	**1.07**	**2.51**	**.02**
Sensitivity (AUC)	-0.42	0.79	-0.53	.60
Bias (*c*)	-0.27	0.20	-1.35	.18
Number of Learning Methods [1-2]				
3+	**-0.45**	**0.22**	**-2.04**	**.047**
Technology Familiarity	**0.18**	**0.08**	**2.17**	**.03**
Education [High school, some postsecondary, or college degree]				
Bachelor's degree	-0.00	0.29	-0.01	.996
Graduate or professional degree	0.10	0.28	0.37	.72
Age	0.01	0.01	0.82	.42
Income [less than $75,000]				
$75,000 or greater	-0.21	0.23	-0.91	.37
Experience [Lower]				
Higher	-0.25	0.21	-1.16	.25

While demographic factors (e.g., age, income) predicted the percent of correct responses on the ACC knowledge questionnaire for owners and non-owners, the only demographic factor that significantly impacted trust was age for ACC owners. Thus, our results suggest that demographic factors may not directly influence trust but may indirectly affect trust through their impact on knowledge.

2.2.4. Reliance Intention

Based on inspection of the raw data (see Figure 13), at all ADAS levels, drivers were more likely to engage in secondary tasks that are legal in most jurisdictions (e.g., Ontario Ministry of

Transportation, 2019) such as talking to passengers, eating, and making phone calls and texting using voice control. Responses were highly variable, but for most secondary tasks, the average likelihood appears to increase from no ADAS to LKA only to ACC only to both ACC and LKA.

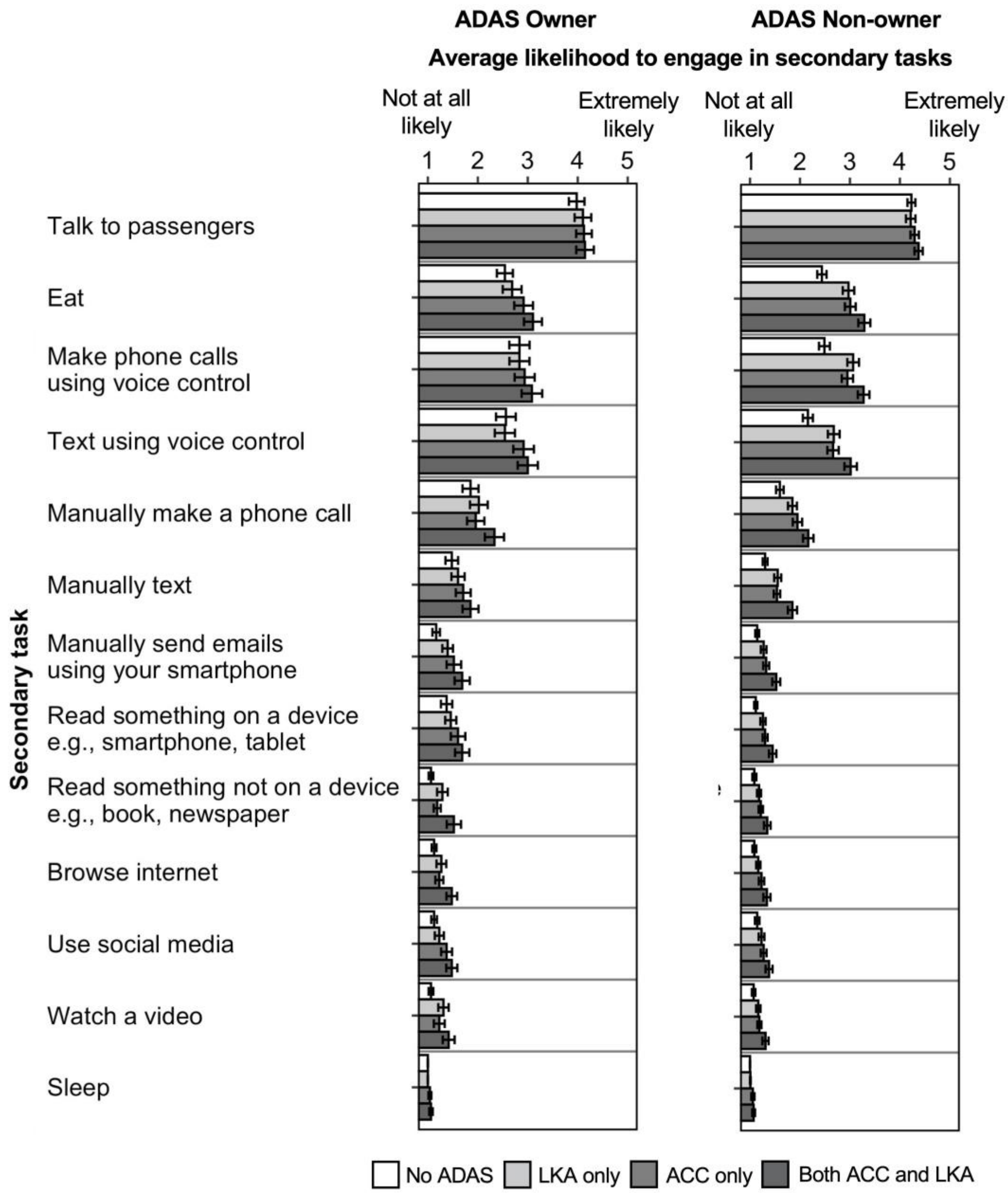


Figure 13. Average likelihood to engage in secondary tasks by ADAS condition in Study 1: 1 = not at all likely, 2 = slightly likely, 3 = moderately likely, 4 = very likely, 5 = extremely likely. Error bars represent standard error.

For both ADAS owners and non-owners, AUC and bias did not significantly improve the reliance intention model that already included ADAS condition and trust as predictors (determined through likelihood ratio tests), thus they were not included in the final models. For non-owners, using LKA only, ACC only, and both systems together were each associated with higher self-reported likelihood to engage in secondary tasks compared to driving with no ADAS (Table 9). In addition, higher average trust in ACC and LKA was associated with a higher average likelihood to engage in secondary tasks while driving. For owners, using ACC only and ACC and LKA together were associated with higher self-reported likelihood to engage in secondary tasks, but there was no significant difference between using LKA only and no ADAS. Higher average trust was also associated with a higher average likelihood to engage in secondary tasks, but the effect was only marginally significant (Table 9), potentially due to sample size limitations.

Table 9. Results for linear mixed models predicting reliance intention in Study 1; significant ($p < .05$) and marginally significant ($p < .1$) results are in bold. For ADAS condition, the reference level is indicated in square brackets.

	Estimate	**DF**	**Standard Error**	***t*-value**	***p*-value**
ADAS Non-owners ($N = 150$)					
Intercept	**1.22**	**447**	**0.18**	**6.87**	**< .001**
ADAS condition [no ADAS]					
LKA only	**0.21**	**447**	**0.03**	**6.42**	**< .001**
ACC only	**0.24**	**447**	**0.03**	**7.24**	**< .001**
ACC and LKA	**0.42**	**447**	**0.03**	**12.94**	**< .001**
Average Trust	**0.14**	**148**	**0.05**	**2.71**	**.008**
ADAS, Owners ($N = 43$)					
Intercept	**1.07**	**126**	**0.39**	**2.72**	**.008**
ADAS condition [no ADAS]					
LKA only	0.11	126	0.07	1.68	.10
ACC only	**0.23**	**126**	**0.07**	**3.41**	**< .001**
ACC and LKA	**0.34**	**126**	**0.07**	**5.04**	**< .001**
Average Trust	**0.20**	**41**	**0.11**	**1.90**	**.06**

While these results reflect self-reported intention to engage in secondary tasks while driving, they are consistent with findings from on-road and simulator studies. In an on-road study, Naujoks, Purucker, and Neukem (2016) found that participants who had experience with ACC engaged more in secondary tasks when using ACC or ACC and LKA together than when driving with no automation. In a simulator study, Körber et al. (2018) found that participants with higher trust in an automated driving system spent more time looking at a secondary task while the automation was engaged. In the current study, neither sensitivity nor bias had a significant impact on reliance intention. However, for non-owners these measures may have an indirect influence on reliance intention through their association with trust.

2.2.5. Limitations and Future Work

As described in Section 2.1.1, approximately 25% of the original data collected was excluded based on reliability checks. The trade-off between sample size and quality is an inherent limitation of crowdsourced data collection. Although others have used similar data collection methods (e.g., Ayoub et al., 2021; Rahman et al., 2018) and research suggests advantages of such an approach (e.g., Walter et al., 2019), future work could explore the use of in-person assessments with fewer participants to obtain qualitative data and reduce data loss. Although we attempted to remove participants with unreliable data, self-report data is still subject to bias. For example, we were not able to verify that the owners actually owned the vehicle that they reported owning or that they had used ACC and LKA, and participants' actual likelihood to engage in secondary tasks while using ADAS may be higher than their reported intention to engage in secondary tasks. While the trends found in our results are consistent with previous work, future research could confirm our results with behavioural data. In addition, our knowledge questionnaires had an uneven number of signal present and signal absent items, which may have affected our estimates for the signal detection theory measures. Future surveys could systematically control this parameter to confirm our findings with regards to sensitivity and bias. Finally, our sample consisted of participants from the U.S. and Canada. Further research is needed to explore whether similar results would be found in other populations.

2.3. Summary and Conclusions

We conducted a survey study with the primary objective of assessing knowledge and trust of ACC and LKA among owners and non-owners and investigating the relationship between knowledge and trust. Our secondary objective was to explore how knowledge and trust impacted reliance intention. The main conclusions are listed below:

1. Current ACC owners may have better knowledge of ACC limitations than owners 6+ years ago.
2. Lower age, higher education, and higher income level are associated with better knowledge of ACC.
3. For owners, learning about ADAS through trial-and-error was associated with better knowledge of ACC limitations.

4. However, owning a vehicle with ACC or LKA does not appear to result in a better understanding of system limitations.
5. For both owners and non-owners, participants tended to overestimate ADAS more than underestimate it.
6. Prior to system use (i.e., for non-owners, who had no experience with ACC or LKA), knowledge of specific capabilities/limitations and response bias affects trust, which in turn, affects reliance intention.
7. Once drivers have experience with the system (i.e., owners in our sample), knowledge of specific system capabilities/limitations and response bias do not have a significant influence on trust.
8. For ACC owners, using the system more frequently is related to lower trust, which in turn was associated with a lower reported likelihood to engage in secondary tasks.
9. Using LKA more frequently was not associated with lower trust, potentially due to the fact that participants were more aware of some of the common limitations, which reduced the negative impact of system failures on trust.

Our results suggest that as ACC continues to become more common in consumer vehicles, owners may be becoming more aware of some of its main limitations. However, a large portion of owners still have misperceptions about their system which could lead to overreliance and have dangerous consequences. Our results also suggest that the informational materials currently available are not effective in improving drivers' knowledge of ACC, as the only learning method that was significantly associated with a better understanding of ACC was trial and error (although we could not isolate its individual effect among the other learning methods used). While trial and error may be associated with better knowledge of ACC among owners, non-owners who have never used ACC before had a similar level of knowledge about system limitations. Further research is needed to understand the relationship between experience with the system and ACC knowledge. However, learning by trial and error does not address risks in the early stages of use, thus additional training and education methods are required to support drivers' early interactions with ACC. Our results suggest that lower age, higher education, and higher income level are associated with better knowledge of ACC. These findings highlight the need to develop better training materials to make the technology more accessible, so that all drivers can benefit from safe use of ACC.

Although we have identified limitations that many drivers are unaware of, our findings suggest that it may be beneficial to shift efforts away from trying to train drivers on all the specific limitations of a system. Owners' knowledge of these limitations was not found to influence trust, and while knowledge of specific capabilities and limitations appears to be beneficial for non-owners, awareness that the system is fallible may be sufficient to support their initial interactions with ADAS. Further, it is impractical to expect drivers to learn and remember all possible limitations. A more feasible training/education strategy may be the responsibility-focused approach, which focuses on improving drivers' overall understanding of the fallibility of ADAS and reinforcing how they should be using ADAS (e.g., their role when using these systems). Future research should investigate the use of this approach to support appropriate trust in and reliance on ADAS.

Chapter 3
Study 2: Online Study Comparing the Responsibility-Focused and Limitation-Focused Training Approaches

This chapter presents the results of a remote face-to-face study, which was conducted to explore the feasibility of the responsibility-focused training approach. Videos were chosen as the training delivery method because they are easy to distribute and the results of Study 1 and other previous research (Abraham et al., 2017) show that videos are one of the preferred ADAS training methods among drivers. Given potential differences in the effects of ADAS system knowledge for drivers with and without ADAS experience (results of Study 1; also Bianchi Piccinini et al., 2015), we collected data from participants with and without experience using ACC and LKA. We collected quantitative data (e.g., from questionnaires) as well as asked participants open-ended questions about the effects of the training and their opinions of the training. Our primary objectives were to investigate whether the responsibility- and limitation-focused training differed in their effects on knowledge, trust, and reliance intention, and whether any potential effects lasted several weeks after the training. Through the open-ended questions, we aimed to gain additional insight into how the different training approaches may affect driver perceptions of ADAS (i.e., their interest in using the technologies and their attitudes toward them) and how drivers intend to use ADAS. We also wanted to obtain feedback about the training from target users (i.e., what they found helpful, what they liked, and suggestions to improve the training) to inform the design of future ADAS training. The contents of this chapter have been published in *Accident Analysis and Prevention* (DeGuzman & Donmez, 2022) and *Transportation Research Record* (DeGuzman, Ayas, & Donmez, 2023).

3.1. Materials and Methods

A remote face-to-face video-based study was conducted, with training approach (limitation-focused, responsibility-focused) and ADAS experience (experienced, no experience) as between-subjects variables, resulting in four experimental groups (Table 10). In terms of ADAS experience, for the experienced group, we recruited participants who had used ACC and LKA five or more times, and for the no experience group, we recruited those who had never used ACC or LKA. Five times was used as the threshold for the experienced group based on previous research showing that trust, acceptance, and self-reported learning for ACC stabilized after approximately five drives (Beggiato et al., 2015).

Table 10. Participant demographics by experimental group in Study 2

	Limitation-focused video		Responsibility-focused video	
	Experienced	**No experience**	**Experienced**	**No experience**
N	16 (8M, 8F)	16 (8M, 8F)	15 (7M, 8F)	15 (7M, 8F)
Age (*M, SD*)	33.9, 12.0	34.1, 15.3	32.4, 8.0	36.2, 11.0
ACC Experience (*N*)				
Used 5-10 times	6	NA	2	NA
Used more than 10 times	10	NA	13	NA
LKA Experience (*N*)				
Used 5-10 times	5	NA	5	NA
Used more than 10 times	11	NA	10	
Completed Follow-up Session (*N*)	14 (6M, 8F)	16 (8M, 8F)	15 (7M, 8F)	15 (7M, 8F)

Each participant completed two sessions conducted over Zoom, which were recorded and transcribed. Data was collected before and after training in the first session and again at a follow-up session at least four weeks later (range: 4-9 weeks, M = 5.1 weeks; see Figure 14 for an overview of the experimental procedure). Thus, the study had a 2x2x3 mixed design, with training approach and ADAS experience being between-subjects variables with two levels each, and study stage being a within-subjects variable with three levels (pre-training, post-training, and follow-up). At each stage, participants viewed a series of dashcam clips and completed several questionnaires (Figure 14). They also answered open-ended questions as part of a semi-structured interview at the end of stages 2 (post-training) and 3 (follow-up), which took approximately 15-20 minutes in the first session and 5 minutes in the follow-up session. Overall, the first session took approximately 90 minutes, while the second session took approximately 30 minutes. Participants were compensated C$25 (Canadian dollars) for the first session and C$10 for the follow-up session. The study was approved by the University of Toronto’s Research Ethics Board.

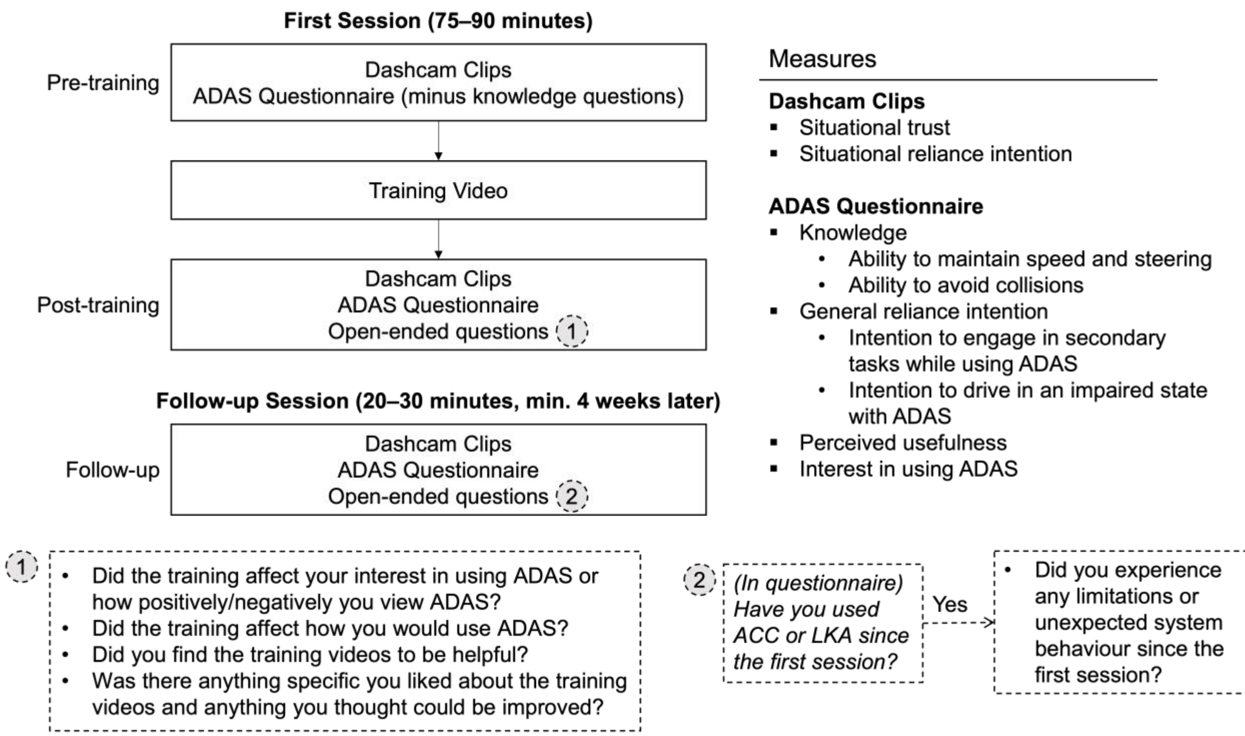


Figure 14. Overview of experimental procedure for Study 2

3.1.1. Participants

Participants were recruited through online postings (e.g., Facebook) and emails to our laboratory's mailing list consisting of individuals who had previously indicated they would like to be contacted about upcoming studies. All participants were required to be Canadian residents with a valid driver's license. Individuals who were interested in participating were invited to fill out a screening questionnaire and eligible participants were contacted to schedule the study sessions.

Sixty-five participants completed the first session. Three participants were excluded from all analyses because they completed the questions in a time frame that suggested that they did not read and understand the questions, their responses indicated that they did not understand the questions, or they reported having ADAS experience in the screening questionnaire but indicated during the study that they had never used ACC or LKA. Of the 62 remaining participants, 60 completed the follow-up session. One additional participant (a man with ADAS experience in the limitation-focused group) was excluded from the analysis of the dashcam clips and ADAS questionnaire because his responses on these measures indicated that he did not understand the questions. Participant demographics by group can be found in Table 10; demographic questions can be found in Appendix D.

3.1.2. Training Videos

Each training video was around 8 minutes long and was split into two parts to reduce potential fatigue. Although the responsibility-focused video was designed to cover less information, both videos were designed to be the same length so that length of training was not a confounding factor. The content of the videos was based on ACC and LKA in the 2021 Toyota Corolla because Toyota was the most common vehicle make among ADAS owners in Study 1 (Appendix C). In part one of the training, both videos introduced ACC and LKA and gave a brief explanation of what each system did and how it worked (i.e., using camera and sensor input). Both videos also showed participants the range of the ACC sensor and where the LKA system was tracking lane markings (i.e., directly ahead). See Figure 15 for a link to the full training videos.

Part two of the limitation-focused video went through 20 situations where ACC may not work, followed by 21 situations where LKA may not work (see Figure 15 top image). An image accompanied each limitation, with 3-4 images on-screen at a time. In contrast, part two of the responsibility-focused video showed only two scenarios where the ACC and LKA may not work (see Figure 15 bottom image). Each scenario was shown twice, once with a depiction of what might happen if a driver was not paying attention while using ACC and LKA and once showing what might happen if they were paying attention. In the first scenario, a driver was looking down at their phone and a slower vehicle cut into the lane ahead of them. The driver did not see the vehicle changing into their lane and the vehicle was too close for the ACC to slow down in time, resulting in a collision. The scenario was then replayed, but with the driver paying attention. The video showed the driver noticing the slower vehicle changing into their lane and braking to avoid the collision. In the second scenario, a collision resulted from the driver looking at their phone and not noticing their vehicle drift into another lane due to missing lane markings. The scenario was replayed with the driver paying attention to the roadway, noticing the vehicle drift out of the lane, and taking over control of the steering wheel to maintain their lane position. The scenarios for the responsibility-focused video were created using a combination of simulator recordings and driver-facing video from a real vehicle. Both training videos went through several rounds of updates based on feedback from researchers within and outside our research group.

Figure 15. Screenshots from part 2 of the limitation-focused video (top) and responsibility-focused video (bottom) in Study 2. Full videos can be found here: https://www.youtube.com/playlist?list=PL_mdfFo99cx6fPGDs_txWeere5H3rs2c1

3.1.3. Procedure

3.1.3.1. Dashcam Clips

Participants were shown clips from real dashcam footage both before and after watching their assigned training video, as well as during the follow-up session (see Figure 14). Overall, there were 16 dashcam clips repeated three times (before and after training video, and follow up), half of which were scenarios where the ADAS should be able to control speed and steering (no takeover scenarios), and half where there was an observable reason why the driver would need to take control of the speed and/or steering (takeover scenarios). The order of the 16 clips was randomized within the three stages and across participants.

Most of the clips (11 of 16) were from a database of YouTube-sourced dashcam clips that have previously been used for driver hazard perception studies (Wolfe, Seppelt, Mehler, Reimer, & Rosenholtz, 2020). Since the database was developed for research on hazard perception while driving without automation, five additional clips were sourced from YouTube dashcam videos that were related to ADAS-specific limitations. Participants were told that all clips were taken from drivers driving without ADAS to avoid potential learning effects from participants thinking they were seeing how the systems worked in various situations.

After watching each clip, participants were asked to verbally describe what they would do in that situation if they were using ACC and LKA (e.g., would they control speed and/or steering). Based on these responses, situational reliance intention was coded as either overreliance, underreliance, or appropriate reliance (see Table 11 for how reliance intention was coded for takeover and no takeover scenarios). Participants were not given feedback about whether any of their responses were correct or incorrect to avoid learning through trial-and-error, as our interest was in the effects of the training videos. Participants also rated their trust in ADAS in each scenario (on a 7-point scale from strongly disagree to strongly agree) as a measure of situational trust.

Table 11. Reliance intention coding for takeover and no takeover scenarios in Study 2. Square brackets indicate response according to signal detection theory framework, where the signal is "takeover required".

	Takeover scenarios	**No takeover scenarios**
Appropriate reliance	Taking control of speed and/or steering (depending on the scenario) [HIT]	Leaving the systems on [CORRECT REJECTION]
Overreliance	Letting ACC and LKA handle the situation [MISS]	Taking their hands off the wheel and/or paying less attention to the road*
Underreliance	Not applicable	Taking control of speed themselves or turning the ACC and/or LKA off [FALSE ALARM]

* Due to a small number of responses in this category (15 out of 1464 observations), this data was not included in the analysis

3.1.3.2. ADAS Questionnaire

Participants also completed an ADAS questionnaire which assessed their knowledge of ACC and LKA limitations, general reliance intention not tied to a specific scenario (i.e., self-reported likelihood to drive while engaging in secondary tasks or in an impaired state while using ADAS), perceived usefulness, and interest in using ADAS in the future (from not at all interested to extremely interested). The questionnaire (see Appendix E) was based on the Study 1 questionnaires and other recent work (Singer & Jenness, 2020).

The knowledge portion of the questionnaire was split into two sets of questions. The first set of questions were related to ADAS' ability to maintain speed and steering. Participants were given a list of situations and were asked to indicate, for each situation, whether or not they expected ACC and LKA to successfully control vehicle speed and keep the vehicle in its lane without the driver doing anything. The second set of questions were related to ADAS' ability to adjust speed and steering to avoid potential collisions. Participants were given a list of situations and were asked to indicate, for each situation, whether or not they expected ACC and LKA to brake and/or steer, without the driver doing anything. For both sets of questions, the response options were: "ACC and LKA definitely will work", "ACC and LKA probably will work", "ACC and LKA probably will not work", "ACC and LKA definitely will not work", and "I have no idea". Thus, the response options reflected participants' confidence in ADAS' ability in each situation. Similar to the dashcam clips, participants were not given feedback about whether any of their responses were correct or incorrect for the knowledge questions.

For general reliance intention, participants were presented with a list of situations that related to driving while engaging in secondary tasks (e.g., manually texting, watching a video) or driving while in an impaired state (e.g., while drowsy, after consuming alcohol). They were asked to rate how likely they would be to drive in each situation with no ADAS and with ADAS (from 1 = not at all likely to 5 = extremely likely). Likelihood was averaged across all situations for no ADAS and ADAS separately. General reliance intention reflected the change in likelihood from using no ADAS to ADAS, with responses split into two categories: likelihood would increase with ADAS, and likelihood would not increase with ADAS. To assess perceived usefulness, participants were asked to rate their agreement with the following statements (from 1 = strongly disagree to 7 = strongly agree): "I expect that ACC and LKA will reduce my stress", "I expect that ACC and LKA will increase my safety", "I expect that ACC and LKA will improve my physical comfort".

Like the dashcam clips, the ADAS questionnaire was completed twice in the first session (pre-training and post-training), and again in the follow-up session (see Figure 14). However, the knowledge questions were excluded from the pre-training questionnaire and presented after the dashcam clips at post-training so that when completing the dashcam clip sections throughout the first session, participants were not focusing specifically on aspects of the clips that were included in the knowledge questions.

3.1.3.3. Open-ended Questions

At the end of the first session and after having watched the videos, participants were asked several open-ended questions to further assess whether the training affected their interest in using ADAS or their attitudes toward the system, as well as if the training affected how they would use ADAS. Participants were also asked about their opinions of the training itself (i.e., if there was anything they found helpful, anything in particular they liked about the training, and any suggestions for improvement). During the questionnaire portion of the follow-up session, participants were asked if they had used ADAS since the first session. At the end of the follow-up session, participants who reported having used ADAS were asked if they experienced any system limitations or unexpected behaviour since the first session. For all open-ended questions, participants were first asked the general questions (found in Figure 14) without any additional prompts or context from the experimenter. After their initial response, the experimenter would provide clarification (e.g., if the participant did not understand the question) or prompt the participant for more detail (e.g., if the participant mentioned something that was unclear or would benefit from further explanation). In general, the experimenter avoided asking the participants leading questions so that participants' self-generated opinions were obtained. Sessions were recorded and transcribed within 4 weeks. Recordings were deleted after transcription.

3.1.4. Analysis

3.1.4.1. Dashcam Clips

Signal detection theory was applied to the situational reliance intention data so that participants' sensitivity (i.e., the extent to which they reported they would intervene in takeover scenarios but not intervene in no takeover scenarios) could be separated from potential response bias (e.g., Macmillan & Creelman, 2005). Sensitivity was measured using d', with higher values indicating better sensitivity. Criterion location (c) was used to measure bias, with negative values reflecting a negative bias (i.e., inclination to say that they would take manual control of the vehicle regardless of whether it was necessary). Throughout this chapter, reliance sensitivity will be used to refer to the situational reliance intention sensitivity measure, and reliance bias will be used to refer to the situational reliance intention bias measure. For the takeover scenarios (N = 1464), one response was not included in the analysis because reliance intention was not clear. For the no takeover scenarios (*N* = 1464), most of the scenarios that were not coded as appropriate were coded as underreliance (one response was unclear and 15 responses were coded as overreliance). Thus, for the no takeover scenarios, we focused on appropriate reliance and underreliance. The response mapping to the signal detection theory framework (e.g., hits, false alarms) can be found in Table 11. For situational trust, we calculated average trust for the takeover scenarios and no takeover scenarios by averaging the trust ratings for the eight takeover scenarios and the eight no takeover scenarios separately.

All four dependent variables (reliance sensitivity, reliance bias, trust in takeover scenarios, and trust in no takeover scenarios) were analyzed using mixed linear models, with training approach, ADAS experience, and study stage (pre-training, post-training, and follow-up) as fixed factors, and participant as a random factor with a compound symmetry variance-covariance matrix. Models were fitted using PROC MIXED in SAS OnDemand for Academics.

3.1.4.2. ADAS Questionnaire

Signal detection theory was also applied to the knowledge questionnaire data. For the knowledge data, sensitivity reflected participants' ability to identify true ADAS limitations and was measured using the area under the receiver operating characteristic curve (AUC). AUC was used because it can be applied to confidence rating scale data like the knowledge questionnaire responses in the current study (e.g., Macmillan & Creelman, 2005; Stanislaw & Todorov, 1999). Bias was measured using *c*. Throughout the paper, knowledge sensitivity and knowledge bias will be used to refer to the signal detection theory measures for the knowledge questionnaire data. Perceived usefulness was averaged across the three perceived usefulness items, with a higher average rating indicating higher perceived usefulness.

Mixed linear models (using PROC MIXED in SAS) were used to analyze the knowledge questionnaire (knowledge sensitivity, knowledge bias) and perceived usefulness data, with training approach, ADAS experience, and study stage as fixed factors, and participant as a random factor with a compound symmetry variance-covariance matrix. Because the knowledge questions were not shown at pre-training, study stage for the knowledge questionnaire models had only two levels (post-training and follow-up).

For general reliance intention, the dependent variable had two levels: likelihood of driving while engaging in secondary tasks or in an impaired state would increase with ADAS, and likelihood would not increase with ADAS. A binomial logit model was used to predict general reliance intention based on training approach, ADAS experience, and study design. Generalized estimating equations (GEE) were used to account for repeated measures. The model was fitted using PROC GENMOD in SAS OnDemand for Academics.

Finally, interest in ADAS at post-training and follow-up was compared to pre-training. At each stage (post-training and follow-up), participants' responses were categorized as either more interested compared to pre-training, no change in interest, or less interested. Thus, participants each had two data points, change in interest from pre-training to post-training and change in interest from pre-training to follow-up. Due to a limited number of responses in the "more interested after training" category, for analysis, the response categories were collapsed into: 1) more interested after training or no change in interest and 2) less interested after training. To explore whether there was an association between interest and training approach or ADAS experience, four chi-square tests were conducted: 1) change in interest from pre-training to post-training by training approach, 2) change in interest from pre-training to follow-up by training approach, 3) change in interest from pre-training to post-training by ADAS experience, 4) change in interest from pre-training to follow-up by ADAS experience.

3.1.4.3. Open-ended Questions

Finally, we conducted a thematic analysis of the responses to the open-ended questions. Thematic analysis is a commonly used method to identify patterns in qualitative data, and requires researchers to familiarize themselves with the data, code the data, develop themes from the data, and revise as necessary (Terry, Hayfield, Clarke, & Braun, 2017). As the first step, the researchers familiarized themselves with the interview transcripts. Then, they used a hybrid coding approach, whereby a predetermined set of codes (i.e., short phrases used to categorize responses, such as ‘‘more interested in using ADAS’’) was created before coding; however, the researchers could also code any emerging topics (Fereday & Muir-Cochrane, 2006). A team of five researchers participated in a 1.5 h training session that covered the predetermined coding scheme and coding on NVivo 12 software. First, the researchers independently coded the same four randomly chosen transcripts, and later discussed their coding process in detail in a 2 h calibration session. Afterwards, one researcher (the author of this dissertation) acted as the first coder and coded all 62 transcripts to further ensure consistency. All 62 transcripts were randomly divided among the other four researchers, who acted as the second coders. NVivo 12 was used for all coding. Once coding was complete, all five researchers discussed the emergent codes and agreed on a final coding hierarchy. They then coded the assigned transcripts again using the final coding scheme. Any coding disagreements were discussed between the first coder and the second coder to reach consensus. Before discussions, percent agreement between the first and second coders ranged from 85% to 92%. The final codes were organized into higher-level themes that corresponded to the different open-ended questions participants were asked (e.g., changes in ADAS interest, helpful aspects of the training).

3.2. Results

3.2.1. Dashcam Clips

There was no significant difference in reliance sensitivity between training approaches. However, there was a significant interaction of ADAS experience and study stage on reliance sensitivity, $F(2, 114) = 3.10$, $p = .049$ (Figure 16). Compared to pre-training, participants with no ADAS experience had significantly better sensitivity post-training, $t(113) = 4.87$, $p < .001$, and at follow-up, $t(113) = 4.34$, $p < .001$. For experienced participants, there was no change in reliance sensitivity across study stages.

There was a significant training by study stage interaction for reliance bias, $F(2, 114) = 6.20$, $p = .003$. For both training approaches, reliance bias was significantly lower at post-training and follow-up, compared to pre-training (Figure 17). The limitation-focused group had a negative bias at post-training, with their criterion being significantly lower than the responsibility-focused group, $t(124) = 2.74$, $p = .007$, but there was no significant difference at follow-up. The limitation-focused group had a slight increase from post-training to follow-up, but this difference was not significant.

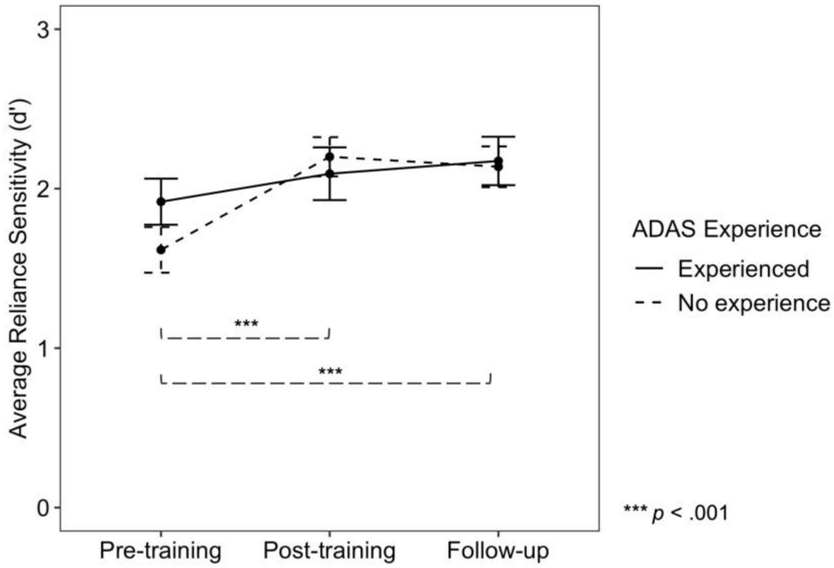


Figure 16. Average reliance sensitivity (*d*') by ADAS experience and study stage in Study 2. In this figure and subsequent figures in this chapter, significant comparisons are indicated, and error bars represent standard error.

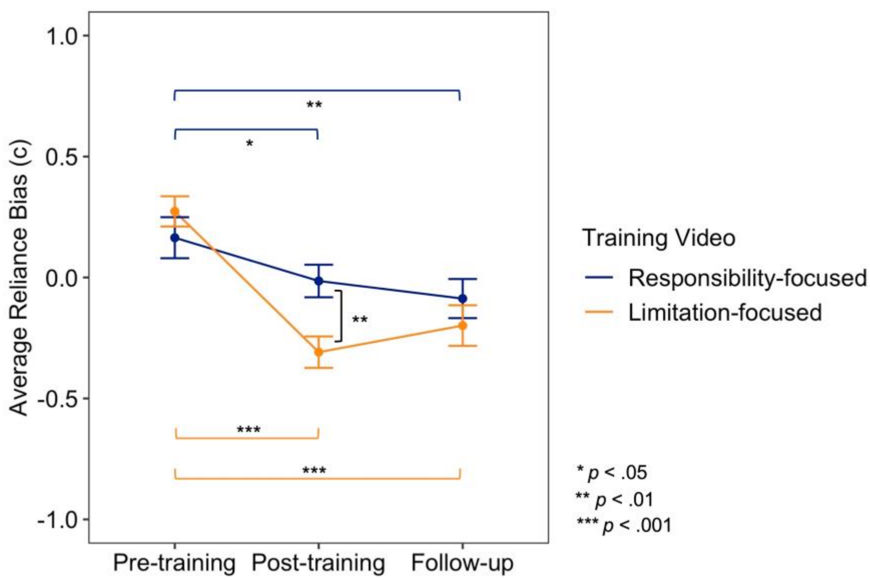


Figure 17. Average reliance bias (*c*) by training approach and study stage in Study 2

For the takeover scenarios, there was a significant main effect of study stage on trust, $F(2, 113) = 40.57$, $p < .001$. For both videos, trust was significantly lower after training (both at post-training and follow-up; see Figure 18). For trust in the no takeover scenarios, there was a significant main effect of training approach, $F(1, 57.4) = 6.54$, $p = .01$, and study stage, $F(2, 115) = 9.15$, $p < .001$. Participants in the limitation-focused group had lower trust compared to the responsibility-focused group, $t(57.4) = -2.56$, $p = .02$, and trust in no takeover scenarios was lower at post-training, $t(114) = 3.84$, $p < .001$, and follow-up, $t(115) = 3.54$, $p < .001$, than pre-training.

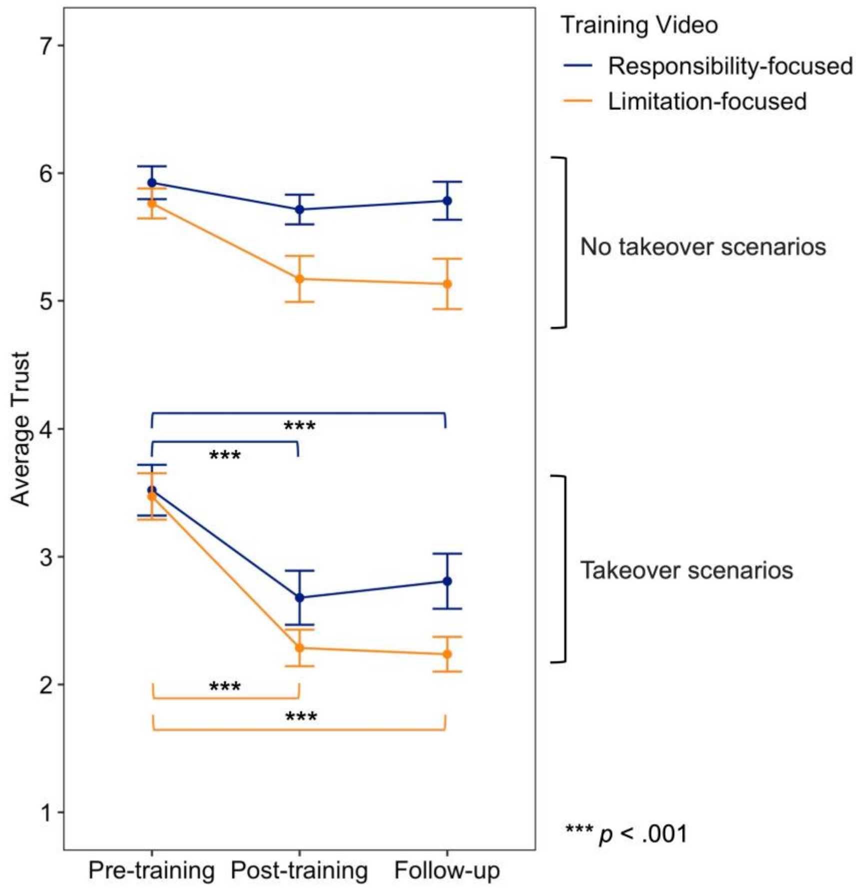


Figure 18. Average situational trust by training approach and study stage in Study 2. The top lines show average trust for no takeover scenarios and the bottom lines show average trust for takeover scenarios.

3.2.2. ADAS Questionnaire

3.2.2.1. Knowledge Questions

For knowledge sensitivity, there were no significant main effects or interaction effects. For knowledge bias, there was a significant training approach by study stage interaction, $F(1, 57) = 4.13$, $p = .047$. Bias was significantly different between training approaches at post-training, $t(85) = 2.48$, $p = .02$, with the limitation-focused group having a negative bias (Figure 19). However, bias became significantly less negative from post-training to follow-up, $t(57.7) = 2.05$, $p = .04$. Bias was no longer significantly different between training approaches at follow-up, and there was no change in bias from post-training to follow-up for the responsibility-focused group.

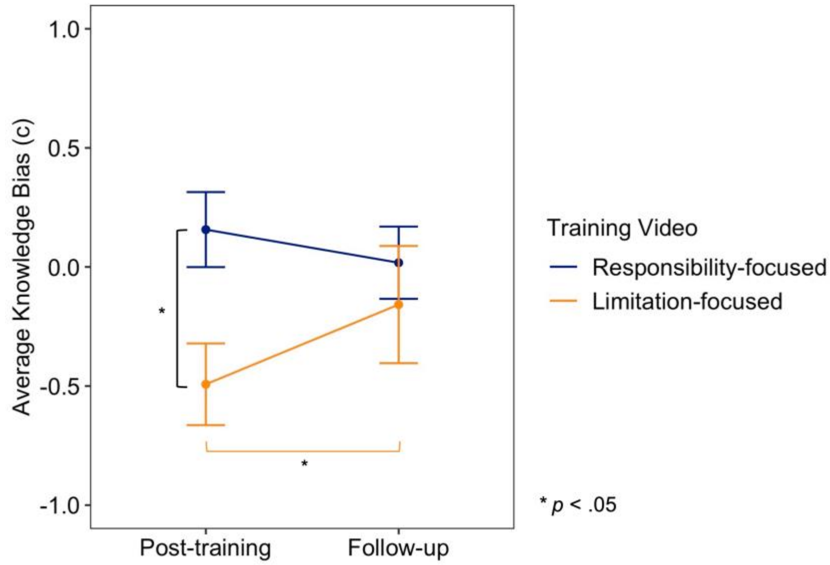


Figure 19. Average knowledge bias (*c*) by training approach and study stage in Study 2. Knowledge questions were not included at pre-training, so only post-training and follow-up study stages are presented.

3.2.2.2. General Reliance Intention

Statistical modelling indicated no significant effects of training approach, ADAS experience, or study stage on general reliance intention. However, descriptive statistics suggest that general reliance intention was lower after training (Figure 20). At pre-training, 61% of participants reported that they would be more likely to drive while engaging in secondary tasks if they were using ADAS compared to if they had no ADAS. This percentage was lower after training, although around half of the participants still reported that they would be more likely to engage in secondary tasks while using ADAS than without ADAS. At pre-training, only 30% of participants reported that they would be more likely to drive in an impaired state while using ADAS compared to without ADAS. After training, this percentage was less than 20%.

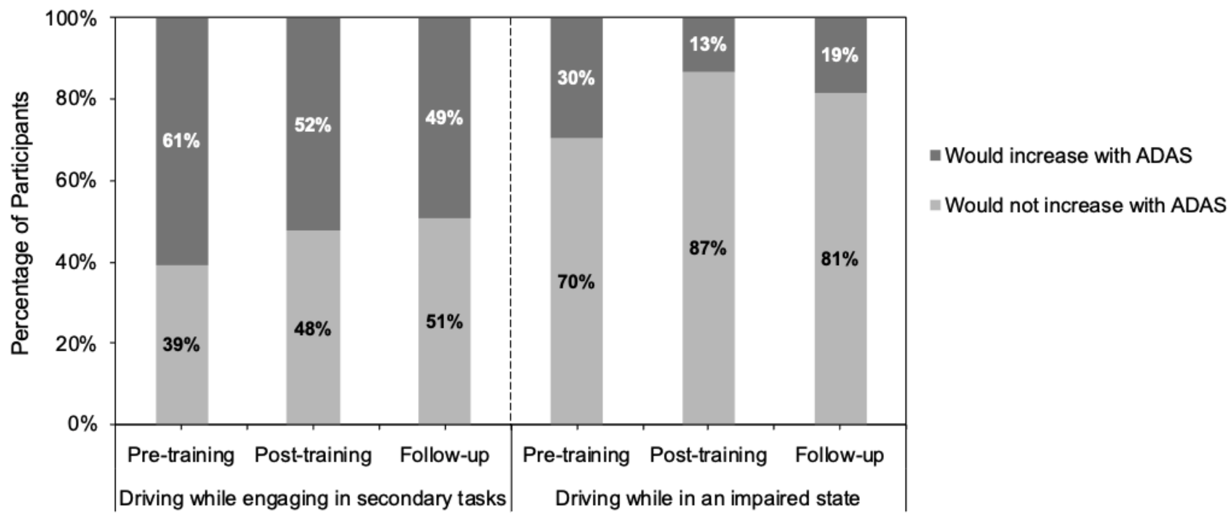
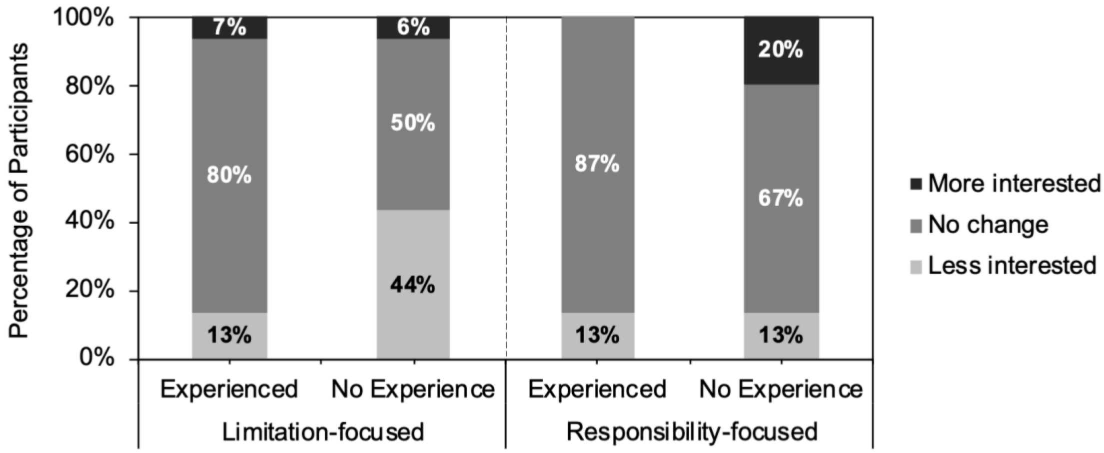


Figure 20. General reliance intention by study stage in Study 2

3.2.2.3. Perceived Usefulness and Interest

There was no significant effect of training approach, ADAS experience, or study stage on perceived usefulness. In other words, neither training approach had a significant impact on perceived usefulness. For interest in using ADAS in the future, descriptive statistics show that at post-training, most participants had no change in their interest in using ADAS. However, more participants in the limitation-focused, no experience group were less interested in ADAS than at pre-training (44% of participants, compared to 13% in all other groups; Figure 21 top). At follow-up, more participants appeared to be more interested in ADAS compared to pre-training, although there were also more people in the responsibility-focused group who were less interested in ADAS compared to pre-training (Figure 21 bottom). However, chi-square tests indicated no significant associations between training approach or experience and change in interest, at post-training or follow-up.



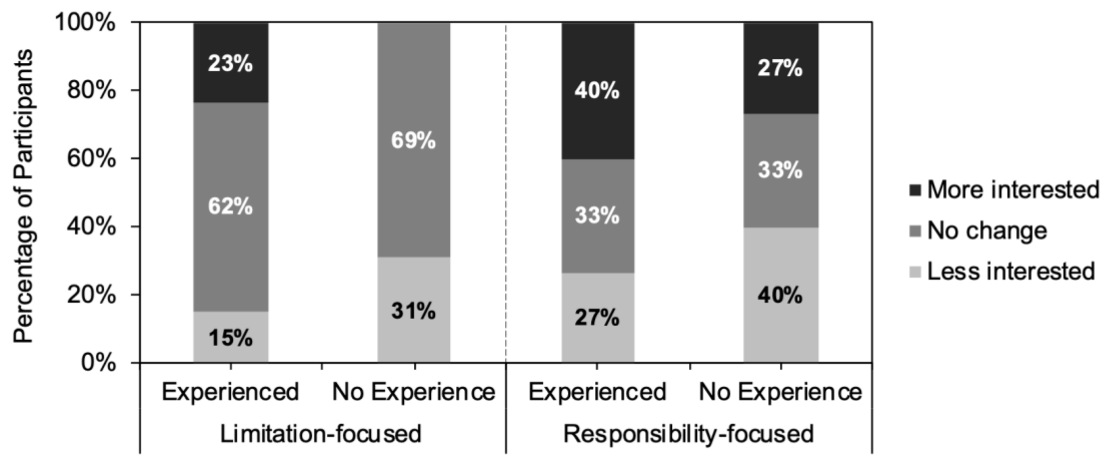


Figure 21. Change in interest from pre-training to post-training (top) and from pre-training to follow-up (bottom) in Study 2

3.2.3. Open-ended Questions

3.2.3.1. Effects of the Training

3.2.3.1.1. Attitudes and Interest in ADAS

In general, the effect of training on attitudes toward and interest in using ADAS depended mainly on the training type but also on ADAS experience, with most participants having no change in attitudes or interest (Figure 22). Among the participants who reported no change in interest, 14 participants in the responsibility-focused group mentioned that while their interest did not change, they learned more about the sensor limitations, compared to only 1 participant in the limitation-focused group. The most common comment for participants in the limitation-focused group who had no change in interest was that their attitude and interest were based on existing experience ($n = 6$; all experienced participants).

Similar to the questionnaire results, the limitation-focused group with no ADAS experience had the highest proportion of respondents that reported a more negative attitude toward or less interest in ADAS after training. This group also had the lowest proportion of respondents that reported a more positive attitude or increased interest. The most common negative comment from among the limitation-focused group (whether their interest changed or not) was that there were too many limitations (n = 15). For the responsibility-focused group, the most common negative comment was that they thought the systems were more capable (n = 8), which was also commonly reported for the limitation-focused group (n = 7). For both training conditions, the most common positive comment about ADAS was that they had a positive view of the system because they gained better knowledge of system capabilities and limitations from the training videos (responsibility-focused n = 6, limitation-focused n = 7).

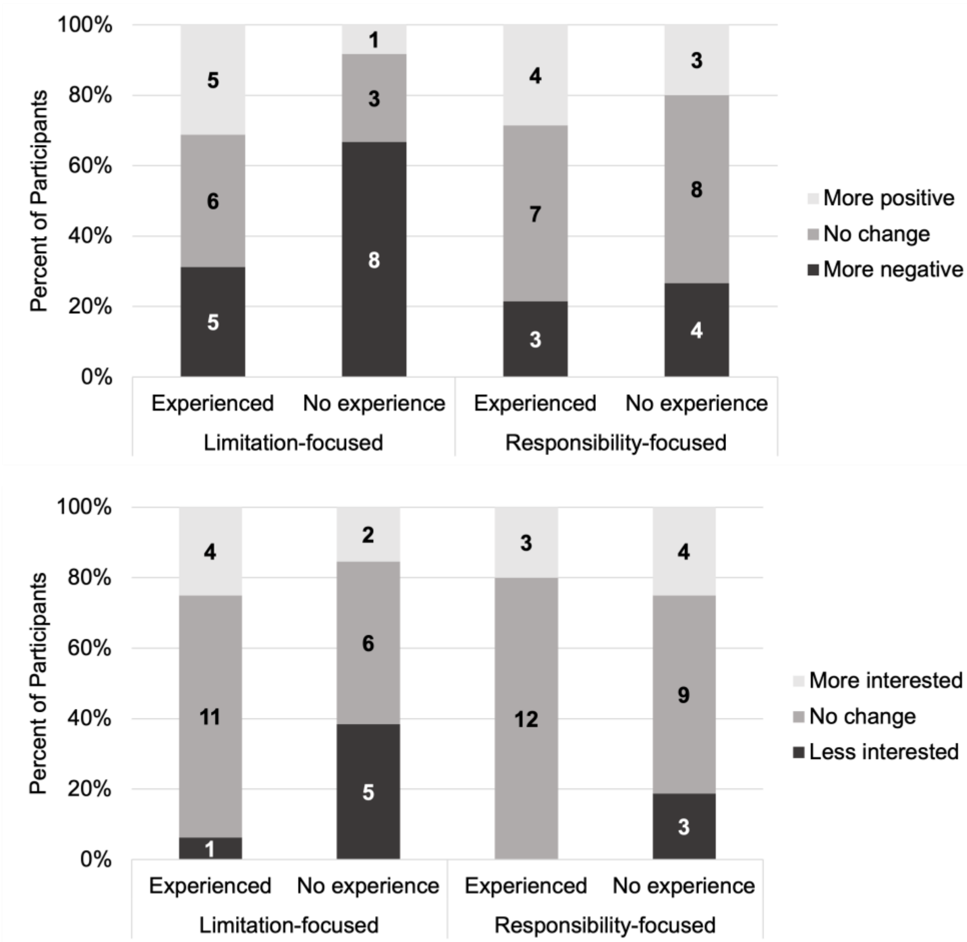


Figure 22. Self-reported change in attitude towards ADAS (top) and interest in using ADAS (bottom) after training in Study 2. Numbers within bars represent count of participants.

3.2.3.1.2. Changes in Intended Distraction Engagement and ADAS Use at Post-training

Responses to whether participants would change how they used ADAS fell into two themes: changes in distraction engagement (e.g., whether they would text, make a phone call, or eat while using ADAS) and changes to when or how frequently they would use ADAS. In terms of engaging in distractions, 31% of participants reported that they would reduce engagement in distracting tasks (Figure 23, top image). The most common reasons given for reducing distraction engagement in the responsibility-focused group were limited sensor capabilities (e.g., the fact that the sensors only detect a limited range ahead; *n* = 7) and the driver's role (e.g., they need to be paying attention and/or have their hands on the wheel; *n* = 3). For the limitation-focused group, the most common reasons given for reducing distraction engagement were the driver's role (*n* = 6) and there being too many limitations (*n* = 4).

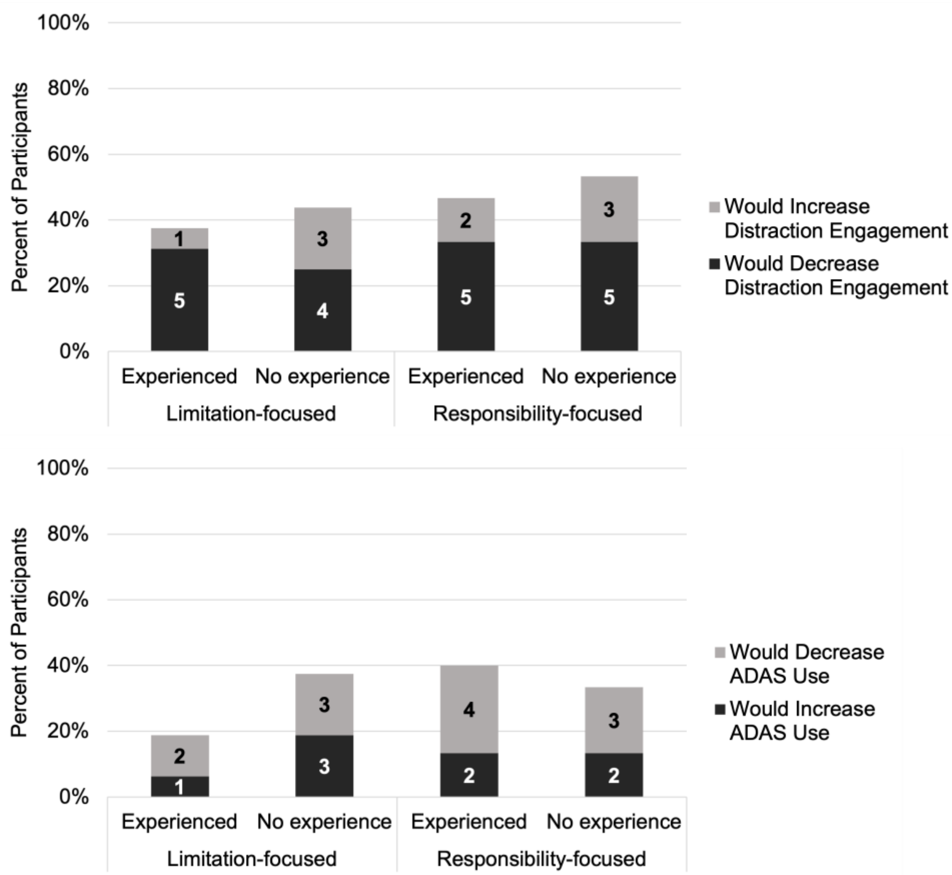


Figure 23. Percent of participants in each group who reported they would change their distraction engagement while using ADAS (top) and ADAS use (bottom) after training in Study 2. Numbers within bars represent count of participants.

Nine participants (6 with no ADAS experience) mentioned that they would increase their engagement in distractions (Figure 23, top image). For participants with and without ADAS experience, one of the explanations was that the ADAS would enable them to engage in tasks that did not require visual attention (e.g., handsfree or handheld call, eating; n = 2 in responsibility- and 2 limitation-focused group). Another explanation was that the systems do some of the work for the driver (n = 3 in responsibility- and 1 in limitation-focused group). For example, two of the experienced participants specifically mentioned being able to send a text message because the lane keeping assist would help keep them in their lane if they looked away for a short period, for example, “I might be more willing to glance away from the road and make that text conversation. That doesn't necessarily make it right, but it means that I know I've got a larger margin for error, than if I didn't have that system”. In contrast, two limitation-focused group participants (with no ADAS experience) mentioned that they would feel more comfortable engaging in distractions in certain situations where the system should work due to learning where the systems would not work. For example, “You kind of rule out the situation in your head and you– you can look around and say, well, I'm– I'm in one of those situations where it's kind of a green– well, green light, metaphorically, to be able to do one of those activities, and this car will be able to handle that or the system will kick in when I need help.”

In terms of how they would use ADAS, some participants indicated that they would use the ADAS less after training (n = 7 in responsibility- and 5 in the limitation-focused group; Figure 23, bottom image). However, participants with and without ADAS experience in the responsibility-focused group explained that they would use ADAS less in specific situations where they thought it would not be appropriate to use (e.g., in poor weather, on busy roads when other drivers may act unpredictably). Some participants at both experience levels in the limitation-focused group also mentioned that they would not use ADAS in specific situations (e.g., in poor weather or when the road was not straight, n = 3), while two participants with no ADAS experience mentioned that they would not use the systems at all because of the number of limitations and because the benefits of ADAS were not clear. One participant stated, “There were many, many possibilities where both of them could fail whether it's the weather, or the road markings, or construction, or the vehicle in front was too low or too high, or my vehicle was too low or too high. Things which you could never, ever foresee. There are just too many negative possibilities.” The other participant said, “I think basically it's just a big list of, ‘don't use it in A, B, C, D, E, F, G, H,’ right? So it's like, basically use it in– again only straight lines, like– not too sunny, but not rain either. Basically, if you run into the circumstance where everything is perfect, then feel free to use it, but you still have to pay full attention so it's like, what's the point? Maybe if it spelled out more of the benefits, because I don't really understand what the benefits are at this point.”

3.2.3.2. Observations About ADAS Use at Follow-up

Twenty-five participants who had used ADAS since the first session (13 in responsibility-focused group, 1 with no experience at the first session; 12 in limitation-focused group, 1 with no experience at the first session) were asked open-ended questions at follow-up. Three participants (with ADAS experience) reported that they experienced a limitation of ADAS since the first session. The reported limitations were ACC not slowing when they were going around a curve (limitation-focused group), not being able to rely on LKA when lanes do not have clear markings (limitation-focused group), and vehicle swerving when in a construction zone (responsibility-focused group). One participant in the limitation-focused (with ADAS experience) group mentioned that they encountered animals on the road while using ADAS and they intervened by braking. Eleven participants mentioned that since the first session, they were more aware of ADAS functionality and limitations when using the systems (6 in the responsibility- and 5 in the limitation-focused group). Some experienced participants (3 responsibility- and 1 limitation-focused) also mentioned that they were more cautious when using ADAS, while others (1 responsibility- and 2 limitation-focused) stated that they did not use ADAS when the system may not work as intended (e.g., when it was raining).

3.2.3.3. Feedback About the Training

When asked if they found the training videos helpful, 61 out of the 62 participants thought that they were helpful. One participant (experienced, limitation-focused group) was neutral about the benefits of the training video as they were already on their second vehicle with ADAS and reported that they were aware of the system limitations. The most common aspect of the videos that participants reported as being helpful was that they learned information about the systems and how to use them (Table 12). Participants in the responsibility-focused group (with and without ADAS experience) mentioned that seeing the consequences of not paying attention (i.e., what would happen if the driver was vs. was not paying attention) was helpful (Table 12).

Another interesting observation is that a small number of participants with no ADAS experience in each of the training groups were unaware that drivers had to keep their hands on the wheel while using ADAS (Table 12).

Table 12. Different aspects of the training videos identified as being helpful by the participants in Study 2 (first column) and the number of participants who did so

		Limitation-focused		Responsibility-focused	
Helpful Aspects of the Training	**Total # of mentions**	**Experienced**	**No Experience**	**Experienced**	**No Experience**
Taught information about ADAS	41	10	11	11	9
Limitations	30	8	7	11	4
How sensors work	13	2	3	3	5
Driver role	5	1	1	3	
Need to keep hands on wheel	4		2		2
System operation	1	1			
Provided a reminder about information they learned previously	7	2		3	2
Driver role	3	1		2	
Sensor limitations	2	1			1
Information from owner's manual	1	1			
Corrected prior assumptions about ADAS	6		2	2	2
Showed the consequences of not paying attention	5			2	3
Better than existing training materials	2	2			
Total # of respondents	61	15	16	15	15

In addition to whether they found the training helpful, participants were also asked if there was anything specific they liked about the training. Twenty-one (out of 30) participants in the responsibility-focused group and 19 (out of 31) participants in the limitation-focused group expressed liking at least one aspect of the training. Participants in both groups liked that the videos were clear (n = 9 and 14, respectively). While the responsibility-focused group reported liking the content of the videos (n = 14) and seeing the driver view (n = 8), the limitation-focused group highlighted liking the visuals (n = 8). Content of the videos were mentioned less in the limitation-focused group (n = 3). Participants also liked that the trainings covered a good amount of detail (n = 4 in responsibility- and 1 in limitation-focused group) and had good length (n = 3 in responsibility- and 2 in limitation-focused group). Participants also suggested ways to improve the training videos, with the most common suggestion for both training videos being to add more information (n = 9). The full breakdown of suggestions can be found in Appendix F.

3.3. Discussion

Given that it may be impractical to expect drivers to learn and remember a wide range of limitations, the goal of the current study was to explore whether the responsibility-focused approach was a feasible alternative to limitation-focused training. Quantitative results from the dashcam clip and questionnaire analyses indicate limited differences between the two approaches in terms of knowledge, reliance intention, and trust, especially several weeks after training. Further, where significant differences between training approaches were observed, some of the results pointed to potential drawbacks of the limitation-focused approach. Results of the thematic analysis also suggest that the limitation-focused approach may be associated with drawbacks like decreased interest in the technology and potential disuse. Thus, the overall findings of the current study suggest that the responsibility-focused approach may be a reasonable alternative to limitation-focused training and should be explored further in future research.

We found no significant difference between approaches in terms of trust in takeover scenarios, appropriate situational reliance (i.e., reliance sensitivity), knowledge sensitivity, or general reliance intention. For all participants, both approaches significantly reduced trust in ADAS in takeover scenarios, where the systems would have difficulty. In addition, for participants with no ADAS experience, both training approaches were associated with better reliance sensitivity at post-training and follow-up. While reliance sensitivity increased after training for experienced participants, the change was not significant. Thirty of the 31 experienced participants reported previously learning about ADAS using at least one method, compared to 23 of the 32 participants without ADAS experience. It is possible that the training may not have impacted situational reliance intention for the experienced group because they had already learned some of the information prior to the study. However, feedback from the experienced participants suggests that they still thought the training was useful as a reminder of important information. These findings supplement prior work that has investigated alternatives to the limitation-focused training approach. Boelhouwer et al. (2019) found that compared to no training, providing structural system information did not improve drivers' ability to identify scenarios that would require them to take over from ADAS. Our results suggest that with regards to situational reliance intention, the responsibility-focused approach is no less effective than the limitation-focused approach.

Neither training approach resulted in significant changes in knowledge sensitivity or general reliance intention measured with the ADAS questionnaire. Based on the questionnaire responses after training, approximately half of the participants reported that they would be more likely to engage in distractions while using ADAS than without ADAS. However, thematic analysis of the open-ended responses showed that training was effective at reducing intended engagement in distractions for 31% of participants. Fifteen percent of participants reported being more likely to engage in distractions while using ADAS after the training, with just under half of these participants specifying that they would engage in distractions that did not require visual attention (e.g., handsfree phone call). A small number of experienced ADAS users felt that the technology would allow them to (briefly) engage in handheld cellphone distractions (i.e., texting). Research shows that current ADAS users frequently engage in distractions while using these systems (Dunn, Dingus, & Soccolich, 2019; Lin, Ma, & Zhang, 2018), and training alone is unlikely to prevent all drivers from engaging in distractions. Thus, other interventions may be needed in conjunction with training to support safe ADAS use. For example, utilizing driver state monitoring to alert drivers when they need to reorient their attention to the roadway (e.g., Gaspar, Schwarz, Kashef, Schmitt, & Shull, 2018) or even limiting drivers' access to distractions (e.g., forwarding incoming calls to voicemail; Piechulla, Mayser, Gehrke, & König, 2003).

There were significant differences between the two training approaches for knowledge bias, reliance bias, and trust in no takeover scenarios. The limitation-focused video was associated with lower trust in no takeover scenarios compared to the responsibility-focused video, consistent with previous work showing that drivers who received an ACC description with more limitations had lower trust after reading the system description than drivers who received ACC descriptions with fewer limitations (Beggiato & Krems, 2013). The greater number of limitations in the limitation-focused video may have negatively impacted participants' trust in ADAS even in situations where it would be appropriate to use. However, it should be noted that the magnitude of the differences is relatively small. For both approaches, average trust in no takeover scenarios was between 5 (somewhat agree) and 6 (agree).

The effect of training on knowledge bias and reliance bias was only significant at post-training. The limitation-focused approach was associated with a negative knowledge bias (i.e., bias towards reporting that the ADAS would not work in a given scenario for the knowledge questionnaire) and a negative reliance bias (i.e., bias towards reporting that they would take manual control for the dashcam clips). Although not statistically significant, questionnaire data also showed that the limitation-focused/no experience group had more participants with decreased interest in using ADAS at post-training. Similarly, the open-ended responses at post-training showed that a more negative attitude towards ADAS and decreased interest in using ADAS were more common among participants without ADAS experience who received limitation-focused training. The most common reason given by the participants for the negative effects was that there were too many system limitations. There were also differences between training approaches in their effects on intended ADAS use as reported in the open-ended questions at post-training. Participants in the responsibility-focused group reported that they would use ADAS less in situations where they may not work. Some participants in the limitation-focused group made similar comments, but two participants with no ADAS experience mentioned that they would not use ADAS at all because there were too many limitations, and the benefits of the technology were not clear. Although our data reflects participants' self-reported intention to use ADAS, the findings are consistent with a recent simulator study which found that training on limitations alone was associated with a higher proportion of ACC disuse than training that included limitations and information about the driver's role and responsibility (Zheng et al., 2023). Overall, our results suggest that focusing training on a series of system limitations may have a negative impact on drivers' interest and willingness to use ADAS, which may be more common for new or prospective users. Given that there are potential safety benefits of these systems (e.g., Highway Loss Data Institute, 2019), effective training should balance reducing overreliance while not increasing disuse so that drivers do not miss out on these benefits.

By the follow-up session, there was no longer a significant difference in knowledge bias or reliance bias between the two approaches. Both knowledge and reliance bias became less negative for the limitation-focused group between post-training and follow-up, although this difference was only significant for knowledge bias. It is possible that this change was partially due to participants in the limitation-focused group forgetting some of the information from the training that had initially impacted their bias, consistent with previous research showing that drivers forget ADAS limitations over time (e.g., Beggiato et al., 2015). While we did not find any significant changes in knowledge sensitivity between post-training and follow-up, it is possible that the forgotten information was not captured by our knowledge questionnaire. Further, based on the questionnaire item assessing interest in using ADAS at follow-up, there were more participants in the responsibility-focused group who had a decreased interested in using ADAS but also more people with an increased interest compared to pre-training. However, statistical analysis indicated no significant association between training approach and interest measured through the questionnaire and we did not ask open-ended questions related to interest in using ADAS at the follow-up session. Further research is needed to investigate how initial training may affect interest in using the systems over longer periods of time.

The changing results from post-training to follow-up highlight the importance of assessing training at various time points. In addition, while knowledge and reliance bias were no longer significantly different between training approaches several weeks after training, it would still be advantageous to avoid imparting a negative bias and negative attitudes towards ADAS shortly after training as it may result in potential users not wanting to try the technology.

Further, at the follow-up session, several weeks after training, only three participants experienced any limitations they learned about during the training and one intervened in anticipation of a limitation. Since drivers forget limitations if they do not experience them (Beggiato et al., 2015) and encountering limitations is relatively rare, the limitation-focused training may be less practical than the responsibility-focused training which provides less information and instead uses two example scenarios to emphasize how the driver should use ADAS. From an implementation perspective, while manufacturers may still be required to list limitations in an owner’s manual for liability reasons, they may be more likely to develop and distribute additional training for their vehicles if the focus is less on the limitations of their technology and more on the driver’s responsibility in using the systems.

In terms of participant feedback about the trainings, all but one participant found the training to be helpful, with two-thirds of participants indicating that they learned something from the training. The prevalence of existing limitation-focused ADAS information may have affected how participants assessed the usefulness of the training. When considering whether they found the videos helpful, participants who received responsibility-focused training may have been comparing the different type of content to information they had previously encountered. In contrast, participants who received the limitation-focused training may be comparing the method of delivery to existing limitation-focused training (e.g., video versus owner’s manual). For example, two experienced participants mentioned that the limitation-focused video was better than existing training materials, specifically owner's manuals. While our results suggest that training designers may not want to develop training that focuses primarily on system limitations, if limitation-focused training is needed, using a video format may be preferred by drivers. Although video-based training has not been found to be more effective than reading an owner's manual (Noble et al., 2019; Singer & Jenness, 2020), more drivers may complete the training if delivered in video format, based on our findings and previous research showing that drivers would like to learn about in-vehicle technology through videos (Abraham et al., 2017). Drivers also report learning about ADAS through trial-and-error in the vehicle (Study 1 findings; also Abraham et al., 2018; McDonald et al., 2018), and variations in ADAS across manufacturers may have affected the aspects of the training that experienced participants found to be helpful. For example, most systems require drivers to have their hands on the steering wheel and alert drivers if they do not detect steering input, which may explain why none of the experienced participants reported learning that they need to keep their hands on the wheel (i.e., they may have learned this through using the system). In contrast, some experienced participants reported that the training taught them about the driver's role, while others did not. Some vehicles have systems that monitor whether the driver is looking at the roadway, and drivers with these systems may already have learned through system use that they need to keep their eyes on the road. However, none of the participants in our study mentioned having an attention monitoring system, and we did not have information about which vehicles each participant drove. Thus, more research is needed to further explore how experience with ADAS and driver monitoring systems affects drivers' perceptions of training and the information they find to be most helpful.

Thirty-two percent of participants provided suggestions to improve the training, suggesting that most of the participants felt the training was adequate. Most suggestions were from drivers without ADAS experience and were related to specific details they wanted to know more about (e.g., how the system determines if the driver's hands are on the steering wheel), which makes sense given they had never used the systems before. Researchers or other training designers may consider these suggestions when designing future ADAS training.

ADAS training and education have been identified as crucial for supporting safe use of driving automation (U.S. Department of Transportation, 2016), and researchers have provided recommendations for what should be included in ADAS training based on driving research (Manser et al., 2019) and training from aviation for pilots using automation (Casner & Hutchins, 2019). However, extensive training would likely be required to teach drivers all the recommended material. Developing and implementing an extensive training program would take time, especially given that ADAS training is currently not required. In the meantime, drivers will continue using ADAS on public roads and training videos may be an effective way to disseminate basic information to drivers to support them in using ADAS safely. Our results suggest that instead of focusing this basic training on system limitations, a feasible alternative may be to highlight the driver's responsibility while using ADAS and the consequences of inappropriate use. One of Casner and Hutchins' (2019) suggestions is to remind drivers that they "will likely be held responsible for whatever happens" (p. 63). In addition, research shows that one of drivers' top concerns about fully automated vehicles is who would be liable if a collision were to occur (Cunningham, Regan, Horberry, Weeratunga, & Dixit, 2019; Schoettle & Sivak, 2014). The same may be true when using ADAS, and thus emphasizing to drivers that they are responsible for all vehicle actions (including collisions) may be an effective way of deterring drivers from disengaging from the driving task.

3.3.1. Limitations and Future Work

Given that we conducted a remote video-based study, we were only able to measure reliance intention and other self-report data, which may not accurately reflect actual behaviour, and thus future work is needed to confirm our results with behavioural data. However, given the limited research on responsibility-focused training, the results from the current study still provide initial support for continuing to investigate this alternative training approach. Since the training in the current study focused specifically on ACC and LKA, future studies could also explore the development of responsibility-focused training that encompasses a wider range of ADAS. Further, while training videos may be useful to provide information to drivers at a single time point, they may not be an effective training strategy on their own. In addition to forgetting information over time, research shows that trust in and reliance on ADAS will likely increase as drivers use the systems and experience relatively reliable systems with infrequent failures (e.g., Dunn et al., 2019; Lin et al., 2018). While drivers could refer back to videos to refresh their memory of the training, providing reminders to drivers on an ongoing basis may also help support appropriate reliance over time. Though our results show that situational reliance intention and trust did not significantly change over several weeks (between post-training and follow-up), more research is needed to confirm these results with behavioural data and over longer periods of time, particularly with owners who have continuing interactions with ADAS. In addition, research is needed to further investigate the effect of training approaches on interest in using ADAS in the future as well as actual ADAS use.

3.4. Summary and Conclusions

Expecting drivers to learn and remember a large range of potential limitations may not be a practical approach to ADAS training, particularly for training that is self-initiated in the absence of formal training requirements. Thus, the current study explored responsibility-focused training as an alternative. Overall, our results indicate limited differences between the limitation-focused and responsibility focused training approaches. Without training on a large range of limitations (i.e., the responsibility-focused approach), appropriate situational reliance intention did not significantly differ from those who were trained using the limitation-focused approach. In addition, our results suggest that there may be potential drawbacks of the limitation-focused approach (e.g., negative bias, disuse), suggesting that the responsibility-focused training approach is worth exploring further.

Chapter 4
Study 3: Simulator Study Investigating the Effects of Training Approach When Drivers Have an Attention Monitoring System

This chapter presents the results of a simulator study that was conducted as a follow up to Study 2 which was conducted remotely. The purpose of the training videos that were developed for this dissertation was to convey to drivers that ADAS are only assistance systems and thus, drivers should always be paying attention to the roadway. Although training may encourage drivers to keep their attention on the road while using ADAS, driver monitoring systems that serve a similar purpose have also been identified as a necessity for vehicles with ACC and LKA (i.e., SAE Level 2 driving automation). The NTSB has recommended that all new vehicles with ACC and LKA should be required to have driver state monitoring systems that "minimize driver disengagement, prevent automation complacency, and account for foreseeable misuse of the automation" (NTSB, 2020, p. 46). Such systems that monitor drivers' attention and alert them when they have been identified as being inattentive are currently available in some consumer vehicles (e.g., GM Super Cruise, Subaru DriverFocus). It is unclear whether training would have any additional benefit when attention monitoring systems are employed, thus, in the current study, an attention monitoring system was implemented for all participants and a no training condition was used as a baseline for comparison.

Study 3 aimed to explore whether the responsibility-focused and limitation-focused training approaches affected reliance behaviour in a driving simulator. Reliance was measured using visual attention measures (e.g., percentage of time looking at a secondary task) and driver behaviour measures (e.g., whether and how soon participants disengage the automation relative to an upcoming event). A secondary objective was to explore differences in knowledge of and self-reported trust in ADAS between training conditions to compare with the findings from Study 2.

4.1. Materials and Methods

A simulator study was conducted with a 3x2x2 mixed design. Training approach was a between-subjects factor with three levels: no training (attention monitoring only), limitation-focused training (plus attention monitoring), and responsibility-focused training (plus attention monitoring). All participants experienced eight events in the simulator which required the ego-vehicle to slow down to avoid a collision. Event type was a within-subjects variable with two levels: covered in training (lane change events; Table 14) and not covered in training (braking events; Table 14). We were not interested in the main effect of event type as the events were not directly comparable, but we were interested in the interaction between event type and training (e.g., whether training affected performance for both event types or only those that were included in training). Event criticality was also a within-subjects variable with two levels: action-necessary (A-N) and action-not-necessary (A-not-N). In A-N events, participants needed to take control of the speed and/or steering to avoid a collision. In A-not-N events, the ADAS was able to slow down the vehicle to avoid a collision. The experiment lasted approximately 2.5 to 3 hours and participants were compensated C$50 (Canadian dollars). Participants were told that the compensation was at a rate of C$14/hr (i.e., C$42 for 3 hours) plus a C$8 bonus based on their driving performance and performance on a secondary task, however, all participants received the full C$50.

4.1.1. Participants

Forty participants completed the study (see Table 13 for the number of participants by training group). Individuals who were interested in participating were first asked to complete a screening questionnaire to determine their eligibility. To be eligible to participate, participants were required to speak English fluently, drive at least a few times a month, and be able to drive in the simulator without glasses, which can negatively affect the quality of the eye tracking system. Given difficulties with recruiting participants with specific levels of ADAS experience that we encountered in Study 2, there were no inclusion criteria related to prior use of ADAS (the number of participants with previous ADAS experience is shown in Table 13). However, participants who were involved in any collisions while using ADAS were excluded as these events may have significantly affected trust in ADAS. In addition, we recruited participants who had never previously used ADAS with an attention monitoring system because these systems are currently only available in vehicles with more sophisticated ADAS (e.g., GM Super Cruise), and thus these drivers may have different levels of trust in ADAS compared to drivers who have never used ADAS or used more widely available ADAS. Finally, to reduce variability in behaviour potentially caused by differences in age or driving experience, participants were required to have been fully licensed for at least 2 years and be at least 25 years old (i.e., novice and young drivers were excluded). Previous research indicates that novice and young drivers

(< 25 years old) have increased crash risk (e.g., McCartt, Mayhew, Braitman, Ferguson, & Simpson, 2009) and may have greater distraction engagement while using ADAS (He, Kanaan, & Donmez, 2022). A cut-off of 2 years of full licensure was chosen for driving experience as previous research shows that crash rates among young drivers (17-20 years old) increase shortly after full licensure and then decrease (Curry, Pfeiffer, Durbin, & Elliott, 2015). Although our sample did not include younger drivers, we still used this 2-year threshold as drivers aged 25 and older may also have an increase in crashes after full licensure. Participants' average age and years of licensure can be found in Table 13. There was no significant difference in age or years of licensure between training groups.

Table 13. Participant characteristics by training group in Study 3

	No training	**Limitation-focused**	**Responsibility-focused**
N	14 (7M, 7F)	13 (7M, 6F)	13 (6M, 7F)
Age (*M*, *SD*)	39.4, 8.6	37.3, 13.8	42.2, 12.8
Years of Full Licensure (*M*, *SD*)	12.4, 7.9	13.1, 15.1	18.4, 16.3
Previously used ACC (*N*)	4 (3M, 1F)	5 (3M, 2F)	4 (1M, 3F)
Previously used LKA (*N*)	3 (1M, 2F)	5 (3M, 2F)	2 (1M, 1F)

4.1.2. Experimental Design

The experiment used four events which have been used previously to investigate drivers' ability to anticipate a potential ADAS limit (He et al., 2021). Two occurred on a rural road (events A and B; Table 14) and two occurred on a highway (events C and D; Table 14). Each event required a change of vehicle speed to avoid a collision. All participants experienced an A-N and A-not-N version of each event, resulting in eight events total for each participant. The A-N events were designed such that the available braking distance was less than what was required for ACC to brake in time to avoid a collision due to ACC's limited braking power. In the A-not-N events, there was sufficient braking distance for the ACC to slow down the vehicle speed to avoid a collision.

The start of each event (event onset) was marked by an action of a lead vehicle or vehicle in an adjacent lane which unambiguously indicated the upcoming event. For example, for event D (Table 14), the left indicator signal of the white vehicle is an indication that the driver intends to change lanes ahead of the participant's vehicle. In the time leading up to the event onset, there were also cues in the environment that indicated the possibility of the upcoming event (i.e., anticipatory cues; He et al., 2021; Stahl, Donmez, & Jamieson, 2014). For event D, the white vehicle getting closer to the slow truck suggests that the white vehicle may change lanes ahead of the participant's vehicle, but the vehicle could also slow down and remain in the right lane.

Each participant completed four experimental drives (two rural and two highway), with two events per drive. Each of the rural drives had both rural events (i.e., event A and B) and each highway drive had both highway events (i.e., event C and D). In each drive, there was one A-N event and one A-not-N event. The average time between events was 2.93 minutes (*SD* = 0.59). Sixteen orders were developed to counterbalance the order of events throughout the experiment (Figure 24). All event orders alternated between highway and rural drives and whether the drive started with an A-N or A-not-N event. These orders were randomly assigned to the participants for each training condition.

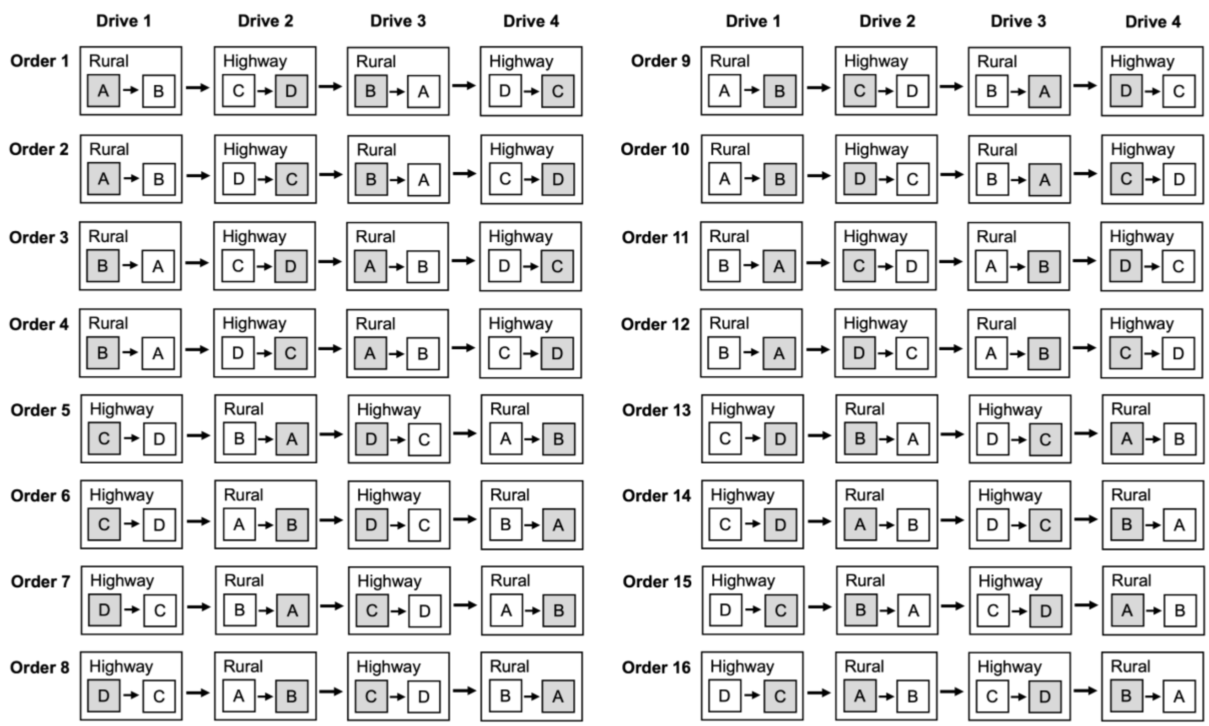
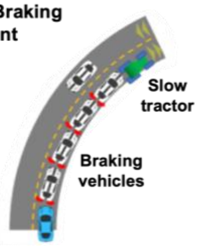
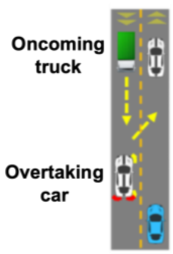
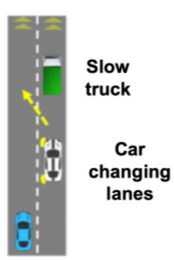


Figure 24. Event orders in Study 3. Each participant was assigned one of the event orders. Grey shading indicates A-N events; events without shading are A-not-N.

Table 14. Descriptions of the events used in Study 3; adopted from He et al. (2021)

Event	Event Details
A: Braking Event 	The ego-vehicle followed a chain of four vehicles on a two-lane rural road with moderate oncoming traffic, traveling at 80.5 km/h (50 mph). The frontmost vehicle was d_1 away from the ego-vehicle. Due to a slow tractor ahead on a curve, traveling at 40.2 km/h (25 mph), the front vehicle started to brake when within d_2 of the tractor, with a deceleration of a_1. The other lead vehicles braked consecutively. **Anticipatory cues:** slow tractor, reduced distance between lead vehicles, successive braking of lead vehicles (except the one directly ahead) **Event onset:** brake lights of the lead vehicle directly ahead of the ego-vehicle **Action-necessary** version: d_1 = 152.4 m (500 feet); d_2 = 61.0 m (200 feet); a_1 = 10 m/s^2 **Action-not-necessary** version: d_1 = 213.4 m (700 feet); d_2 = 30.5 m (100 feet); a_1 = 8 m/s^2
B: Lane Change Event 	The ego-vehicle followed a lead vehicle on a rural road. The vehicle directly behind (overtaking vehicle) signaled left with high beams on, pulled into the opposite lane, and accelerated to be v_1 faster than the ego-vehicle to overtake the ego-vehicle. Because of an oncoming truck (relative speed of v_2 to the ego-vehicle), the overtaking vehicle had to slow down to 72.4 km/h (45 mph), cut in front of the ego-vehicle abruptly after signaling right, when the distance between the ego-vehicle and the truck fell under d_1. The overtaking vehicle accelerated after merging right. No cut-in happened if the ego-vehicle sped up and passed the overtaking vehicle before event onset; in this case, the overtaking vehicle had to merge back to the right lane behind the ego-vehicle. **Anticipatory cues:** left signal and left lane change of the overtaking vehicle, and emergence of the oncoming truck **Event onset:** right signal of the overtaking vehicle **Action-necessary** version: v_1 = 16.1 km/h (10 mph); v_2 = 144.8 km/h (90 mph); d_1 = 259.1 m (850 feet) **Action-not-necessary** version: v_1 = 25.8 km/h (16 mph); v_2 = 136.8 km/h (85 mph); d_1 = 274.3 m (900 feet)
C: Braking Event 	The ego-vehicle was driving on the left lane of a four-lane divided highway. Because of a stranded truck and two police cars behind, two lead vehicles on the right lane were forced to brake in sequence with a deceleration of 5 m/s^2, and merged left after signaling left, when the distance between the first lead vehicle on the right lane and the police car behind fell below d_1. This forced the two lead vehicles on the left lane to brake. At this moment, the distance between the ego-vehicle and the lead vehicle directly ahead on the left lane was d_2 and the lead vehicle was forced to brake for t_1 with a deceleration of a_1. **Anticipatory cues:** the truck and the police vehicles becoming visible, the merging of two vehicles on the right, the braking of all other vehicles except the one directly ahead of the ego-vehicle, and the reducing distances between all vehicles except the distance between the ego-vehicle and the lead vehicle directly ahead. **Event onset:** brake lights of vehicle directly ahead **Action-necessary** version: d_1 = 134.1 m (440 feet); d_2 = 30.5 m (100 feet); t_1 = 3.5 s; a_1 = 10 m/s^2 **Action-not-necessary** version: d_1 = 137.2 m (450 feet); d_2 = 100.6 m (330 feet); t_1 = 2 s; a_1 = 8 m/s^2
D: Lane Change Event 	The ego-vehicle traveled at 96.6 km/h on the left lane while driving on a four-lane divided highway. The ego-vehicle approached a truck and a following vehicle on the right lane, initially traveling at 72.4 km/h (45 mph). As the distance between the truck and the ego-vehicle fell under d_1, the truck slowed down to be 36.1 km/h (22.4 mph) slower than ego-vehicle, forcing the following vehicle to slow down to be 10.8 km/h (6.7 mph) slower than the ego-vehicle. After about t_1, the following vehicle signaled left and moved to the ego-vehicle lane with its speed v_1 slower than the ego-vehicle, trying to pass the truck. If the ego-vehicle sped up and passed the vehicles on its right before event onset, then the following vehicle moved to the left behind the ego-vehicle. Otherwise, the following vehicle moved to the left lane in front of the ego-vehicle and about t_2 seconds later, it accelerated to drive away after moving left. **Anticipatory cues:** changes in speed and reduced distance between the truck and the following vehicle **Event onset:** left signal of the following vehicle **Action-necessary** version: d_1 = 79.0 m (260 feet); t_1 = 11 s; v_1 = 24.1 km/h (15 mph); t_2 = 6 s **Action-not-necessary** version: d_1 = 92.2 m (302 feet); t_1 = 11 s; v_1 = 8.1 km/h (5 mph); t_2 = 6 s

Notes: The blue vehicle represents the participant's vehicle in the simulator. Dashed yellow arrows show the potential paths of the vehicles. Lane Change events (B and D) were covered in training; braking events (A and C) were not covered in training.

4.1.3. Apparatus

This experiment was conducted on a NADS MiniSim Driving Simulator, which has three 50” screens (approximately a 140-degree field of view), and two speakers for stereo sound. The simulator has a motion system that provides pitch, heave, and roll motion of the cab. It also provides engine and road vibration that corresponds with the current road surface type. The simulator can simulate ACC and LKA, which can work simultaneously. The LKA implemented in the simulator steers when it reaches the lane boundary. Driving performance data, including headway, vehicle speed, steering wheel movement, lane deviation, and the positions of the brake and accelerator pedals were recorded from the simulator at 60Hz. A Surface Pro 2 laptop (10.6” screen) was mounted to the right of the dashboard to display a secondary task and a smartphone (4.7” screen) was mounted above the dashboard to simulate a head-up display (HUD) for the visual component of the attention monitoring system (Figure 25).

A head-mounted eye tracking system by Ergoneers Dikablis was used to record participants’ eye movements at 60Hz and provide real-time data to the attention monitoring system (Figure 25). The eye-tracker uses one forward facing camera and two eye tracking cameras to determine where the participant is looking. Four other participant-facing cameras placed around the simulator were used to record hand and foot movements that may not be registered by the simulator (e.g., hovering a foot over the brake pedal).

Figure 25. Study 3 experimental setup. 1 = Ergoneers Dikablis eye tracker. 2 = Surface tablet which displayed the training videos (before experimental drives) and secondary task (during experimental drives). 3 = smartphone which displayed the visual component of the attention monitoring system.

4.1.4. Driving Task

Participants were told that their main task was operating the vehicle safely. They were instructed to use the ACC and LKA systems as much as possible, but that they should intervene whenever they felt it was necessary to maintain driving safely. Both ACC and LKA could be engaged and disengaged using buttons on the steering wheel. In addition to the buttons on the steering wheel, the ACC could be disengaged by pressing the brake pedal and the LKA could be disengaged by turning the steering wheel at a rate of 200 degrees per second (determined through pilot testing). The ACC cruise speed could be adjusted using buttons on the steering wheel; participants were asked to set the ACC cruise speed to the speed limit for each drive. Overall, participants used the ACC 82% of the time (11% *SD*), and LKA 94% of the time (*SD* = 6%); there was no difference across training groups.

4.1.5. Secondary Task

A visual-manual secondary task was available to participants throughout the experimental drives. The task, developed by Donmez, Boyle, and Lee (2007), required participants to scroll through a list of 10 phrases and select the one that matched the target phrase “Discover Project Missions”. A match occurred when any of the three words were in their correct positions (i.e., “Discover” was in the first position, “Project” was in the second position, or “Missions” was in the third position). For each trial, only 2 of the 10 phrases appeared on the screen at a given time and participants used buttons on the screen to scroll through the phrases. The task mimicked searching for a song on an in-vehicle infotainment system.

4.1.6. ADAS Training and Attention Monitoring System

The limitation-focused and responsibility-focused training videos used in the study were modified versions of training videos used in Study 2. The videos were modified so that both the limitation-focused and responsibility-focused training mentioned limitations related to a vehicle changing lanes ahead (events B and D; Table 14), but did not mention limitations related to very slow or suddenly braking vehicles (events A and C; Table 14). Similar to the videos used in Study 2, both training videos were approximately 8 minutes long, and each video was split into two parts to reduce potential fatigue. The full videos used in Study 3 can be found here: https://youtube.com/playlist?list=PL_mdfFo99cx4k96yXbRTnWjnbFY7JZVzW.

All participants had an attention monitoring system, which was based on alert systems that are currently available in consumer vehicles. For example, the Subaru DriverFocus and GM Super Cruise alert systems both use a driver-facing camera that monitors head and eye movements to detect if the driver is looking away from the road (GMC, 2023; Subaru, 2023). If the systems detect that the driver is looking away from the road for more than a few seconds (between 4.1 and 8.1 seconds on average, based on testing by the American Automobile Association [AAA]; AAA, 2022), they will trigger an alert. The Subaru system sends a combined visual alert ("Keep eyes on road" displayed on the dashboard) and auditory alert to prompt drivers to direct their attention back to the roadway (Subaru, 2023). The Super Cruise system has a graded alert, whereby the first alert is visual only (green flashing light on the steering wheel), the second alert is visual (red flashing light on the steering wheel) and auditory or haptic (can be set by the driver), and the third alert is a voice alert letting the driver know that Super Cruise will disengage (GMC, 2023). Similarly, we provided a two-stage graded alert based on how long participants had been looking away from the road. The attention monitoring system began timing once the participant looked away from the front roadway and reset once participants looked back towards the front roadway. If the timer reached 3 s, a visual alert (red eye icon) appeared on the HUD and remained on the display until the participant looked at the road. If the timer reached 4 s, an auditory alert was triggered, consisting of a short sequence of 4 beeps, which repeated until the participant looked at the road. Based on ISO standards for minimum fixation durations (ISO, 2013b) and pilot testing, a glance was required to be at least 160 ms long to count as a valid glance, in order to account for potential noise in the real-time eye-tracking data. Thus, participants would have to look back towards the road for a minimum of 160 ms for the alert timer to reset.

The alert thresholds were originally set to 2 s for the visual alert and 3 s for the auditory alert, based on naturalistic data showing increased crash/near-crash risk for off-road glances greater than 2 seconds (Klauer, Dingus, Neale, Sudweeks, & Ramsey, 2006) and consistent with NHTSA guidelines for in-vehicle distractions (NHTSA, 2013). However, during pilot testing, the 2 s threshold was found to produce a high rate of alerts that was deemed annoying/frustrating to drivers. In addition, testing of current attention monitoring systems show that in practice, there is a larger threshold between when drivers look away from the road and when they receive an alert (between 4.1 and 8.1 s on average; AAA, 2022). Through pilot testing, we found that a threshold of 3 s for the visual alert and 4 s for the auditory alert resulted in some visual and auditory alerts in each drive without becoming annoying to participants, thus we adopted those thresholds for the experiment.

4.1.7. Procedure

Eligible participants were invited to schedule a study session. Upon arrival at the lab for the session, participants were presented with a consent form to read through and sign prior to the start of the experiment. They were informed through the consent form and verbally by the experimenter that there was bonus compensation available, which depended on their driving performance during experimental drives and as their secondary task performance. After completing the consent process, participants were trained on how to complete the secondary task and use the driving simulator, including how to operate the ACC and LKA systems. Following this training, they completed a 10-minute practice drive to familiarize themselves with driving in the simulator (first half of the practice drive) and engaging/disengaging the ADAS (second half of the practice drive). After 10 minutes, participants were asked if they wanted more time to practice driving in the simulator and could continue the practice drive until they felt comfortable moving on to the next step of the study.

Next, participants completed the ADAS training for their group (if applicable). The responsibility-focused and limitation-focused groups were shown the training videos on the Surface tablet (Figure 25). For all groups, the experimenter then provided a brief description of the attention monitoring system. Participants were told that the attention monitoring system would keep track of where they were looking using the eye tracker and alert them if they were looking away from the road for too long. They were told that if they were looking away from the road for more than a few seconds, they would first get a visual alert, followed by an auditory alert if they kept looking away from the road.

Finally, participants were asked to put on the eye tracker and went through a calibration procedure. Participants then completed an extra training drive, which they were told was the first experimental drive. In this practice drive, like in the experimental drives, participants were asked to use the ADAS when possible, had the secondary task available, and the attention monitoring system was active. Participants experienced two abrupt-onset hazards (sudden lead vehicle braking events that were different than the ones tested in the experimental drives), one A-N and one A-not-N. The purpose of this drive was for participants to experience the limited capabilities of the ADAS to adjust their trust and reliance on the systems before the actual experimental drives.

Participants then completed the four experimental drives, in one of the orders from Figure 24. Experimental drives were 6.5 minutes long on average (*SD* = 0.4). After the last training drive (which participants were told was the first experimental drive) and each of the experimental drives, participants filled out questionnaires to assess trust in the ADAS, driver acceptance of the ADAS, and perceived workload. The trust in ADAS questionnaire included four items from Jian, Bisantz, and Drury's (2000) trust in automation scale, which were rated on a scale from 1 (not at all) to 7 (extremely). The acceptance questionnaire had nine items which required participants to rate their feeling about the ADAS on a 5-point semantic differential scale scored from -2 to +2 (adapted from van der Laan, Heino, & de Waard, 1997). Finally, perceived workload was measured using a modified version of the NASA-TLX, which asked participants to rate their workload on six subscales (mental demand, physical demand, temporal demand, performance, effort, frustration level) from 1 to 20 (Hart & Staveland, 1988); the paired comparisons were not included. The full post-drive questionnaires can be found in Appendix G.

After completing all experimental drives, participants filled out several post-experiment questionnaires, including a questionnaire to assess knowledge of ADAS (based on the questionnaire used in our prior online study; DeGuzman & Donmez, 2022) and a basic demographic questionnaire (e.g., income, education level; see Appendix I for participant demographics). The knowledge questionnaire contained two sets of items. The first set of items was related to ADAS' ability to maintain the vehicle's speed and lane position. Half of the items represented situations where the ADAS may have difficulty maintaining the vehicle's speed and lane position, while the other half represented situations where the ADAS should work. The second set of items were related to ADAS' ability to avoid a collision, where half represented situations where ADAS may have difficulty avoiding a collision and half represented situations where ADAS should work. For each set of items, participants were asked to check all of the situations where ADAS may have difficulty maintaining the vehicle's speed and lane position or avoiding a collision, respectively. The full knowledge questionnaire can be found in Appendix H. After completing the post-experiment questionnaires, participants received their compensation and were provided with a debrief form, which explained the purpose of the experiment and the deception related to the bonus (i.e., all participants who completed the experiment received the full bonus regardless of their secondary task and driving performance).

4.1.8. Analysis

4.1.8.1. Dependent Variables

Four types of dependent variables were analyzed for each event: visual attention, manual secondary task interactions, driving performance, and anticipatory driving behaviours. For visual attention, we measured the percent of time participants spent looking at three areas of interest (AOIs; the secondary task, road, and anticipatory cues), and the average glance duration to the secondary task and the road. Ergoneers' D-Lab software was used to process the eye tracking data. First, glances to the road and secondary task were identified using D-Lab's automatic AOI glance detection feature. Glances during the analysis periods (see Figure 26) were then manually reviewed in D-Lab to correct for any inaccuracies. Following the ISO 15007:2013 standard, glances to an AOI had to be greater than 120 ms (ISO, 2013a) and any glances to the same AOI separated by blinks less than 500 ms were treated as one continuous glance (ISO, 2013b). Glances to the anticipatory cues were marked manually in D-Lab by the author.

Visual attention and the rate of manual secondary task interactions were analyzed both before and after cue onset, where cue onset is the time when the anticipatory cues first became visible in the scenario. Glances to the anticipatory cues were analyzed during the after cue onset period (from cue onset until event onset or takeover, whichever occurred first; Figure 26). All other visual attention measures and the rate of manual secondary task interactions were analyzed during the before cue onset period (20 s before cue onset until cue onset) and after cue onset period (Figure 26). For the number of long glances within a data extraction period, glances that fell partially within a data extraction period were counted as one glance. However, for calculating the average glance duration, following previous research (He et al., 2021; Seppelt et al., 2017), if a glance fell partially within a data extraction period, only the portion of the glance within the data extraction was counted towards the number of glances. For example, if 600 ms of a 1 s glance was contained within a data extraction period, it would be counted as 0.6 glances.

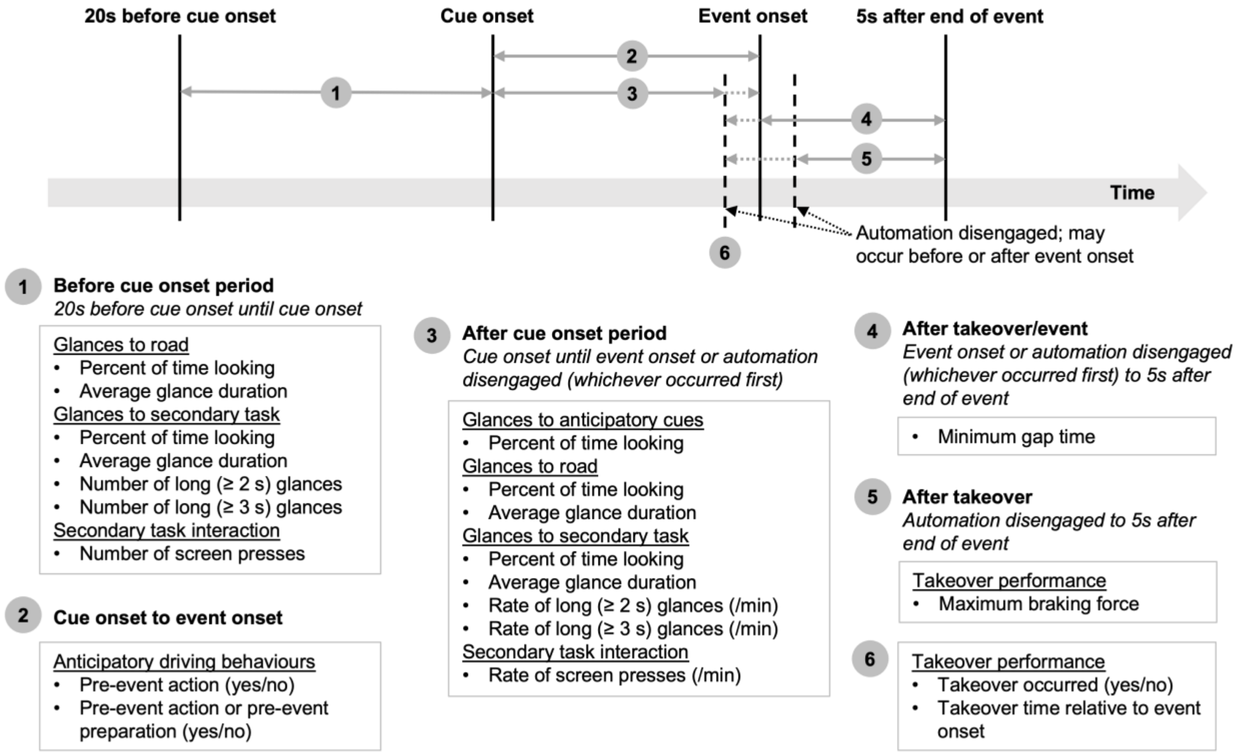


Figure 26. Time periods and measures extracted for event-related analyses in Study 3. The average time from cue onset to event onset was 38.9 s for event A, 10.3 s for event B, 13.1 s for event C, and 11.0 s for event D. The time from event onset to 5 s after the end of the event was 9 s for events A and B, 11 s for event D, 8.5 s for the A-N version of event C, and 7 s for the A-not-N version of event C.

Four driving performance measures were collected: (1) minimum gap time, (2) whether a takeover occurred, and if so, (3) the maximum braking force and (4) takeover time. Minimum gap time was the time (in seconds) from the ego-vehicle's front bumper to the lead vehicle's rear bumper and was used as an overall indicator of driving safety; it was collected during the time period from event onset or takeover (whichever occurred first) to 5 s after the end of the event (Figure 26). If a collision occurred, the minimum gap time was recorded as 0. Only 16 collisions occurred, thus there was not enough data to analyze them separately, but they were captured in the minimum gap time analysis. If a collision occurred, the participant's vehicle would overlap with the other vehicle in the simulation but there was no other feedback (i.e., the collision sound, haptic, and other visual effects, such as cracked windshield, were disabled). For events where the ADAS was disengaged (n = 251), maximum braking force and takeover time were used as measures of takeover performance. Maximum braking force was the maximum force (from 0 to 180) recorded by the brake pedal and was recorded from takeover to 5 s after the end of the event (Figure 26), with larger values indicating higher braking force. Takeover time was the time relative to event onset when the automation was disengaged, thus smaller values indicated earlier takeover time and a negative value indicated that participants took over before event onset. The ACC disengagement time was used as the takeover time; in some cases (n = 21) participants also disengaged the LKA but it occurred after the ACC disengagement.

Measures of anticipatory driving behaviour were based on prior research on anticipation in driving (e.g., He & Donmez, 2018; He et al., 2021; Stahl et al., 2014; Stahl, Donmez, & Jamieson, 2016, 2019). Stahl et al. (2014) defined anticipatory driving in non-automated vehicles as “a high level cognitive competence that describes the identification of stereotypical traffic situations on a tactical level through the perception of characteristic cues, and thereby allows for the efficient positioning of a vehicle for probable, upcoming changes in traffic” (p. 605). Thus, anticipation involves drivers interpreting how the traffic will develop based on ambiguous cues in the environment (i.e., anticipatory cues). For example, an anticipatory cue for event D in this study (Table 14) is the decreasing distance between the white vehicle and the slow truck, which suggests that the white vehicle may change lanes ahead of the participant’s vehicle. However, the white vehicle could also slow down and change lanes behind the participant’s vehicle or remain in the right lane. In non-automated driving, anticipatory driving behaviours are actions that the driver takes to position the vehicle based on their interpretation of the cues, and must occur before event onset (i.e., the point at which the cues in the environment unambiguously indicate the upcoming event) (He & Donmez, 2018; Stahl et al., 2014, 2016, 2019). After event onset, driver actions are no longer based on anticipating the upcoming event, but reacting to the event that has started to unfold (Stahl et al., 2014). As such, these behaviours are also referred to as pre-event actions. While using ADAS, pre-event actions include taking over manual control of the speed and steering, but could also include manually adjusting the ACC settings (i.e., to increase or decrease the set speed). However, drivers using ADAS may correctly interpret anticipatory cues but not exhibit any pre-event actions (e.g., because they think the ADAS will successfully handle the situation, or they are waiting to see if the ADAS will handle the situation before intervening). Thus, He et al. (2021) expanded the concept of anticipatory driving behaviours in vehicles with ADAS to include pre-event preparations, where the driver exhibits an intention to take over control of the vehicle or adjust the automation settings (e.g., moving their foot towards the brake pedal), but does not exhibit a pre-event action.

In this study, anticipatory driving behaviours (i.e., pre-event actions and pre-event preparations) were analyzed from cue onset to event onset (Figure 26). Following the method in He et al. (2021), a pre-event action for this study was defined as any control action taken by the participant to take over control of the vehicle speed or change the set speed of the ACC (i.e., using the buttons on the steering wheel) before event onset. A pre-event preparation was defined as any observed intention to intervene in the driving task before event onset (e.g., moving their foot towards the brake or hovering their fingers over the ACC buttons on the steering wheel). Two raters blind to the participants' training group (one with 10+ years of driving experience and one with 3-4 years of driving experience) reviewed the participant-facing recordings for each cue to event onset period and coded the presence of a pre-event preparation and/or pre-event action. There was 83% agreement between the two raters after the initial review. A third rater (8-9 years of driving experience) independently reviewed the recordings for any instances where there was a disagreement between the first two raters and coded the presence of any anticipatory behaviours. All three raters then met to discuss the disagreements and come to a consensus. For events where an anticipatory behaviour was identified, but the participant did not have any glances to the anticipatory cues, the event was marked as no action or preparation. Prior to coding the data, all raters were trained on the types of anticipatory behaviours drivers might exhibit, but they were not given strict criteria for how to classify anticipatory behaviours; they were asked to use their judgement based on their driving experience.

Of the 320 observations for the event-related analyses, 26 were removed from all measures due to missing data, equipment issues, an event not occurring as expected in the simulation, or the A-N event in the training drive not occurring as expected in the simulation (in this case, data up to the first A-N event in the experimental drives was removed). Of the remaining 294 observations, 3 were removed from any measures collected after cue onset (i.e., time periods 2-6 in Figure 26) because participants disengaged the ADAS shortly before cue onset. Finally, for one participant, calibration of the eye tracking data was not precise enough to determine if they were looking at the anticipatory cues, so an additional 7 observations from this participant were removed for the analyses of anticipatory behaviours and glances to the anticipatory cues.

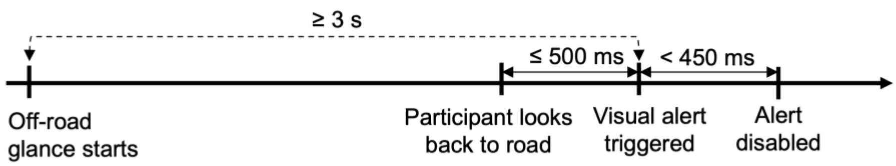
In addition to the event-related measures in Figure 26, post-drive questionnaire (trust, acceptance, and workload) and post-experiment questionnaire (ADAS knowledge) data was analyzed. The four items on the trust questionnaire were averaged, resulting in a single average trust score. The acceptance questionnaire contained two subscales (usefulness and satisfaction); the items for each subscale were averaged resulting in an average usefulness and average satisfaction score. For perceived workload, the Raw TLX was calculated by averaging the workload ratings across the subscales, resulting in one score for average workload (Hart, 2006). Of the 160 observations for the post-drive questionnaires, 1 was removed because the simulation crashed partway through the drive and the participant did not fully experience either event. Finally, for the knowledge questionnaire, we calculated the percent of ADAS limitations (i.e., situations where ADAS may have difficulty maintaining the vehicle's speed and lane position or avoiding a collision) that participants correctly identified. We also calculated sensitivity (d') and bias (c, criterion location) based on signal detection theory (e.g., Macmillan & Creelman, 2005; Stanislaw & Todorov, 1999), where a signal was an ADAS limitation. Sensitivity represented participants' ability to identify situations where ADAS may not work ($d' = 0$ indicated chance performance), while response bias reflected their inclination towards a certain response (e.g., a positive response bias would indicate an inclination to respond that ADAS would work regardless of the situation).

4.1.8.2. Attention Monitoring System Performance

We also calculated the false alarm rate of the attention monitoring system for the before cue onset and after cue onset periods for which we had cleaned eye tracking data. The false alarm rate (number of false alarms/number of true negatives; see Figure 27) was calculated by comparing the data from the attention monitoring system to the cleaned eye-tracking data obtained after post-processing. False alarm rates were calculated separately for the visual and auditory components of the alert. For the visual component, a false alarm occurred when the alert was triggered but the participant was either looking at the road or the off-road glance was < 3 s (Figure 27). For the auditory component, a false alarm occurred when the alert was triggered but the participant had looked back to the road within 1 s of the visual alert being triggered (Figure 27). However, given lags that could occur with the real-time eye-tracking (e.g., it could take a few hundred milliseconds for the eye-tracker to register in real-time when the participants looked back towards the road due to head motion), we included a short lag time when determining whether an alert was considered a hit or false alarm. For the visual component of the alert, if the cleaned eye-tracking data showed the participant had been looking at the road for 500 ms or less when the alert was triggered and the alert was active for less than 450 ms, it was still considered a hit (Figure 27). For the auditory component of the alert, if the cleaned eye tracking data showed that the participant had been looking at the road for 100 ms or less when the alert was triggered, and the alert was active for less than 450 ms, it was still considered a hit (Figure 27). Thus, the minimum off-road glance duration for a valid visual alert was 2.5 s and the minimum time between a visual alert and valid auditory alert was 900 ms (Figure 27). Overall, the visual component of the alert had an average false alarm rate of 3.1% (*SD* = 4.4%), and the auditory component of the alert had an average false alarm rate of 13.5% (*SD* = 29.4%). There was no significant difference in false alarm rates between training groups. At least one visual alert should have been triggered in 35% of the data collection periods; the visual alert had a miss rate of 38.6% (*SD* = 40.7). At least one auditory alert should have been triggered in 17% of the data collection periods; the auditory alert had a miss rate of 23.2% (*SD* = 40.3). The miss rate was not analyzed further due to the relatively low proportion of data collection periods with a true positive (i.e., where an alert should have been triggered).

	Visual alert triggered	Visual alert not triggered
Off-road glance ≥ 3 s & participant looking away from road*	Hit	Miss
Off road glance < 3 s or participant looking at road	False Alarm	Correct Rejection

*Allowance for a short lag in detection was included. If the alert was triggered when the participant was looking at the road, but they had been looking at the road for 500ms or less and the alert lasted less than 450 ms (see below), this was considered a hit.



	Auditory alert triggered	Auditory alert not triggered
Visual alert triggered, participant cont'd off-road glance for ≥ 1 s*	Hit	Miss
Visual alert triggered, participant looked at road in < 1 s	False alarm	Correct rejection

*Allowance for a short lag in detection was included. If the alert was triggered when the participant was looking at the road, but they had been looking at the road for 100ms or less and the alert lasted less than 450 ms (see below), this was considered a hit.

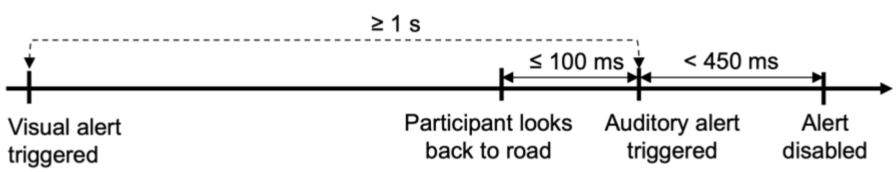


Figure 27. Signal detection classification for the visual alert (top) and auditory alert (bottom) in Study 3. Number of true positives = number of hits + number of misses. Number of true negatives = number of false alarms + number of correct rejections.

4.1.8.3. Statistical Models

All statistical analyses were conducted using SAS OnDemand for Academics. For percent of time looking at the cues and maximum braking force, beta regression was used due to non-normality and the bounded nature of the data. Poisson regression was used to analyze count data (i.e., number of glances 2 s or greater, number of glances 3 s or greater, and number of manual secondary task interactions), with the length of the after cue onset period used as an offset variable for analyses of the after cue onset data. Binary logistic regression was used to analyze the anticipatory behaviour and takeover occurrence data. Linear models were used to analyze all other data. To correct for non-normality and outliers in the data, average glance duration to the road (before and after cue onset) was log-transformed and takeover time was cube-transformed prior to analysis. Since takeover time could be negative (i.e., if participants took over before event onset), a constant of 50 was added to takeover time before transformation so that all values were positive. Participant was added as a repeated measure in all linear models (fitted using PROC MIXED) except for the knowledge questionnaire analyses for which we only had one response per participant. For beta regression models (fitted using PROC GLIMMIX), participant was added as a random factor, and for binary logistic and Poisson models (fitted using PROC GENMOD), generalized estimating equations were used to account for the repeated measures.

For the before cue onset analyses, only training group was included as an independent variable as the event-related factors (event type and event criticality) were only relevant after cue onset. For the rest of the analyses, main effects of training, event type, and event criticality were included as independent variables, along with the training by event type and training by event criticality interactions. The event type by event criticality interaction and 3-way interaction were included during model fitting but removed if not significant, as these were not of interest in our experimental design. Although there were no differences in false alarm rates across training groups, given that a higher false alarm rate could affect participants' glance behaviour or opinions about the ADAS, the false alarm rates were included as covariates in the visual attention and post-drive questionnaire models to account for any potential effects. The visual and auditory false alarm rates were correlated, $r = 0.32$, $p < .001$, but given that it was not a large correlation, the false alarm rates were entered as individual covariates. The false alarm rate during the analysis period was used (e.g., for the before cue onset analyses, the false alarm rates during the before cue onset period were used as the covariates). Follow-up comparisons were done for any significant main effects and interactions; only significant ($p < .05$) follow-up comparisons are reported.

4.2. Results

4.2.1. Visual Attention

4.2.1.1. Before Cue Onset

Before cue onset, there was a significant effect of training group on the number of glances 3 s or longer to the secondary task (Table 15). For the responsibility-focused group, the number of glances 3 s or longer was 75% lower than the no training group [95% CI: 0.10, 0.65], $\chi^2(1) = 8.14$, $p = .004$, and 65% lower than the limitation-focused group [95% CI: 0.13, 0.96], $\chi^2(1) = 4.14$, $p = .04$ (Figure 28). There was also a significant effect of the visual alert false alarm rate on glances to the road and secondary task (Tables 15 and 16). A higher false alarm rate was associated with lower percent of time looking at the road, $t(169) = -3.49$, $p < .001$, higher percent of time looking at the secondary task, $t(287) = 2.82$, $p = .005$, and longer average glance duration to the secondary task, $t(167) = 4.11$, $p < .001$. A 1% increase in the visual false alarm rate was associated with 1.05 times the number of glances 2 s or longer to the secondary task [95% CI: 1.02, 1.07], $\chi^2(1) = 13.85$, $p < .001$, and 1.05 times the number of glances 3 s or longer to the secondary task [95% CI: 1.01, 1.10], $\chi^2(1) = 6.01$, $p = .01$.

Table 15. Results of glance metrics for the secondary task and secondary task interactions before cue onset in Study 3. Significant ($p < .05$) results are in bold.

	Average glance duration to the secondary task			Percent of time looking at the secondary task			Number of glances ≥ 2s to the secondary task			Number of glances ≥ 3s to the secondary task			Rate of secondary task interactions		
	DF	*F*	*p*	*DF*	*F*	*p*	*DF*	χ^2	*p*	*DF*	χ^2	*p*	*DF*	χ^2	*p*
Training	2, 31.7	1.74	.19	2, 35.8	0.51	.61	2	3.74	.15	**2**	**8.53**	**.01**	2	0.17	.92
Visual FAR	**1, 167**	**16.90**	**< .001**	**1, 287**	**7.97**	**.005**	**1**	**13.85**	**< .001**	**1**	**6.01**	**.01**	1	1.04	.31
Auditory FAR	1, 116	0.33	.57	1, 282	1.26	.26	1	0.12	.73	1	0.33	.57	1	0.03	.86

Notes: FAR = false alarm rate. FARs were calculated for the before cue onset period.

Table 16. Results of glance metrics for the road before cue onset in Study 3. Significant ($p < .05$) results are in bold.

	Average glance duration to the road			Percent of time looking at the road		
	DF	*F*	*p*	*DF*	*F*	*p*
Training	2, 37.1	0.17	.85	2, 36.4	0.68	.51
Visual FAR	1, 272	0.67	.41	**1, 169**	**12.16**	**< .001**
Auditory FAR	1, 267	0.14	.71	1, 133	3.02	.08

Notes: FAR = false alarm rate. FARs were calculated for the before cue onset period.

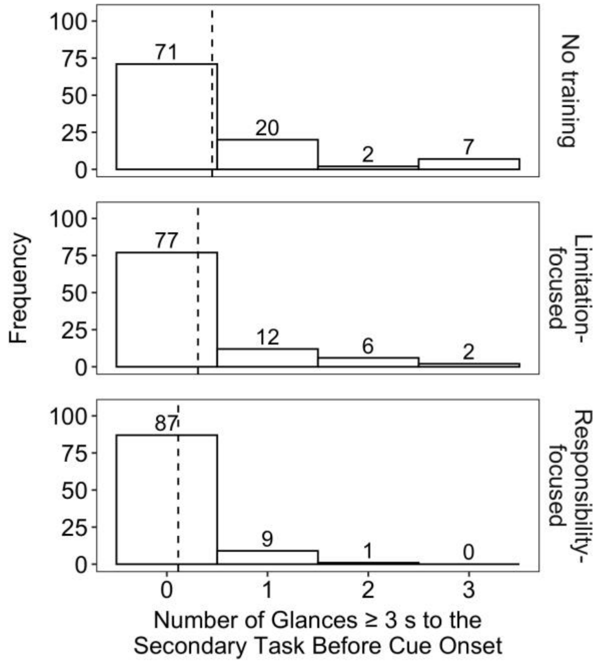


Figure 28. Number of glances 3 s or longer to the secondary task before cue onset by training group in Study 3. Numbers above the bars indicate the frequency; the dashed line indicates the mean.

4.2.1.2. After Cue Onset

There was a significant main effect of training on percent of time looking at the cues (Table 17). The responsibility-focused group had a higher percent of time looking at the cues compared to the limitation-focused group, $t(36) = 2.48$, $p = .02$ (Figure 29). None of the independent variables of interest had a significant effect on average glance duration towards the road or percent of time looking at the road (Table 17). However, a higher visual false alarm rate was associated with higher average glance duration to the road, $t(265) = 2.75$, $p = .006$ (Table 17).

Table 17. Results of glance metrics for the road and cues in the after cue onset period in Study 3. Significant (p < .05) results are in bold.

	Average glance duration to the road			Percent of time looking at the road			Percent of time looking at the cues		
	DF	*F*	*p*	*DF*	*F*	*p*	*DF*	*F*	*p*
Visual FAR	**1, 265**	**7.55**	**.006**	1, 270	0.90	.34	1, 237	1.55	.22
Auditory FAR	1, 263	1.01	.32	1, 268	1.64	.20	1, 237	0.34	.56
Training	2, 37.2	0.00	.998	2, 37.3	0.56	.58	**2, 36**	**3.58**	**.04**
Event Type	1, 246	0.09	.77	1, 247	1.55	.21	1, 36	0.00	.99
Event Criticality	1, 245	2.35	.13	1, 245	1.10	.29	1, 36	0.33	.57
Training × Event Type	2, 245	1.60	.20	2, 246	2.39	.09	2, 36	2.60	.09
Training × Event Criticality	2, 245	2.00	.14	2, 245	1.52	.22	2, 36	0.87	.43

Note: FAR = false alarm rate. FARs were calculated for the after cue onset period.

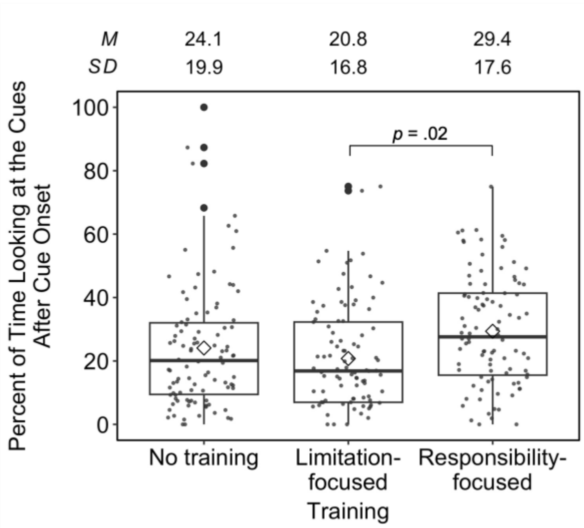


Figure 29. Percent of time looking at the cues by training group in Study 3. Boxplots represent the five-number summary, the diamond indicates the mean. At the top, mean (*M*) and standard deviation (*SD*) values are provided.

There was a significant training by event type interaction for average glance duration to the secondary task and percent of time looking at the secondary task (Table 18). Compared with the no training group, the responsibility-focused group had lower average glance duration to the secondary task, $t(38.4) = -2.47$, $p = .02$, and lower percent of time looking at the secondary task, $t(60.1) = -2.08$, $p = .04$, for the lane change events (Figure 30).

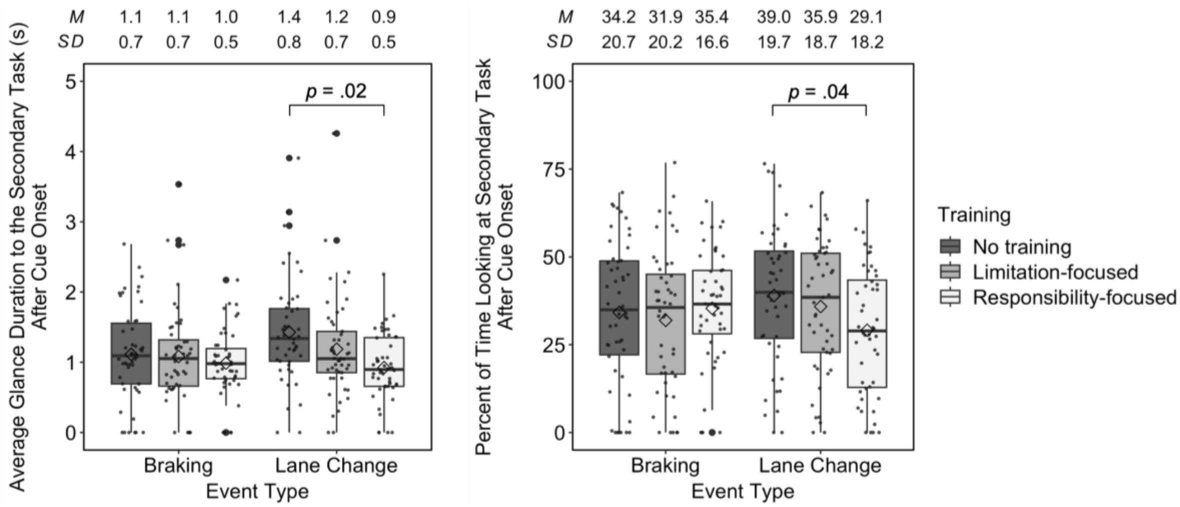


Figure 30. Average glance duration to the secondary task (left) and percent of time looking at the secondary task (right) after cue onset, by event type and training group in Study 3. At the top, mean (*M*) and standard deviation (*SD*) values are provided.

For long glances to the secondary task, there was a significant effect of training on the rate of glances 3 s or longer (Table 18). The rate of glances 3 s or longer to the secondary task was 84% lower for the responsibility-focused group compared with the no training group [95% CI: 0.04, 0.59], $\chi^2(1) = 7.58$, $p = .006$ (Figure 31).

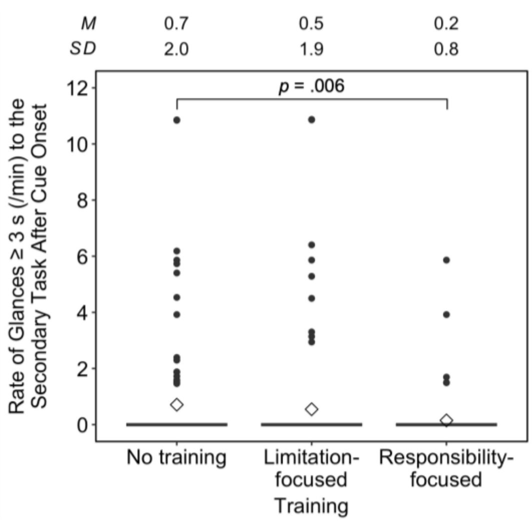


Figure 31. Rate of glances 3 s or longer to the secondary task after cue onset by training group in Study 3. At the top, mean (*M*) and standard deviation (*SD*) values are provided.

4.2.2. Manual Secondary Task Interactions

There was a significant training by event type interaction effect on the rate of secondary task interactions after cue onset (Table 18). Results of the follow-up contrasts showed no significant differences between training approaches for either event type (Figure 32). However, for the no training group, the rate of secondary task interactions for the lane change event was 1.20 times higher than the braking event [95% CI: 1.02, 1.42], $\chi^2(1) = 4.97$, $p = .03$. Similarly, for the limitation-focused training group, the rate of secondary task interactions for the lane change event was 1.29 times higher than the braking event [95% CI: 1.03, 1.60], $\chi^2(1) = 5.09$, $p = .02$. There was no difference between events for the responsibility-focused group.

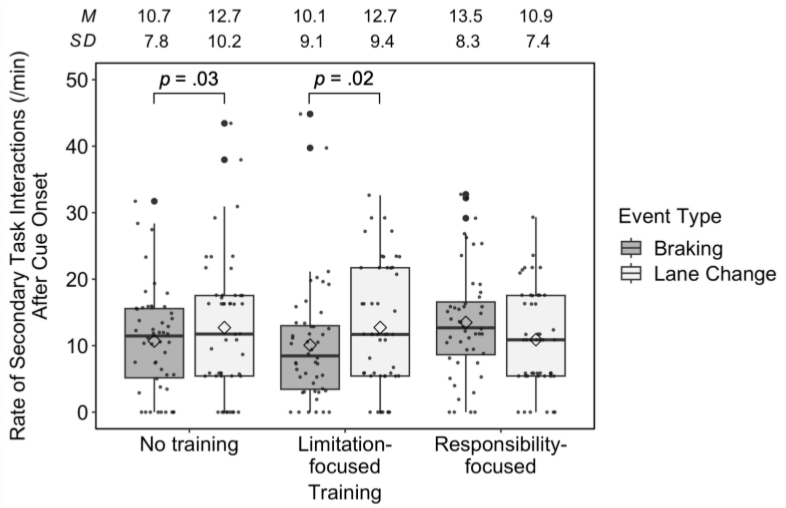


Figure 32. Rate of secondary task interactions (/min) after cue onset, by training group and event type in Study 3. At the top, mean (*M*) and standard deviation (*SD*) values are provided.

4.2.3. Driving Performance

4.2.3.1. Minimum Gap Time

Event type and event criticality had a significant effect on minimum gap time (Table 19). A-not-N events had longer minimum gap time than A-N events and braking events had a longer minimum gap time than lane change events (Figure 33).

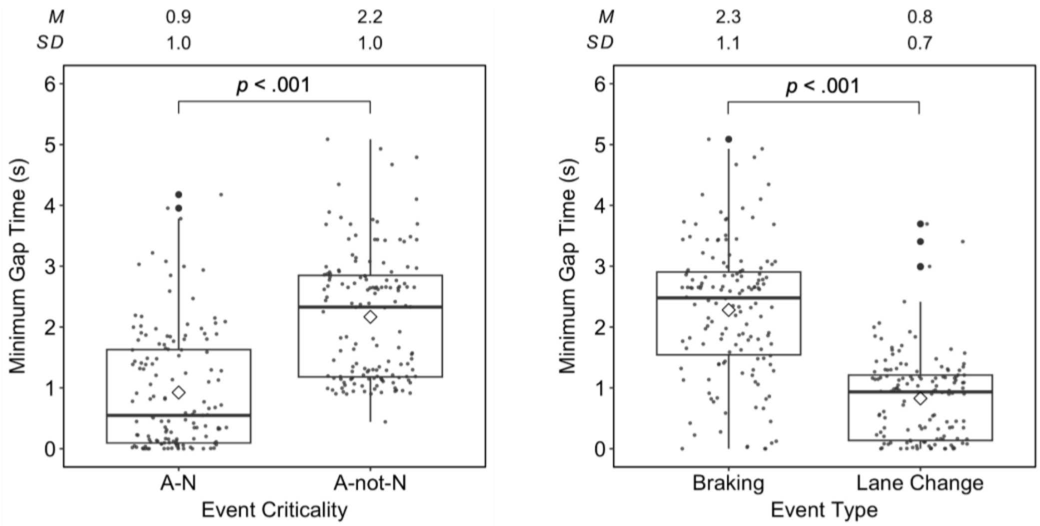


Figure 33. Minimum gap time (s) by event type (left) and event criticality (right) in Study 3. At the top, mean (*M*) and standard deviation (*SD*) values are provided.

Table 18. Results of glance metrics for the secondary task and secondary task interactions after cue onset in Study 3. Significant (p < .05) results are in bold.

	Average glance duration to the secondary task			Percent of time looking at the secondary task			Rate of glances ≥ 2s to the secondary task			Rate of glances ≥ 3s to the secondary task			Rate of secondary task interactions		
	DF	*F*	*p*	*DF*	*F*	*p*	*DF*	χ^2	*p*	*DF*	χ^2	*p*	*DF*	χ^2	*p*
Visual FAR	1, 104	2.21	.14	1, 269	0.33	.57	1	3.04	.08	1	0.37	.54	--	--	--
Auditory FAR	1, 79.8	0.17	.68	1, 267	2.45	.12	1	2.28	.13	1	2.87	.09	--	--	--
Training	2, 38.2	0.57	.57	2, 37.4	0.71	.50	2	3.76	.15	**2**	**6.33**	**.04**	2	0.15	.93
Event Type	**1, 40.7**	**7.80**	**.008**	1, 247	0.49	.49	1	1.36	.24	1	0.35	.56	1	1.56	.21
Event Criticality	1, 30.3	0.39	.54	1, 245	0.07	.79	1	0.14	.71	1	1.30	.25	1	0.14	.70
Training × Event Type	**2, 37.1**	**7.04**	**.003**	**2, 246**	**3.32**	**.04**	2	0.46	.80	2	0.54	.76	**2**	**8.65**	**.01**
Training × Event Criticality	2, 30.1	1.17	.32	2, 245	0.52	.59	2	0.50	.78	2	1.42	.49	2	1.60	.45

Note: FAR = false alarm rate. FAR is calculated for the after-cue-onset period.

Table 19. Results for anticipatory driving and driving performance measures in Study 3. Significant (p < .05) results are in bold.

	Pre-event action vs. no pre-event action (yes = 50, no = 234)			Anticipatory behaviour vs. no anticipatory behaviour (yes = 118, no = 166)			Minimum gap time			Takeover (yes = 250, no = 41)			Takeover time			Maximum braking force		
	DF	χ^2	*p*	*DF*	χ^2	*p*	*DF*	*F*	*p*	*DF*	χ^2	*p*	*DF*	*F*	*p*	*DF*	*F*	*p*
Training	2	1.15	.56	2	2.51	.29	2, 34.7	0.83	.45	2	1.86	.40	**2, 12.6**	**10.24**	**.002**	2, 36	1.45	.25
Event Type	**1**	**10.21**	**.001**	1	0.07	.78	**1, 245**	**362.11**	**< .001**	**1**	**5.38**	**.02**	**1, 25.1**	**12.33**	**.002**	**1, 35**	**34.14**	**< .001**
Event Criticality	1	2.80	.09	1	1.97	.16	**1, 244**	**268.72**	**< .001**	**1**	**10.82**	**.001**	1, 46.8	0.23	.63	**1, 34**	**110.48**	**< .001**
Training × Event Type	2	0.88	.65	**2**	**18.91**	**< .001**	2, 245	0.65	.52	2	0.68	.71	2, 24.8	0.58	.57	2, 35	0.06	.94
Training × Event Criticality	2	0.28	.87	2	0.47	.79	2, 244	0.37	.69	2	0.77	.68	2, 45.9	0.90	.41	2, 34	0.83	.45

4.2.3.2. Takeover Performance

There was a main effect of event type and event criticality on whether or not participants took over control of the vehicle. Odds of taking over were 3.18 times higher for A-N events than A-not-N events, [95% CI: 1.55, 6.52], $\chi^2(1) = 10.00$, $p = .002$, and 2.09 higher for braking than lane change events, [95% CI: 1.04, 4.18], $\chi^2(1) = 4.13$, $p = .04$. Although there was no effect of training on whether participants took over, there was a significant effect of training on takeover time (Table 19). Participants in the responsibility-focused group took over earlier than those in the limitation-focused group, $t(12.3) = -4.52$, $p < .001$, and no training group, $t(13.7) = -2.26$, $p = .04$ (Figure 34a). There was also a significant main effect of event type on takeover time (Table 19), whereby participants took over earlier for the braking events than the lane change events, $t(31.3) = -4.56$, $p < .001$ (Figure 34b). For maximum braking force, there was a significant main effect of event criticality and event type (Table 19). A-N events had higher maximum braking force than A-not-N events, $t(34) = 10.51$, $p < .001$ (Figure 34c), and braking events had higher maximum braking force than lane change events, $t(35) = 5.84$, $p < .001$ (Figure 34d).

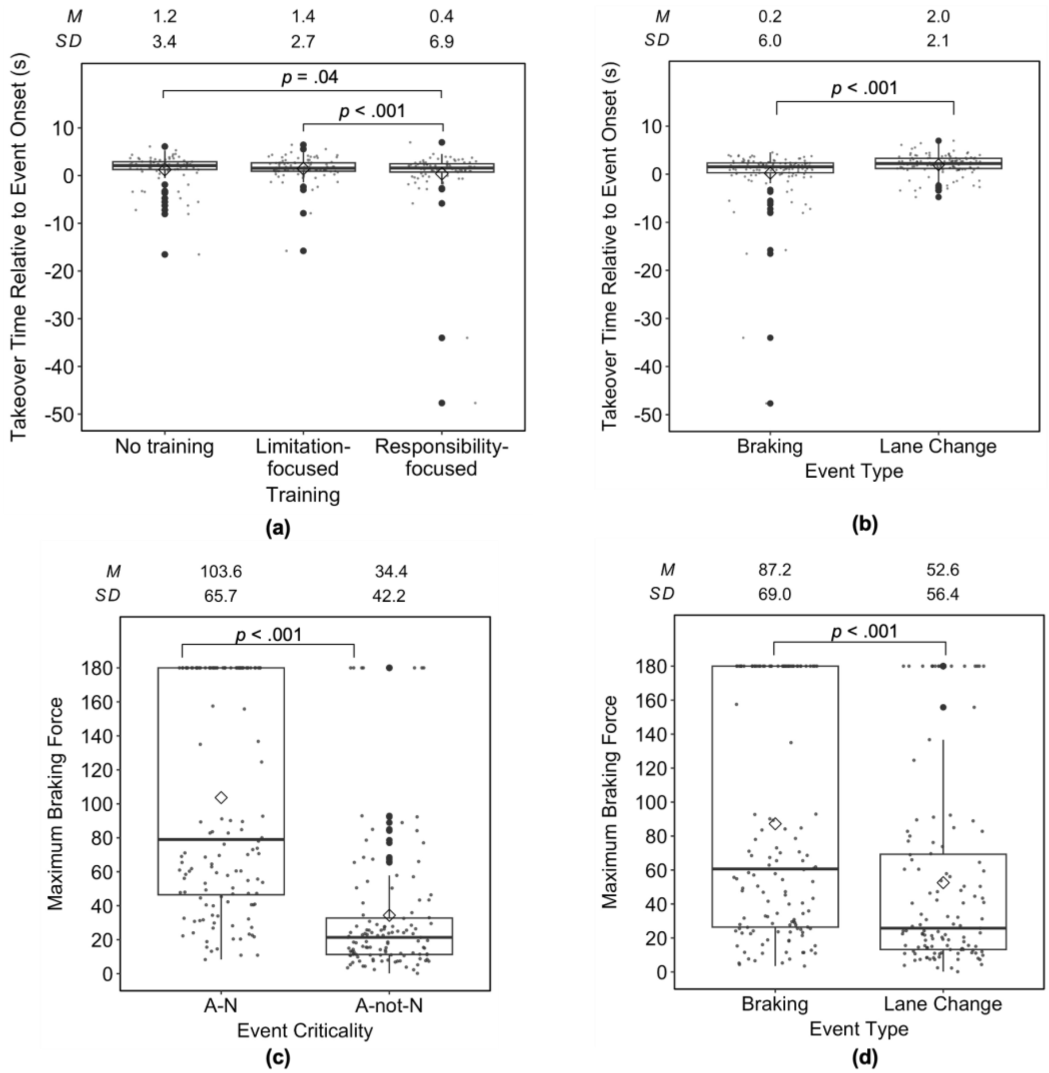


Figure 34. Takeover performance results in Study 3: (a) Takeover time (s) relative to event onset by event criticality and training group. (b) Takeover time (s) relative to event onset by event type, for events with a takeover. (c) Maximum braking force by event criticality for events with a takeover. (d) Maximum braking force by event type for events with a takeover. At the top, mean (*M*) and standard deviation (*SD*) values are provided.

4.2.4. Anticipatory Behaviours

There was a significant training by event type interaction on whether or not participants exhibited an anticipatory behaviour (i.e., either pre-event action or pre-event preparation) (Table 19). The responsibility-focused training group had 4.73 higher odds of an anticipatory behaviour compared with no training, but only for lane change events [95% CI: 1.63, 13.77], $\chi^2(1) = 8.15$, $p = .004$ (Figure 35). There was a significant main effect of event type on the odds of exhibiting a pre-event action (Table 19). Odds of a pre-event action were 2.28 times higher for braking events than lane change events [95% CI: 1.38, 3.79], $\chi^2(1) = 10.21$, $p = .001$ (Figure 35).

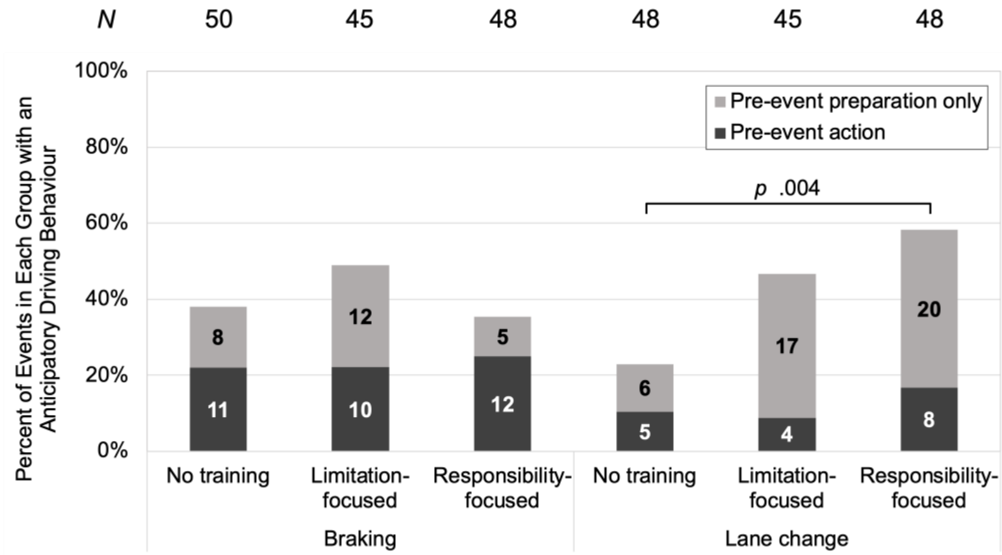


Figure 35. Percent of events with an anticipatory behaviour by training group and event type in Study 3. Number in bars represent counts. Counts along the top of the figure represent the total number of events for each training group by event type.

4.2.5. Questionnaires

There were no significant results for the post-drive questionnaires or the ADAS knowledge questionnaire. Based on inspection of the raw data (Figure 36a), average trust for participants in the limitation- and responsibility-focused groups fell near the middle of the 7-point scale (M = 4.2 and 3.9, respectively), while participants in the no training group had slightly higher trust. Average workload was on the lower half of the scale (i.e., less than 10) for all groups, but was lowest for the no training group (Figure 36b). Average usefulness and satisfaction ratings were positive across all training groups (Figure 36c and d). For the knowledge questionnaire, on average, all groups had better than chance performance at identifying the true ADAS limitations, with the limitation- and responsibility-focused groups having higher sensitivity than the no training group (Figure 37a). Average bias was close to 0 for all groups (Figure 37b), although the no training group had a slightly positive bias (i.e., bias towards reporting that an item was not an ADAS limitation) while the limitation- and responsibility-focused groups had a slightly negative bias (i.e., bias towards reporting that an item was an ADAS limitation).

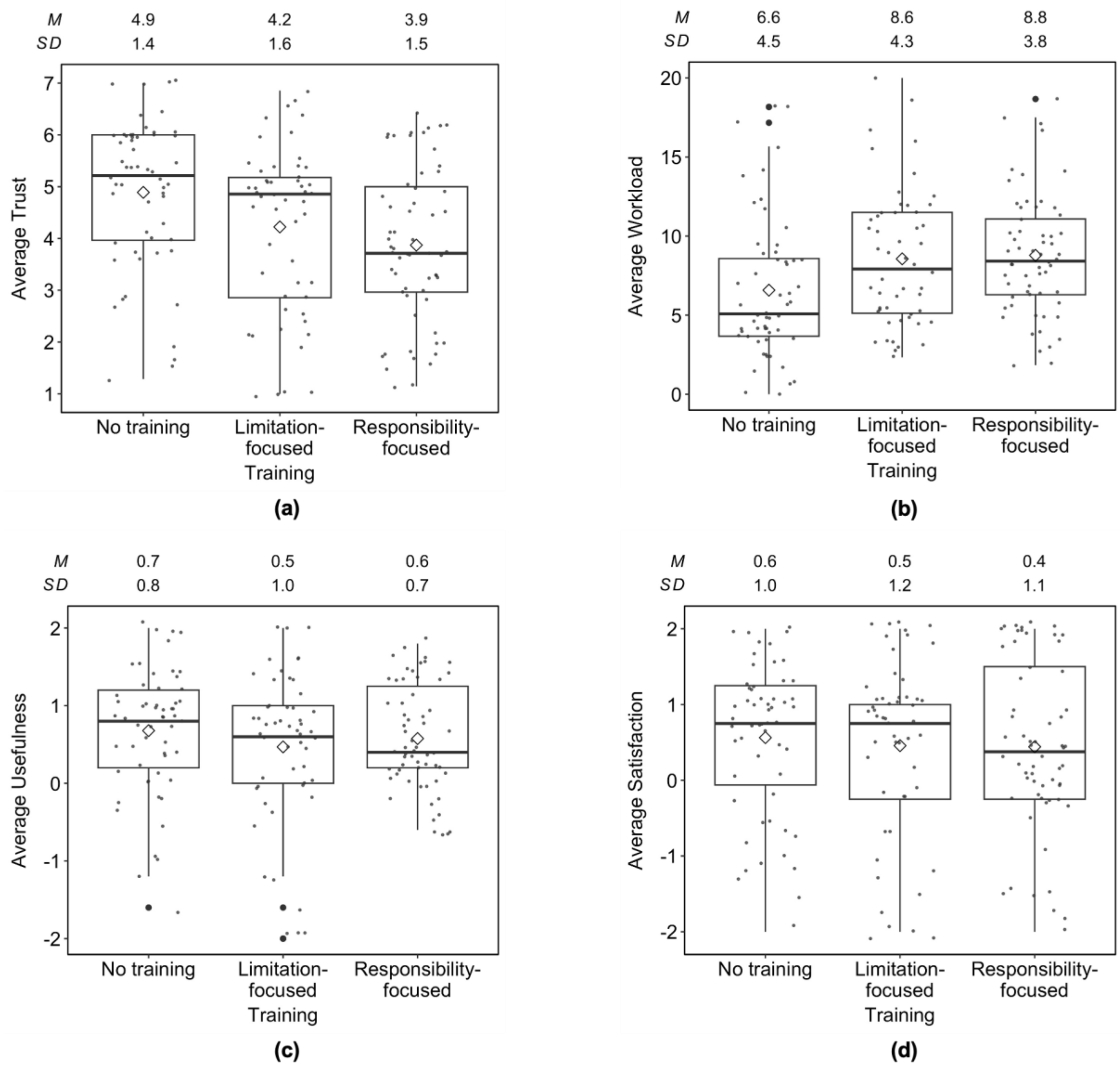


Figure 36. Post-drive questionnaire results by training group in Study 3: (a) average trust, (b) average workload, (c) average usefulness, (d) average satisfaction. Boxplots represent the five-number summary, the diamond indicates the mean. At the top, mean (*M*) and standard deviation (*SD*) values are provided.

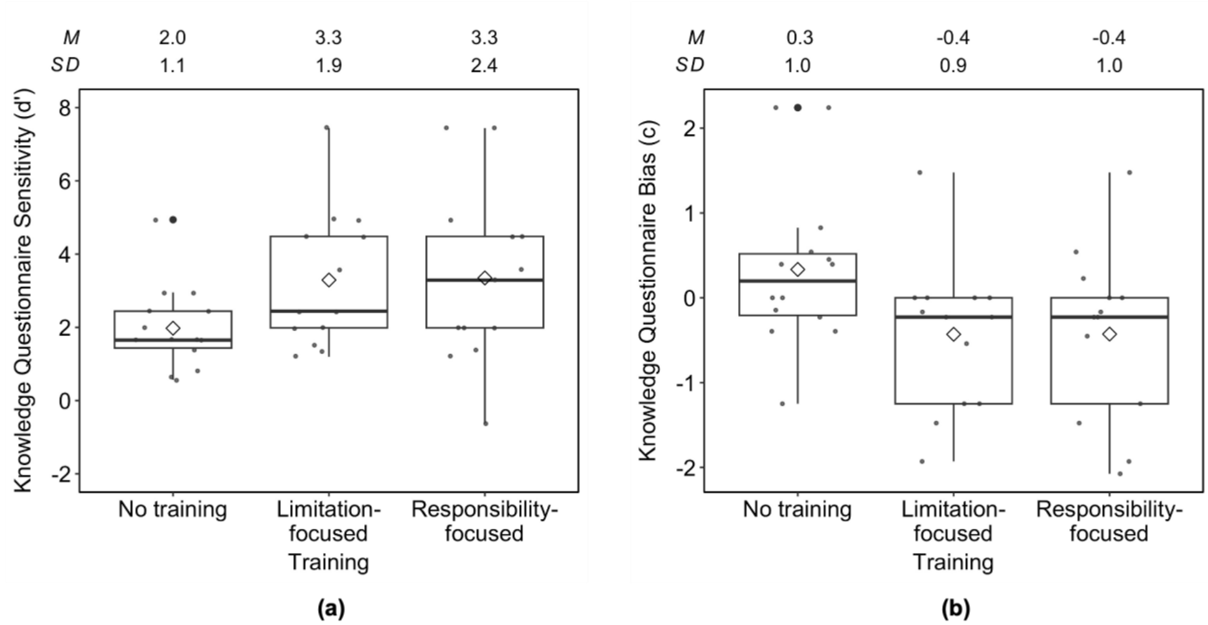


Figure 37. Knowledge questionnaire results in Study 3: (a) Sensitivity (*d′*) and (b) bias (*c*) for the post-experiment knowledge questionnaire by training group. Boxplots represent the five-number summary, the diamond indicates the mean. At the top, mean (*M*) and standard deviation (*SD*) values are provided.

4.3. Discussion

The primary objective of this simulator study was to investigate the effects of training on drivers' reliance on ADAS when an attention monitoring system was also implemented and whether there were differences between limitation-focused and responsibility-focused training as a follow-up to Study 2. Attention monitoring systems aim to support appropriate use of ADAS by reminding drivers to keep their eyes on the road. However, our findings suggest that even if attention monitoring systems are implemented, there may be benefits of responsibility-focused training compared to no training or limitation-focused training. A secondary objective of the study was to explore whether training affected drivers' knowledge of ADAS limitations or self-reported trust, acceptance, and workload, however, we found no significant effects.

The responsibility-focused training group made fewer long glances (3 s or greater) to the secondary task than the no training group (both before and after cue onset) and the limitation-focused group (before cue onset). The responsibility-focused group also spent more time looking at anticipatory cues than the limitation-focused group. In a previous study using the same simulator scenarios, an in-vehicle display that provided information about surrounding traffic (in combination with a TOR and automation capability information) was also associated with a lower percentage of time looking at the secondary task and higher percentage of time looking at the anticipatory cues (He et al., 2021). However, this type of interface would require connected vehicle technology to acquire information about the surrounding traffic. Our findings suggest that responsibility-focused training may also support drivers in making fewer long glances to a secondary task and paying more attention to relevant cues in the environment without requiring any additional technology. In a test track study, Victor et al. (2018) also implemented an attention monitoring system with a graded alert; a visual alert was triggered if participants were looking off road for more than 3.4 s or if they had been looking predominantly off-road over a 12 s period. Participants who had the attention monitoring system and who were informed that they should monitor the road as they would without driving automation had fewer off-path glances greater than 2 s and 4 s than those without the attention monitoring system who did not receive that instruction. Our results suggest even when all participants had an attention monitoring system, the responsibility-focused group had fewer glances 3 s or greater to the secondary task, suggesting that they may have been better able to manage their attention compared to those who had only the attention monitoring system. Unlike Victor et al. (2018), we did not find any difference in the rate of glances 2 s or greater to the secondary task, which may be due to participants feeling more comfortable making longer glances away from the road in the simulator compared to in a real vehicle.

While there was no effect of training on whether or not participants disengaged the ADAS, when they did take over, the responsibility-focused group took over sooner than the limitation-focused and no training groups. Thus, responsibility-focused training may result in improved monitoring of relevant information in the roadway, which helps drivers to anticipate upcoming events, leading to faster takeover times. Previous work shows that better knowledge of ACC limitations was associated with faster takeover time when limitations are encountered potentially due to reduced uncertainty about whether or not the ACC will work in a given situation (e.g., Bianchi Piccinini et al., 2015; Gaspar, Carney, Shull, & Horrey, 2021). Our findings suggest that responsibility-focused training may also lead to faster takeover times (regardless of whether the situation was covered in training), potentially due to reduced uncertainty about the driver's responsibility while using ADAS.

There were additional benefits of responsibility-focused training for the lane change events, which were covered in both training videos. Compared with no training, the responsibility-focused group had shorter average glance duration to the secondary task, lower percent of time looking at the secondary task, and a higher number of anticipatory behaviours. For the no training and limitation-focused group, the lane change event had higher rate of secondary task interactions compared with the braking event. However, there was no difference between events for the responsibility-focused training, which may suggest that participants were anticipating the event and thus interacting less with the task. Thus, to maximize training benefits, future research could investigate a combined approach, where responsibility-focused training is supplemented with additional information about system limitations. While the results of Study 2 suggest that limitation-focused training may be associated with decreased interest in using the technology and potential disuse, recent work found that combining training on ACC limitations and the drivers' role and responsibility while using ACC was associated with a higher percentage of ACC usage in a simulator than training on limitations alone (Zheng et al., 2023). Thus, potential negative effects of training on system limitations may be reduced if provided as a supplement to responsibility-focused training. Future research is needed to explore how a combination training approach compares to responsibility-focused and limitation-focused only.

With regards to the effects of training on knowledge and trust, we found no significant differences between training approaches on trust in ADAS in the simulator where participants experienced both action-necessary and action-not-necessary events. Similarly, in Study 2 we found no significant difference between training approaches for trust in scenarios that required a takeover. Also consistent with the findings of Study 2, we found no difference in knowledge sensitivity between training approaches. For knowledge bias, the results of Study 2 showed that limitation-focused training was associated with a negative bias at post-training but not at the follow-up session. The findings from Study 3 show no significant difference in bias between training approaches, which could be due to the delay in assessing knowledge. In Study 2, the post-training knowledge assessment was conducted only 10-15 minutes after training, while the follow-up session was a minimum of four weeks later. In Study 3, the knowledge assessment was conducted 1.5-2 hours after training, and thus it is possible that the effects of training on knowledge bias are only present for a short time (e.g., less than a couple of hours). However, it could also be due to participants' experience using ADAS between training and the knowledge questionnaire in Study 3. Further research is needed to investigate how timing and experience affect knowledge bias.

The findings of this study add to the existing literature on training approaches for ADAS. There have been relatively few studies on the effects of changing ADAS training content. As mentioned previously, Zheng et al. (2023) investigated the effects of adding training on the driver's role and responsibility while using ACC to training on system limitations. In addition to increased ACC use, they found that adding roles and responsibility training was associated with higher trust in ACC. Boelhouwer et al. (2019) found that providing participants with structural information (e.g., details about how the system/sensors work) did not differ from no training in terms of participants' ability to identify situations in which they should take over control from ADAS. The authors attributed the lack of significant results to the difficulty required for drivers to apply structural information in different scenarios. While previous work has found that better knowledge of ADAS limitations is associated with better takeover performance (e.g., Bianchi Piccinini et al., 2015; Gaspar et al., 2021; Krake et al., 2020), we found that when an attention monitoring system was implemented to encourage drivers to remain attentive to the roadway, there were no benefits of limitation-focused training compared with no training for takeover or visual attention measures. In contrast, the responsibility-focused training was associated with better takeover and monitoring performance.

4.3.1. Limitations and Future Work

While responsibility-focused training was associated with positive effects on driver behaviour (e.g., fewer long glances to the secondary task and faster takeover time), these effects were observed shortly after training. Studies of drivers with real-world experience using ADAS show that trust in and reliance on the systems increase with use (e.g., Dunn et al., 2019; Lin et al., 2018), and thus, longitudinal research is needed to whether the effects of training persist over time and with ongoing ADAS use. In addition, we did not assess knowledge prior to training as we did not want participants to look for certain situations in the experimental drives, so we were not able to assess any changes in knowledge from pre-training to post-training. Future work could explore the differences in ADAS knowledge before and after training for each approach. Finally, the performance of the attention monitoring system varied across participants, and the false alarm rate was found to have a significant association with some of the visual attention measures. While the performance of attention monitoring systems will likely also vary in real-world driving conditions, future ADAS training research in lab settings could attempt to control the false alarm rate to reduce any potential effects. Further, the effect of the visual false alarm rate differed depending on whether there were anticipatory cues in the environment. For example, before cue onset, a higher visual false alarm rate was associated with lower percent of time looking at the road, whereas after cue onset a higher visual false alarm rate was associated with higher average glance duration to the road. Thus, drivers may change how they respond to false alarms depending on what is occurring in the environment. Future research could also systematically vary the false alarm rate to explore how environmental cues affect the relationship between false alarm rates and driver visual behaviour.

4.4. Summary and Conclusions

Overall, we found benefits of the responsibility-focused training compared to no training and limitation-focused training, and no benefits of limitation-focused training compared to no training for both visual attention and takeover performance aspects of reliance on ADAS. The responsibility-focused training was associated with a lower rate of long glances to the secondary task, more time spent looking at anticipatory cues, and faster takeover time regardless of event type. There were also additional benefits for events that were covered in training (e.g., lower percent of time looking at the secondary task, more anticipatory behaviours), thus, future research may want to consider a combined approach to maximize training benefits. However, for situations where minimizing training length is advantageous (e.g., for self-initiated training), our results suggest that responsibility-focused training may be preferable to limitation-focused training.

Chapter 5
Summary and Conclusions

5.1. Summary of Key Findings

5.1.1. Study 1: Survey of North American Drivers

- Owning a vehicle with ACC or LKA does not appear to result in a better understanding of system limitations. For both owners and non-owners, participants tended to overestimate ADAS more than underestimate it.
- Prior to system use (i.e., for non-owners, who had no experience with ACC or LKA), knowledge of specific capabilities and response bias affects trust, which in turn, affects reliance intention (i.e., reported likelihood to engage in secondary tasks while using ADAS).
- Once drivers have experience with the system (i.e., owners in our sample), knowledge of specific system capabilities and response bias do not have a significant influence on trust. Higher trust was associated with higher reliance intention, however the effect was only marginally significant, potentially due to limited sample size.
- Given that knowledge of specific limitations does not appear to have a significant influence on trust or reliance intention once drivers have used ADAS, general training videos that aim to provide information to all drivers may not want to focus on teaching system limitations and instead investigate alternative training approaches.

5.1.2. Study 2: Remote Study

- There were limited differences between responsibility-focused and limitation-focused training for the quantitative measures we analyzed. Where we did find significant differences, they indicated potential drawbacks of the limitation-focused training approach.
- There was no difference between limitation-focused and responsibility-focused training in terms of trust in takeover scenarios; both training approaches significantly reduced trust in ADAS in takeover scenarios where the ADAS may not work. However, the limitation-focused training was associated with lower trust in no takeover scenarios, where the ADAS should work.
- At post-training, the limitation-focused approach was associated with a negative knowledge bias (i.e., bias towards reporting that the ADAS would not work in a given scenario for the

knowledge questionnaire) and a negative reliance bias (i.e., bias towards reporting that they would take manual control for the dashcam clips). By the follow-up session (minimum 4 weeks later), there were no longer any significant differences between training approaches. However, responses to the open-ended questions at post-training also revealed that reduced interest in using ADAS was highest among participants who had never previously used ADAS and received the limitation-focused training. Effective training would ideally balance reducing overreliance without dissuading people from using ADAS altogether, and limitation-focused training may have the drawback of imparting negative perceptions of ADAS on new or prospective users.

- Based on responses to the open-ended questions, fifteen percent of participants reported being more likely to engage in distractions while using ADAS after the training. While just under half of these participants specified that they would engage in distractions that did not require visual attention, a small number of experienced ADAS users felt that the technology would allow them to (briefly) engage in handheld cellphone distractions (i.e., texting). Thus, other interventions, like driver state monitoring, may be needed in conjunction with training to support safe ADAS use.

5.1.3. Study 3: Simulator Study

- When an attention monitoring system was implemented for all participants, there were still benefits of the responsibility-focused training compared to no training and limitation-focused training, but we did not find any benefits of the limitation-focused training compared to no training.
- The responsibility-focused training was associated with a lower rate of long glances (3 s or longer) to the secondary task than limitation-focused training (before anticipatory cues became visible) and no training (before and after anticipatory cues became visible), a higher percent of time looking at anticipatory cues than the limitation-focused group, and faster takeover time than both the no training and limitation-focused group.
- There were additional benefits of the responsibility-focused training compared with the no training group for the events that were covered in the training (i.e., lane change events). For lane change events, the responsibility-focused group had shorter average glance duration to secondary task, lower percent of time looking at secondary task, and a higher number of anticipatory behaviours compared with no training. Future research may want to consider a

combined responsibility- and limitation-focused approach to maximize training benefits, as training drivers on system limitations may have a reduced negative impact if provided in combination with responsibility-focused training.

- For situations where minimizing training length is advantageous and a more lengthy combined training approach may not be feasible (e.g., for self-initiated training), our results suggest that responsibility-focused training may be preferable to limitation-focused training.

5.2. Contributions

The relationship between knowledge of ADAS capabilities and limitations, trust, and reliance is not clear based on previous research. Some evidence indicated knowledge of limitations may be associated with more appropriate reliance (e.g., Bianchi Piccinini et al., 2015; Dickie & Boyle, 2009), while other research suggested that knowledge of limitations may not be sufficient (Victor et al., 2018). Further, it was unclear whether any potential effects of knowledge on reliance were direct or whether knowledge had an indirect effect on reliance through its impact on trust. Study 1 aimed to address this gap for drivers with and without ADAS experience, which helped to inform the alternative training approach used in Study 2 and 3 and can also inform future ADAS training.

Previous ADAS training has focused on teaching drivers various situations in which the ADAS may not work (i.e., system limitations) so that they have a better understanding of ADAS capabilities and limitations and may be better prepared to take over control of the vehicle if they encounter these situations. However, there are practical shortcomings of this limitation-focused approach. There are a wide range of system limitations, which may be unreasonable to expect drivers to learn and remember. Even if drivers were able to learn all of the potential limitations, they are likely to forget specific limitations over time unless they experience them (Beggiato et al., 2015). Further, with some manufacturers making changes to ADAS systems through over-the-air updates (e.g., Toyota, 2021), ADAS functioning in certain situations may change over time. The findings of Study 1 also add support to the idea that using limitation-focused training may not be ideal, as knowledge of specific ADAS limitations does not appear to influence trust in ADAS or reliance intention after drivers have used these systems. However, research on the design of ADAS training has primarily focused on teaching drivers this limitation-focused information, but changing the method of delivery (e.g., videos, in-car demonstrations, simulator training; Krampell et al., 2020; Noble et al., 2019; Singer & Jenness, 2020) to test the effects on driver behaviour and understanding of ADAS.

This dissertation adds to the limited literature on investigating changes to training content. Boelhouwer et al. (2019) acknowledged the impracticalities associated with limitation-focused training and investigated providing structural system information as an alternative. However, they found no significant differences between drivers who were provided with structural system information and those who received no training, which they attribute to potential difficulty with applying structural information when faced with different driving scenarios. This dissertation focused on a novel approach of highlighting the drivers' responsibility when using ADAS, instead of focusing on the system limitations. Other recent research has investigated the influence of training drivers on their role and responsibility while using ACC in addition to training on system limitations (Zheng et al., 2023). However, this dissertation focused on training for both ACC and LKA and provided responsibility-focused training without additional training on system limitations.

The advantage of investigating the separate effects of responsibility- and limitation-focused training is that it can inform the design of ADAS training if there are time constraints. Currently, there is no formal training for ADAS. Thus, shorter training videos are likely to be more successful, as drivers may not pay attention for lengthy training video that contain various types of information. In this context, the findings of this dissertation suggest that as a starting point, and if there is limited information that can be conveyed to the driver, a responsibility-focused approach may be preferable to a limitation-focused approach.

5.3. Limitations and Future Work

In addition to the limitations discussed in each study chapter, there are some general limitations of this research. Although we controlled for the length of training in the design of the responsibility-focused and limitation-focused videos, participants' level of engagement in the training may have differed between groups, which could have affected our results. The responsibility-focused video had dynamic scenarios including driver-facing recordings and recordings from our simulator. In contrast, the limitation-focused video had static pictures, which may have been less engaging, but was a trade-off made to keep the video to a similar length as the responsibility-focused training. Nonetheless, it is possible that participants were less engaged in the limitation-focused training and thus obtained less information, which may have affected their responses. We did not collect any measures of engagement in the training, but future research could use methods such as eye-tracking or questionnaires to investigate participants' engagement in different types of training and if differences in engagement are related to performance differences.

Future research could also further investigate the relationship between knowledge, trust, and reliance that was explored in Study 1. Because Study 1 was an online survey, we only collected data on reliance intention and could not measure actual reliance behaviour. While we were able to collect behavioural data for Study 3, we did not have the sample size to model the relationship between knowledge, trust, and reliance behaviour among drivers with and without ADAS experience to confirm our findings from Study 1. Thus, behavioural studies with a larger sample of drivers could be conducted to explore the effect of knowledge on trust and reliance behaviour.

Our results are specific to ADAS that are currently available on the market, and we focused specifically on vehicles that have ACC and LKA, as these systems provide continuous support for both speed and steering. However, there are many other ADAS that are often available along with ACC and LKA (e.g., automatic emergency braking [AEB], forward collision warning). Drivers may have (or use) different ADAS combinations (e.g., ACC, LKA, and AEB; ACC and AEB but not LKA) but may not be able to distinguish between the different ADAS in their vehicle or recognize the unique capabilities and limitations of each system. Further, research shows that ADAS performance can vary depending on the manufacturer and environment (Charlebois et al., 2023). Limitation-focused training would have even higher cognitive load if the limitations of additional systems were added and may require adapting for various manufacturers based on performance differences. Thus, responsibility-focused training may also be better for training drivers at a larger scale because it is a more general approach which emphasizes the driver's responsibility (which does not change) as opposed to limitation-focused training which focuses on the system performance (which can change depending on the environment and manufacturer). Future studies could explore responsibility-focused training for vehicles with a wider range of ADAS and varying levels of system performance. Naturalistic studies could be used to collect more realistic data on the effect of training on driver behaviour while using various ADAS as well as long-term effects of training.

Further, more advanced automated driving systems (ADS) that do not require drivers continuously monitor the roadway (i.e., SAE Level 3 driving automation, SAE International, 2021), are set to become available to U.S. consumers in Nevada and California later this year (Mercedes-Benz, 2023a, 2023b). These systems allow the driver to disengage from the driving task, thus changing the driver's role and responsibility. Although ADS are designed such that drivers do not need to monitor the roadway while the systems are engaged, the driver will still need to be attentive enough to take over when a request is issued. There may be common issues between ADAS and ADS in terms of ensuring drivers are aware of how they should be using the system and ensuring they are maintaining a sufficient level of attention to the driving environment to take over control of the vehicle when necessary (e.g., Campbell et al., 2018). Thus, the findings from this dissertation may also inform training to support driver reliance on ADS. Future work is needed to explore whether responsibility-focused training is effective for ADS. While research could investigate responsibility-focused training for ADS alone, vehicles with ADS may still also have ADAS, meaning drivers could use various automation modes throughout a drive. In this case, drivers would have varied responsibility depending on what driving automation mode they are using. Thus, training would likely need to be expanded to address potential issues with mode confusion (e.g., Feldhütter, Segler, & Bengler, 2018; Sarter & Woods, 1995), which can be dangerous if drivers think they are in ADS mode and stop monitoring the roadway when in fact they are in ADAS mode. Future research would be needed to investigate the effectiveness of responsibility-focused training for systems with various levels of driving automation.

Future work could also explore the effect of responsibility-focused training in other domains. The use of automation in the driving domain is unique because it is in a safety critical environment, but the operator can be anyone with a driver's license, in contrast to other domains (e.g., aviation) where operators are more highly skilled and received intensive training. While this research focused on short training and thus may not be directly transferable to domains where more in-depth training is required, the findings may provide insights that could inform future research in other domains. For example, studies have shown that clinicians may overrely on automated decision aids in healthcare settings (e.g., Harada, Katsukura, Kawamura, & Shimizu, 2021; Lyell & Coiera, 2017), and publications have noted the importance of training clinicians on how to use these systems (e.g., Mongan & Kohli, 2020; Paranjape, Schinkel, Panday, Car, & Nanayakkara, 2019). One potential avenue for future research could be to investigate whether the addition of responsibility-focused training impacts reliance on automated decision aids.

References

Abraham, H., Lee, C., Brady, S., Fitzgerald, C., Mehler, B., Reimer, B., & Coughlin, J. F. (2017). Autonomous vehicles and alternatives to driving: Trust, preferences, and effects of age. *Transportation Research Board Annual Meeting*. Washington, DC. Retrieved from https://agelab.mit.edu/index.php/system/files/2018-12/2017_TRB_Abraham.pdf

Abraham, H., Reimer, B., & Mehler, B. (2018). Learning to use in-vehicle technologies: Consumer preferences and effects on understanding. *Proceedings of the Human Factors and Ergonomics Society, 3*, 1589–1593. https://doi.org/10.1177/1541931218621359

American Automobile Association. (2022). *Effectiveness of Driver Monitoring Systems*. Washington, DC. Retrieved from https://newsroom.aaa.com/wp-content/uploads/2022/01/Driver-Monitoring-Full-Report-February-2022-Final.pdf

Ayoub, J., Yang, X. J., & Zhou, F. (2021). Modeling dispositional and initial learned trust in automated vehicles with predictability and explainability. *Transportation Research Part F: Traffic Psychology and Behaviour*, *77*, 102–116. https://doi.org/10.1016/j.trf.2020.12.015

Beggiato, M., & Krems, J. F. (2013). The evolution of mental model, trust and acceptance of adaptive cruise control in relation to initial information. *Transportation Research Part F: Traffic Psychology and Behaviour*, *18*, 47–57. https://doi.org/10.1016/j.trf.2012.12.006

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. https://doi.org/10.1016/j.trf.2015.10.005

Benjamini, Y., & Hochberg, Y. (1995). Controlling the false discovery rate: A practical and powerful approach to multiple testing. *Journal of the Royal Statistical Society. Series B (Methodological)*, *57*(1), 289–300. https://doi.org/10.1111/j.2517-6161.1995.tb02031.x

Benson, A. J., Tefft, B. C., Svancara, A. M., & Horrey, W. J. (2018). *Potential Reductions in Crashes, Injuries, and Deaths from Large-Scale Deployment of Advanced Driver Assistance Systems (Research Brief)*. Washington, DC. Retrieved from http://aaafoundation.org/wp-content/uploads/2018/09/18-0567_AAAFTS-ADAS-Potential-Benefits-Brief_v2.pdf

Bianchi Piccinini, G. F., Rodrigues, C. M., Leitão, M., & Simões, A. (2015). Reaction to a critical situation during driving with Adaptive Cruise Control for users and non-users of the system. *Safety Science*, *72*, 116–126. https://doi.org/10.1016/j.ssci.2014.09.008

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

Brame, C. J. (2016). Effective educational videos: Principles and guidelines for maximizing student learning from video content. *CBE Life Sciences Education*, *15*(4), 1–6. https://doi.org/10.1187/cbe.16-03-0125

Campbell, J. L., Brown, J. L., Graving, J. S., Richard, C. M., Lichty, M. G., Bacon, L. P., … Sanquist, T. (2018). *Human Factors Design Guidance for Level 2 and Level 3 Automated Driving Concepts (Report No. DOT HS 812 555)*. Washington, DC. Retrieved from https://www.nhtsa.gov/sites/nhtsa.gov/files/documents/13494_812555_l2l3automationhfguidance.pdf

Carney, C., Gaspar, J. G., & Horrey, W. J. (2022). Longer-term exposure vs training: Their effect on drivers' mental models of ADAS technology. *Transportation Research Part F: Traffic Psychology and Behaviour*, *91*, 329–345. https://doi.org/10.1016/j.trf.2022.09.017

Casler, K., Bickel, L., & Hackett, E. (2013). Separate but equal? A comparison of participants and data gathered via Amazon's MTurk, social media, and face-to-face behavioral testing. *Computers in Human Behavior*, *29*(6), 2156–2160. https://doi.org/10.1016/j.chb.2013.05.009

Casner, S. M., & Hutchins, E. L. (2019). What Do We Tell the Drivers? Toward Minimum Driver Training Standards for Partially Automated Cars. *Journal of Cognitive Engineering and Decision Making*, *13*(2), 55–66. https://doi.org/10.1177/1555343419830901

Charlebois, D., Anctil, B., Dube, S., Saleh, A., Pierre, G., Chirila, V., & Nahimana, F. (2023). The ideal vulnerable road user – A study of parameters affecting VRU detection. *Traffic Injury Prevention*, *24*(S1), S62–S67. https://doi.org/10.1080/15389588.2022.2159762

Chen, H. Y. W., & Donmez, B. (2016). What drives technology-based distractions? A structural equation model on social-psychological factors of technology-based driver distraction engagement. *Accident Analysis and Prevention*, *91*, 166–174. https://doi.org/10.1016/j.aap.2015.08.015

Consumer Reports. (2021). *Understanding the Current State of Vehicle Automation*. Retrieved from https://data.consumerreports.org/reports/understanding-the-current-state-of-vehicle-automation/

Cowan, N. (2010). The magical mystery four: How is working memory capacity limited, and why? *Current Directions in Psychological Science*, *19*(1), 51–57. https://doi.org/10.1177/0963721409359277

Cunningham, M. L., Regan, M. A., Horberry, T., Weeratunga, K., & Dixit, V. (2019). Public opinion about automated vehicles in Australia: Results from a large-scale national survey. *Transportation Research Part A: Policy and Practice*, *129*(February), 1–18. https://doi.org/10.1016/j.tra.2019.08.002

Curry, A. E., Pfeiffer, M. R., Durbin, D. R., & Elliott, M. R. (2015). Young driver crash rates by licensing age, driving experience, and license phase. *Accident Analysis and Prevention*, *80*, 243–250. https://doi.org/10.1016/j.aap.2015.04.019

DeGuzman, C. A., Ayas, S., & Donmez, B. (2023). Limitation-focused versus responsibility-focused advanced driver assistance systems training: A thematic analysis of driver opinions. *Transportation Research Record: Journal of the Transportation Research Board*, 1–11. https://doi.org/10.1177/03611981221151022

DeGuzman, C. A., & Donmez, B. (2021a). Drivers still have limited knowledge about adaptive cruise control even when they own the system. *Transportation Research Record*, *2675*(10), 328–339. https://doi.org/10.1177/03611981211011482

DeGuzman, C. A., & Donmez, B. (2021b). Knowledge of and trust in advanced driver assistance systems. *Accident Analysis and Prevention*, *156*, 106121. https://doi.org/10.1016/j.aap.2021.106121

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 and Prevention*, *178*, 106871. https://doi.org/10.1016/j.aap.2022.106871

Deslauriers, L., McCarty, L. S., Miller, K., Callaghan, K., & Kestin, G. (2019). Measuring actual learning versus feeling of learning in response to being actively engaged in the classroom. *Proceedings of the National Academy of Sciences of the United States of America*, *116*(39), 19251–19257. https://doi.org/10.1073/pnas.1821936116

Dickie, D. A., & Boyle, L. N. (2009). Drivers' understanding of adaptive cruise control limitations. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *53*(23), 1806–1810. https://doi.org/10.1177/154193120905302313

Dikmen, M., & Burns, C. M. (2016). Autonomous driving in the real world: Experiences with Tesla Autopilot and Summon. *Proceedings of the 8th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*, 225–228. Ann Arbor, MI. https://doi.org/10.1145/3003715.3005465

Donmez, B., Boyle, L. N., & Lee, J. D. (2007). Safety implications of providing real-time feedback to distracted drivers. *Accident Analysis and Prevention*, *39*(3), 581–590. https://doi.org/10.1016/j.aap.2006.10.003

Dunn, N., Dingus, T., & Soccolich, S. (2019). *Understanding the impact of technology: Do advanced driver assistance and semi-automated vehicle systems lead to improper driving behavior? (Technical Report)*. Washington, DC. Retrieved from https://aaafoundation.org/wp-content/uploads/2019/12/19-0460_AAAFTS_VTTI-ADAS-Driver-Behavior-Report_Final-Report.pdf

Eby, D. W., Molnar, L. J., Zakrajsek, J. S., Ryan, L. H., Zanier, N., Louis, R. M. S., … Strogatz, D. (2018). Prevalence, attitudes, and knowledge of in-vehicle technologies and vehicle adaptations among older drivers. *Accident Analysis and Prevention*, *113*, 54–62. https://doi.org/10.1016/j.aap.2018.01.022

Feldhütter, A., Segler, C., & Bengler, K. (2018). Does shifting between conditionally and partially automated driving lead to a loss of mode awareness? In N. Stanton (Ed.), *Advances in Human Aspects of Transportation. Proceedings of the AHFE 2017 International Conference on Human Factors in Transportation.* (Vol. 597, pp. 730–741). Springer, Cham. https://doi.org/10.1007/978-3-319-60441-1_70

Fereday, J., & Muir-Cochrane, E. (2006). Demonstrating Rigor Using Thematic Analysis: A Hybrid Approach of Inductive and Deductive Coding and Theme Development. *International Journal of Qualitative Methods*, *5*(1), 80–92. https://doi.org/10.1177/160940690600500107

Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences of the United States of America*, *111*(23), 8410–8415. https://doi.org/10.1073/pnas.1319030111

Gaspar, J. G., Carney, C., Shull, E., & Horrey, W. J. (2021). Mapping drivers' mental models of adaptive cruise control to performance. *Transportation Research Part F: Psychology and Behaviour*, *81*, 622–638. https://doi.org/10.1016/j.trf.2021.07.012

Gaspar, J. G., Schwarz, C., Kashef, O., Schmitt, R., & Shull, E. (2018). *Using Driver State Detection in Automated Vehicles*. SAFER-SIM University Transportation Center. Retrieved from SAFER-SIM University Transportation Center website: http://safersim.nads-sc.uiowa.edu/final_reports/UI 1 Y1 report.pdf

GMC. (2023). Super Cruise: Hands-free Driver Assistance. Retrieved May 31, 2023, from https://www.gmccanada.ca/en/supercruise

Guo, P. J., Kim, J., & Rubin, R. (2014). How video production affects student engagement: An empirical study of MOOC videos. *Proceedings of the 1st ACM Conference on Learning at Scale*, 41–50. https://doi.org/10.1145/2556325.2566239

Hagl, M., & Kouabenan, D. R. (2020). Safe on the road – Does Advanced Driver-Assistance Systems Use affect Road Risk Perception? *Transportation Research Part F: Traffic Psychology and Behaviour*, *73*, 488–498. https://doi.org/10.1016/j.trf.2020.07.011

Harada, Y., Katsukura, S., Kawamura, R., & Shimizu, T. (2021). Effects of a differential diagnosis list of artificial intelligence on differential diagnoses by physicians: An exploratory analysis of data from a randomized controlled study. *International Journal of Environmental Research and Public Health*, *18*(11), 5562. https://doi.org/10.3390/ijerph18115562

Hardman, S., Berliner, R., & Tal, G. (2019). Who will be the early adopters of automated vehicles? Insights from a survey of electric vehicle owners in the United States. *Transportation Research Part D: Transport and Environment*, *71*(December 2018), 248–264. https://doi.org/10.1016/j.trd.2018.12.001

Hart, S. G. (2006). NASA-task load index (NASA-TLX); 20 years later. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *50*(9), 904–908. https://doi.org/10.1177/154193120605000909

Hart, S. G., & Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In P. A. Hancock & N. Meshkati (Eds.), *Human Mental Workload* (pp. 139–183). Amsterdam: North Holland Press.

He, D., & Donmez, B. (2018). The Effects of Distraction on Anticipatory Driving. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *62*(1), 1960–1964. https://doi.org/10.1177/1541931218621444

He, D., Kanaan, D., & Donmez, B. (2021). In-vehicle displays to support driver anticipation of traffic conflicts in automated vehicles. *Accident Analysis and Prevention*, *149*, 105842. https://doi.org/10.1016/j.aap.2020.105842

He, D., Kanaan, D., & Donmez, B. (2022). Distracted when using driving automation: A quantile regression analysis of driver glances considering the effects of road alignment and driving experience. *Frontiers in Future Transportation*, *3*, 772910. https://doi.org/10.3389/ffutr.2022.772910

Helldin, T., Falkman, G., Riveiro, M., & Davidsson, S. (2013). Presenting system uncertainty in automotive UIs for supporting trust calibration in autonomous driving. *Proceedings of the 5th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*, 210–217. Eindhoven, The Netherlands: ACM. https://doi.org/10.1145/2516540.2516554

Highway Loss Data Institute. (2019). 2013–17 BMW collision avoidance features. *HLDI Bulletin*, *36*(37), 1–30. Retrieved from https://www.iihs.org/media/0b76abcd-6b24-46d9-8e98-65ea962a4cb1/rNOCTg/HLDI Research/Bulletins/hldi_bulletin_36.37.pdf

Hoff, K. A., & Bashir, M. (2015). Trust in automation: Integrating empirical evidence on factors that influence trust. *Human Factors*, *57*(3), 407–434. https://doi.org/10.1177/0018720814547570

ISO. (2013a). *Road vehicles — Measurement of driver visual behaviour with respect to transport information and control systems — Part 1: Definitions and parameters* (No. ISO/FDIS 15007-1:2013(E)).

ISO. (2013b). *Road vehicles — Measurement of driver visual behaviour with respect to transport information and control systems — Part 2: Equipment and procedures* (No. ISO/TS 15007-2:2013(E)).

Jenness, J. W., Lerner, N. D., Mazor, S., Osberg, J. S., & Tefft, B. C. (2008). *Use of advanced in-vehicle technology by young and older early adopters: Survey results on adaptive cruise control systems*. Washington, DC. Retrieved from https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/documents/811_004.pdf

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

Khastgir, S., Birrell, S., Dhadyalla, G., & Jennings, P. (2018). Calibrating trust through knowledge: Introducing the concept of informed safety for automation in vehicles. *Transportation Research Part C: Emerging Technologies*, *96*, 290–303. https://doi.org/10.1016/j.trc.2018.07.001

Klauer, S. G., Dingus, T. A., Neale, V. L., Sudweeks, J. D., & Ramsey, D. J. (2006). *The Impact of Driver Inattention On Near-Crash/Crash Risk: An Analysis Using the 100-Car Naturalistic Driving Study Data (Report No. DOT HS 810 594)*. Washington, DC. Retrieved from https://rosap.ntl.bts.gov/view/dot/62931

Körber, M., Baseler, E., & Bengler, K. (2018). Introduction matters: Manipulating trust in automation and reliance in automated driving. *Applied Ergonomics*, *66*, 18–31. https://doi.org/10.1016/j.apergo.2017.07.006

Krake, A., Jonas, R., Hoyos, C., Crump, C., Lester, B., Cades, D., & Harrington, R. (2020). *Effects of training on learning and use of an adaptive cruise control system (SAE Technical Paper 2020-01-1033)*. https://doi.org/10.4271/2020-01-1033

Krampell, M., Solís-Marcos, I., & Hjälmdahl, M. (2020). Driving automation state-of-mind: Using training to instigate rapid mental model development. *Applied Ergonomics*, *83*(102986). https://doi.org/10.1016/j.apergo.2019.102986

Larsson, A. F. L., Kircher, K., & Hultgren, J. A. (2014). Learning from experience: Familiarity with ACC and responding to a cut-in situation in automated driving. *Transportation Research Part F: Traffic Psychology and Behaviour*, *27*(PB), 229–237. https://doi.org/10.1016/j.trf.2014.05.008

Lee, J. D., & See, K. A. (2004). Trust in automation: Designing for appropriate reliance. *Human Factors*, *46*(1), 50–80. https://doi.org/10.1518/hfes.46.1.50_30392

Liljamo, T., Liimatainen, H., & Pöllänen, M. (2018). Attitudes and concerns on automated vehicles. *Transportation Research Part F: Traffic Psychology and Behaviour*, *59*, 24–44. https://doi.org/10.1016/j.trf.2018.08.010

Lin, R., Ma, L., & Zhang, W. (2018). An interview study exploring Tesla drivers' behavioural adaptation. *Applied Ergonomics*, *72*, 37–47. https://doi.org/10.1016/j.apergo.2018.04.006

Llaneras, R. E. (2006). *Exploratory study of early adopters, safety related driving with advanced technologies. Final Report. (Report No. DOT HS 809 972)*. Washington, DC. Retrieved from https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/doths_809972.pdf

Lyell, D., & Coiera, E. (2017). Automation bias and verification complexity: A systematic review. *Journal of the American Medical Informatics Association*, *24*(2), 423–431. https://doi.org/10.1093/jamia/ocw105

Macmillan, N. A., & Creelman, C. D. (2005). *Detection Theory: A User's Guide* (2nd ed.). Mahwah, New Jersey: Lawrence Erlbaum Associates.

Manser, M. P., Noble, A. M., Machiani, S. G., Shortz, A., Klauer, S. G., Higgins, L., & Ahmadi, A. (2019). *Driver training research and guidelines for automated vehicle technology (Report No. 01-004)*. Retrieved from https://safed.vtti.vt.edu/wp-content/uploads/2020/07/01-004_FinalResearchReport_Final.pdf

McCartt, A. T., Mayhew, D. R., Braitman, K. A., Ferguson, S. A., & Simpson, H. M. (2009). Effects of age and experience on young driver crashes: Review of recent literature. *Traffic Injury Prevention*, *10*(3), 209–219. https://doi.org/10.1080/15389580802677807

McDonald, A. B., Carney, C., & McGehee, D. V. (2018). *Vehicle Owners' Experiences with and Reactions to Advanced Driver Assistance Systems*. Retrieved from https://aaafoundation.org/wp-content/uploads/2018/09/VehicleOwnersExperiencesWithADAS_TechnicalReport.pdf

McDonald, A. B., McGehee, D. V., Chrysler, S. T., Askelson, N. M., Angell, L. S., & Seppelt, B. D. (2016). National survey identifying gaps in consumer knowledge of advanced vehicle safety systems. *Transportation Research Record: Journal of the Transportation Research Board*, *2559*(1), 1–6. https://doi.org/10.3141/2559-01

Mehlenbacher, B., Wogalter, M. S., & Laughery, K. R. (2002). On the reading of product owner's manuals: Perceptions and product complexity. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *46*(6), 730–734. https://doi.org/10.1177/154193120204600610

Mercedes-Benz. (2023a). Certification for SAE Level 3 system for U.S. market. Retrieved June 29, 2023, from https://group-media.mercedes-benz.com/marsMediaSite/en/instance/ko.xhtml?oid=55116818&ls=L2VuL2luc3RhbmNlL2tvLnhodG1sP29pZD00ODM2MjU4

Mercedes-Benz. (2023b). Conditionally automated driving: Mercedes-Benz DRIVE PILOT further expands U.S. availability to the country's most populous state through California certification. Retrieved June 29, 2023, from https://media.mercedes-benz.com/article/37f8acd0-df37-4755-acec-9534308c8e7b

Mongan, J., & Kohli, M. (2020). Artificial intelligence and human life: Five lessons for radiology from the 737 MAX disasters. *Radiology: Artificial Intelligence*, *2*(2), e190111. https://doi.org/10.1148/ryai.2020190111

Nandavar, S., Kaye, S.-A., Senserrick, T., & Oviedo-Trespalacios, O. (2023). Exploring the factors influencing acquisition and learning experiences of cars fitted with advanced driver assistance systems (ADAS). *Transportation Research Part F: Traffic Psychology and Behaviour*, *94*, 341–352. https://doi.org/10.1016/j.trf.2023.02.006

National Highway Traffic Safety Administration. (2013). *Visual-Manual NHTSA Driver Distraction Guidelines for In-Vehicle Electronic Devices (Docket No. NHTSA-2010-0053)*. Washington, DC.

National Highway Traffic Safety Administration. (2022). *Summary Report: Standing General Order on Crash Reporting for Level 2 Advanced Driver Assistance Systems (DOT HS 813 325)*. Washington, DC. Retrieved from https://www.nhtsa.gov/sites/nhtsa.gov/files/2022-06/ADAS-L2-SGO-Report-June-2022.pdf

National Transportation Safety Board. (2020). *Collision Between a Sport Utility Vehicle Operating With Partial Driving Automation and a Crash Attenuator, Mountain View, California, March 23, 2018 (Highway Accident Report NTSB/HAR-20/01)*. Washington, DC. Retrieved from https://www.ntsb.gov/investigations/AccidentReports/Reports/HAR2001.pdf

Naujoks, F., Purucker, C., & Neukum, A. (2016). Secondary task engagement and vehicle automation - Comparing the effects of different automation levels in an on-road experiment. *Transportation Research Part F: Traffic Psychology and Behaviour*, *38*, 67–82. https://doi.org/10.1016/j.trf.2016.01.011

Noble, A. M., Klauer, S. G., Doerzaph, Z. R., & Manser, M. P. (2019). Driver training for automated vehicle technology – Knowledge, behaviors, and perceived familiarity. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *63*(1), 2110–2114. https://doi.org/10.1177/1071181319631249

Noble, A. M., Miles, M., Perez, M. A., Guo, F., & Klauer, S. G. (2021). Evaluating driver eye glance behavior and secondary task engagement while using driving automation systems. *Accident Analysis and Prevention*, *151*(December 2020), 105959. https://doi.org/10.1016/j.aap.2020.105959

Nylen, A. B., Reyes, M. L., Roe, C. A., & McGehee, D. V. (2019). Impacts on Driver Perceptions in Initial Exposure to ADAS Technologies. *Transportation Research Record*, *2673*(10), 354–360. https://doi.org/10.1177/0361198119847975

Ontario Ministry of Transportation. (2019). Distracted Driving. Retrieved February 2, 2021, from Distracted driving website: https://www.ontario.ca/page/distracted-driving#section-0

Paranjape, K., Schinkel, M., Panday, R. N., Car, J., & Nanayakkara, P. (2019). Introducing artificial intelligence training in medical education. *JMIR Medical Education*, *5*(2), e16048. https://doi.org/10.2196/16048

Parasuraman, R., & Riley, V. (1997). Humans and automation: Use, misuse, disuse, abuse. *Human Factors*, *39*(2), 230–253. https://doi.org/10.1518/001872097778543886

Pew Research Center. (2016). America’s Shrinking Middle Class: A Close Look at Changes Within Metropolitan Areas. Retrieved July 28, 2020, from http://www.pewsocialtrends.org/2016/05/11/americas-shrinking-middle-class-a-close-look-at-changes-within-metropolitan-areas/

Piechulla, W., Mayser, C., Gehrke, H., & König, W. (2003). Reducing drivers’ mental workload by means of an adaptive man-machine interface. *Transportation Research Part F: Traffic Psychology and Behaviour*, *6*(4), 233–248. https://doi.org/10.1016/j.trf.2003.08.001

Pradhan, A. K., Hungund, A., & Sullivan, D. (2022). *Impact of Advanced Driver Assistance Systems (ADAS) on Road Safety and Implications for Education, Licensing, Registration, and Enforcement (Report No. 22-027)*. Boston, MA. Retrieved from https://www.mass.gov/doc/impact-of-advanced-driver-assistance-systems-adas-on-road-safety-and-implications-for-education-licensing-registration-and-enforcement-final-report/download

Rahman, M. M., Strawderman, L., Lesch, M. F., Horrey, W. J., Babski-Reeves, K., & Garrison, T. (2018). Modelling driver acceptance of driver support systems. *Accident Analysis and Prevention*, *121*(May), 134–147. https://doi.org/10.1016/j.aap.2018.08.028

Reimer, B., Mehler, B., Dobres, J., & Coughlin, J. F. (2013). *The Effects of a Production Level "Voice-Command" Interface on Driver Behavior: Reported Workload, Physiology, Visual Attention, and Driving Performance (MIT AgeLab Technical Report No. 2013-17A).* Cambridge, MA. Retrieved from http://web.mit.edu/reimer/www/pdfs/MIT_AgeLab_Technical_Report_2013-17A_(Voice_Interfaces).pdf

Rothbaum, J., & Edwards, A. (2019). U.S. Median Household Income Was $63,179 in 2018, Not Significantly Different From 2017. Retrieved July 28, 2020, from Uniteed States Census Bureau website: https://www.census.gov/library/stories/2019/09/us-median-household-income-not-significantly-different-from-2017.html

SAE International. (2021). *Taxonomy and definitions for terms related to driving automation systems for on-road motor vehicles (J3016-202104)*.

Sarter, N. B., & Woods, D. D. (1995). How in the world did we ever get into that mode? Mode error and awareness in supervisory control. *Human Factors*, *37*(1), 5–19. https://doi.org/10.1518/001872095779049516

Schoettle, B., & Sivak, M. (2014). *A survey of public opinion about autonomous and self-driving vehicles in the U.S., the U.K., and Australia (Report No. UMTRI-2014-21)*. Ann Arbor, MI. Retrieved from https://deepblue.lib.umich.edu/bitstream/handle/2027.42/108384/103024.pdf?sequence=1&isAllowed=y

Seppelt, B. D. (2009). *Supporting operator reliance on automation through continuous feedback* (University of Iowa). University of Iowa. Retrieved from https://ir.uiowa.edu/cgi/viewcontent.cgi?article=1617&context=etd

Seppelt, B. D., & Lee, J. D. (2007). Making adaptive cruise control (ACC) limits visible. *International Journal of Human Computer Studies*, *65*(3), 192–205. https://doi.org/10.1016/j.ijhcs.2006.10.001

Seppelt, B. D., & Lee, J. D. (2019). Keeping the driver in the loop: Dynamic feedback to support appropriate use of imperfect vehicle control automation. *International Journal of Human-Computer Studies*, *125*, 66–80. https://doi.org/10.1016/j.ijhcs.2018.12.009

Seppelt, B. D., Seaman, S., Lee, J., Angell, L. S., Mehler, B., & Reimer, B. (2017). Glass half-full: On-road glance metrics differentiate crashes from near-crashes in the 100-Car data. *Accident Analysis and Prevention*, *107*. https://doi.org/10.1016/j.aap.2017.07.021

Singer, J., & Jenness, J. W. (2020). *Impact of Information on Consumer Understanding of a Partially Automated Driving System*. Washington, DC. Retrieved from https://aaafoundation.org/wp-content/uploads/2020/09/ImpactOfInfoOnUnderstandingPartiallyAutomatedDrivingSystem_FinalReport.pdf

Solís-Marcos, I., Ahlström, C., & Kircher, K. (2018). Performance of an additional task during level 2 automated driving: An on-road study comparing drivers with and without experiences with partial automation. *Human Factors*, *60*(6), 778–792. https://doi.org/10.1177/0018720818773636

Spurlock, C. A., Sears, J., Wong-Parodi, G., Walker, V., Jin, L., Taylor, M., … Todd, A. (2019). Describing the users: Understanding adoption of and interest in shared, electrified, and automated transportation in the San Francisco Bay Area. *Transportation Research Part D: Transport and Environment*, *71*(January), 283–301. https://doi.org/10.1016/j.trd.2019.01.014

Stahl, P., Donmez, B., & Jamieson, G. A. (2014). Anticipation in driving: The role of experience in the efficacy of pre-event conflict cues. *IEEE Transactions on Human-Machine Systems*, *44*(5), 603–613. https://doi.org/10.1109/THMS.2014.2325558

Stahl, P., Donmez, B., & Jamieson, G. A. (2016). Supporting anticipation in driving through attentional and interpretational in-vehicle displays. *Accident Analysis and Prevention*, *91*, 103–113. https://doi.org/10.1016/j.aap.2016.02.030

Stahl, P., Donmez, B., & Jamieson, G. A. (2019). Eye glances towards conflict-relevant cues: The roles of anticipatory competence and driver experience. *Accident Analysis and Prevention*, *132*, 105255. https://doi.org/10.1016/j.aap.2019.07.031

Stanislaw, H., & Todorov, N. (1999). Calculation of signal detection theory measures. *Behavior Research Methods, Instruments, and Computers*, *31*(1), 137–149. https://doi.org/10.3758/BF03207704

Subaru. (2023). Subaru DriverFocus. Retrieved May 31, 2023, from https://www.subaru.ca/WebPage.aspx?WebSiteID=282&WebPageID=22756

Sweller, J., van Merriënboer, J. J. G., & Paas, F. (2019). Cognitive architecture and instructional design: 20 years later. *Educational Psychology Review*, *31*, 261–292. https://doi.org/10.1007/s10648-019-09465-5

Terry, G., Hayfield, N., Clarke, V., & Braun, V. (2017). Thematic Analysis. In W. Stainton Rogers & C. Willig (Eds.), *The SAGE Handbook of Qualitative Research in Psychology* (pp. 17–36). London: SAGE Publications Ltd. https://doi.org/10.4135/9781526405555.n2

Thomas, K. A., & Clifford, S. (2017). Validity and Mechanical Turk: An assessment of exclusion methods and interactive experiments. *Computers in Human Behavior*, *77*, 184–197. https://doi.org/10.1016/j.chb.2017.08.038

Toyota. (2021). Toyota T-Mate: The new name for Toyota's Safety and Advanced Driver Assistance Systems. Retrieved June 2, 2023, from Toyota Europe Newsroom website: https://newsroom.toyota.eu/toyota-t-mate-the-new-name-for-toyotas-safety-and-advanced-driver-assistance-systems

U.S. Department of Transportation. (2016). *Federal Automated Vehicles Policy: Accelerating the Next Revolution In Roadway Safety*. Washington, DC. Retrieved from https://www.transportation.gov/sites/dot.gov/files/docs/AV policy guidance PDF.pdf

van der Laan, J. D., Heino, A., & 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., & Aust, M. L. (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

Walter, S. L., Seibert, S. E., Goering, D., & O'Boyle, E. H. (2019). A Tale of Two Sample Sources: Do Results from Online Panel Data and Conventional Data Converge? *Journal of Business and Psychology*, *34*(4), 425–452. https://doi.org/10.1007/s10869-018-9552-y

Wolfe, B., Seppelt, B., Mehler, B., Reimer, B., & Rosenholtz, R. (2020). Rapid holistic perception and evasion of road hazards. *Journal of Experimental Psychology: General*, *149*(3), 490–500. https://doi.org/10.1037/xge0000665

Xiong, H., Boyle, L. N., Moeckli, J., Dow, B. R., & Brown, T. L. (2012). Use patterns among early adopters of adaptive cruise control. *Human Factors*, *54*(5), 722–733. https://doi.org/10.1177/0018720811434512

Zheng, H., Mason, J. R., Classen, S., & Giang, W. C. W. (2023). Pilot study: Effect of roles and responsibility training on driver's use of adaptive cruise control between younger and older adults. *Transportation Research Part F: Traffic Psychology and Behaviour*, *94*, 53–66. https://doi.org/10.1016/j.trf.2023.01.023

Appendices

Appendix A: Study 1 Main Survey

Demographics

Q1. What is your age?
[Text entry field]
Q2. What is your sex?
Male; Female
Q3. What country do you currently reside in?
Canada; United States; Other **[Exclude if Other]**
Q4. What state/province do you currently reside in?
[Drop-down list]
Q5. What city do you currently live in?
[Text entry field]
[For U.S. residents] **Q6. Yearly household income in 2019:**
Less than $15,000; $15,000 to $29,999; $30,000 to $39,999; $40,000 to $54,999; $55,000 to $74,999; $75,000 - $114,999; $115,000 - $149,999; $150,000 - $224,999; More than $225,000
[For Canadian residents] **Q6. Yearly household income in 2019:**
Less than $20,000; $20,000 to $34,999; $35,000 to $49,999; $50,000 to $74,999; $75,000 to $99,999; $100,000 - $149,999; $150,000 - $199,999; $200,000 - $299,999; More than $300,000
Q7. On a scale of 1 to 10, with 1 being very inexperienced and 10 being very experienced, how would you rate your level of experience with technology (for example, cell phones, automatic teller machines, digital cameras, and computers)?
Very inexperienced 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9 – 10 Very experienced
Q8. Some people prefer to avoid new technologies as long as possible while others like to try them out as soon as they become available. In general, how would you rate yourself as being an avoider or an early adopter of new technology?
Avoid new technologies 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9 – 10 Try new technologies as soon as possible
Q9. I find learning new technology to be:
Very difficult 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9 – 10 Very easy

Driving History

[For U.S. residents] **Q10. What type of driver's license do you currently hold?**
Learner's permit or instruction permit; Full license; Other - Please Specify
[For Canadian residents] **Q10. What type of driver's license do you currently hold?**
Learner's permit or instruction permit (for example, G1, G2); Full license (for example, G); Other - Please Specify
Q11. How old were you when you got your first learner's permit?
[Text entry field]
Q12. Before the COVID-19 outbreak, how often did you drive?
Almost every day; A few times a week; A few times a month; A few times a year; Never
[For U.S. residents] **Q13. In 2019, what was the average distance you drove per week?**
0 – 30 miles (~ under 1600 miles per year); 31 – 60 miles (~ 1600 – 3199 miles per year); 61 – 185 miles (~ 3200 – 9699 miles per year); 186 – 310 miles (~ 9700 – 15999 miles per year); 311 – 434 miles (~ 16000 – 22499 miles per year); 435 – 558 miles (~ 22500 – 28999 miles per year); 559+ miles (~ over 29000 miles per year)
[For Canadian residents] **Q13. In 2019, what was the average distance you drove per week?**
0 – 49 km (~ under 2500 km per year); 50 – 99 km (~ 2500 – 4999 km per year); 100 – 299 km (~ 5000 – 14999 km per year); 300 – 499 km (~ 15000 – 24999 km per year); 500 – 699 km (~ 25000 – 34999 km per year); 700 – 899 km (~ 35000 – 44999 km per year); 900+ km (~ over 45000 km per year)
Q14. In 2019, how much of your driving time was spent on highways/interstates?
0 – 20%; 21 – 40%; 41 – 60%; 61 – 80%; 81 – 100%
Q15. Do you currently own/lease a vehicle?
Yes; No

Current Vehicle/ADAS Experience

[If Q15 = Yes] **Q16. What is the make and model of the car you currently own/lease? (If your household has multiple vehicles, pick the one that has advanced driver assistance systems, if any).**
Make [Text entry field]; Model [Text entry field]; Year [Text entry field]
[If Q15 = Yes] **Q17. How long have you owned/leased this vehicle?**
Less than 1 year; 1-2 years; 3-5 years; 6+ years

[If Q15 = Yes]
Some vehicles are equipped with advanced driver assistance systems that can control some of the driving tasks for you. The questions throughout the rest of the survey will focus on your experience with and understanding of two of these systems: Adaptive Cruise Control (ACC) and Lane Keeping Assist (LKA).

In some vehicles, ACC and LKA are part of one combined system, whereas in other vehicles, ACC and LKA are separate systems. Here we will describe each system separately. If you have experience using a combined version of ACC and LKA, when answering a question about ACC or LKA, please think about only that aspect of the system.

Adaptive Cruise Control (ACC)
This system is designed to control the speed of the vehicle, like normal cruise control, but also automatically slows down and speeds up based on the behavior of the vehicle ahead.

Different automotive manufacturers have different names for this technology and in some vehicles, ACC is combined with other advanced driver assistance systems (like LKA, which will be described later). Throughout the rest of the survey, we will use the term ACC to refer to any advanced driver assistance system (or component of a system) that fits the description above.

Q18. To the best of your knowledge, does your current vehicle have ACC?
Yes; No; Not sure
[If Q18 = Yes] **Q19. Is this the first vehicle you have owned that has an ACC system?**
Yes; No; Not sure
[If Q18 = Yes] **Q20. Can the ACC system in your current vehicle be used in stop-and-go traffic, like in-town driving or heavy traffic on highways?**
Yes; No; Not sure
[If Q18 = Yes] **Q21. When driving on a <u>highway or interstate</u>, how often do you use the ACC in your vehicle?**
Almost every time; Most of the time; Sometimes; Rarely; Never
[If Q21 = Never] **Q22. You indicated that you do not use the ACC system in your vehicle when driving on the <u>highway or interstate</u>. Please check all that apply to indicate why you do not use the technology when driving on the <u>highway/interstate</u>.**
I don’t understand it; I don’t trust it; I think it is dangerous; It makes me nervous/anxious; It is annoying; It doesn’t work on the highway/interstate; It is distracting; I don’t need/want it; Other - please explain
[If Q20 = Yes OR Not sure] **Q23. When driving in <u>stop-and-go traffic</u>, like in-town driving or heavy traffic on highways, how often do you use the ACC in your vehicle?**
Almost every time; Most of the time; Sometimes; Rarely; Never
[If Q23 = Never] **Q24. You indicated that you do not use the ACC system in your vehicle when driving in <u>stop-and-go traffic</u>, like in-town driving or heavy traffic on highways. Please check all that apply to indicate why you do not use the technology when driving in <u>stop-and-go traffic</u>.**
I don’t understand it; I don’t trust it; I think it is dangerous; It makes me nervous/anxious; It is annoying; It doesn’t work in stop-and-go traffic; It is distracting; I don’t need/want it; Other - please explain

[If Q15 = No OR (Q15 = Yes AND Q18 = No OR Not sure)]
Some vehicles are equipped with advanced driver assistance systems that can control some of the driving tasks for you. The questions throughout the rest of the survey will focus on your experience with and understanding of two of these systems: Adaptive Cruise Control (ACC) and Lane Keeping Assist (LKA). In some vehicles, ACC and LKA are part of one combined system, whereas in other vehicles, ACC and LKA are separate systems. Here we will describe each system separately. If you have experience using a combined version of ACC and LKA, when answering a question about ACC or LKA, please think about only that aspect of the system.

Adaptive Cruise Control (ACC)
This system is designed to control the speed of the vehicle, like normal cruise control, but also automatically slows down and speeds up based on the behavior of the vehicle ahead.

Different automotive manufacturers have different names for this technology and in some vehicles, ACC is combined with other advanced driver assistance systems (like LKA, which will be described later). Throughout the rest of the survey we will use the term ACC to refer to any advanced driver assistance system (or component of a system) that fits the description above.

Q25. Have you ever used ACC?
Yes; No; Not sure **[Exclude if Yes]**

[If Q15 = Yes]
Lane Keeping Assist (LKA)
This system is designed to automatically steer the vehicle to stay within the current lane. Some systems steer the vehicle once it begins to approach the lane boundary while others steer continuously to keep the vehicle in the center of the lane.

Different automotive manufacturers have different names for this technology and in some vehicles, ACC and LKA are combined. Throughout the rest of the survey we will use the term LKA to refer to any advanced driver assistance system (or component of a system) that fits the description above.

Q26. To the best of your knowledge, does your current vehicle have LKA?
Yes; No; Not sure
[If Q26 = Yes] **Q27. How does your vehicle's LKA system work?**
It steers the vehicle once it begins to approach the lane boundary; It steers continuously to keep the vehicle in the center of the lane; Not sure
[If Q26 = Yes] **Q28. Is this the first vehicle you have owned that has an LKA system?**
Yes; No; Not sure
[If Q26 = Yes] **Q29. When driving on a <u>highway or interstate</u>, how often do you use the LKA in your vehicle?**
Almost every time; Most of the time; Sometimes; Rarely; Never

[If 29 = Never] **Q30. You indicated that you do not use the LKA system in your vehicle when driving on the highway or interstate. Please check all that apply to indicate why you do not use the technology when driving on the highway or interstate.**
I don't understand it; I don't trust it; I think it is dangerous; It makes me nervous/anxious; It is annoying; It doesn't work on the highway/interstate; It is distracting; I don't need/want it; Other - please explain
[If Q26 = Yes] **Q31. When driving in stop-and-go traffic, like in-town driving or heavy traffic on highways, how often do you use the LKA in your vehicle?**
Almost every time; Most of the time; Sometimes; Rarely; Never
[If Q31 = Never] **Q32. You indicated that you do not use the LKA system in your vehicle when driving in stop-and-go traffic, like in-town driving or heavy traffic on highways. Please check all that apply to indicate why you do not use the technology when driving in stop-and-go traffic.**
I don't understand it; I don't trust it; I think it is dangerous; It makes me nervous/anxious; It is annoying; It doesn't work on the highway/interstate; It is distracting; I don't need/want it; Other - please explain

[If Q15 = No OR (Q15 = Yes AND Q26 = No OR Not sure)]
Lane Keeping Assist (LKA)
This system is designed to automatically steer the vehicle to stay within the current lane. Some systems steer the vehicle once it begins to approach the lane boundary while others steer continuously to keep the vehicle in the center of the lane.

Different automotive manufacturers have different names for this technology and in some vehicles, ACC and LKA are combined. Throughout the rest of the survey we will use the term LKA to refer to any advanced driver assistance system (or component of a system) that fits the description above.

Q33. Have you ever used LKA?
Yes; No; Not sure **[Exclude if Yes]**

[If (Q21 = Almost every time OR Most of the time OR Sometimes OR Rarely) AND (Q29 = Almost every time OR Most of the time OR Sometimes OR Rarely)] **Q34. When driving on a highway or interstate, how often do you use both the ACC and LKA at the same time in your vehicle?**
Almost every time; Most of the time; Sometimes; Rarely; Never
[If Q34 = Never] **Q35. You indicated that you have used the ACC and LKA systems in your vehicle separately when driving on the highway or interstate, but that you have never used the ACC and LKA system at the same time in your vehicle when driving on the highway or interstate. Please check all that apply to indicate why you have not used the technology at the same time when driving on the highway or interstate.**
I don't understand it; I don't trust it; I think it is dangerous; It makes me nervous/anxious; It is annoying; It doesn't work on the highway/interstate; It is distracting; I don't need/want it; Other - please explain

[If (Q23 = Almost every time OR Most of the time OR Sometimes OR Rarely) AND (Q31 = Almost every time OR Most of the time OR Sometimes OR Rarely)] **Q36. When driving in <u>stop-and-go traffic</u>, how often do you use both the ACC and LKA at the same time in your vehicle?**
Almost every time; Most of the time; Sometimes; Rarely; Never
[If Q36 = Never] **Q37. You indicated that you have used the ACC and LKA systems in your vehicle separately when driving in <u>stop-and-go traffic</u>, like in-town driving or heavy traffic on highways, but that you have never used the ACC and LKA system at the same time in your vehicle when driving in <u>stop-and-go traffic</u>. Please check all that apply to indicate why you have not used the technology at the same time when driving in <u>stop-and-go traffic</u>.**
I don’t understand it; I don’t trust it; I think it is dangerous; It makes me nervous/anxious; It is annoying; It doesn’t work on the highway/interstate; It is distracting; I don’t need/want it; Other - please explain
[If Q18 = Yes OR Q26 = Yes] **Q38a. How did you learn about the advanced driver assistance systems in your vehicle? Check all that apply.**
Read the vehicle manual; Asked sales staff at the dealership for information; Staff at the dealership offered information (you did not specifically ask); Asked a friend or family member for information; Friends or family were talking about advanced driver assistance systems (you did not specifically ask); Looked for information on the internet; Searched for online videos; Saw a video or commercial by chance; Drove the vehicle to learn by trial-and-error; Observed the advanced driver assistance systems as a passenger; Other - please specify; None of the above
[Each item from Q38a displayed] **Q38b. How much did information from each source contribute to your understanding of the advanced driver assistance systems in your vehicle? [Rated for each item]**
Not at all 1 – 2 – 3 – 4 – 5 – 6 – 7 A lot

Past/Preferred Learning about ADAS

[If (Q25 = No OR Not sure) AND (Q33 = No or Not sure)] **Q39. How much do you know about advanced driver assistance systems?**
A lot; A little bit; Nothing
[If Q39 = A lot OR A little bit] **Q40a. How did you learn about advanced driver assistance systems? Check all that apply.**
Read the vehicle manual; Asked sales staff at the dealership for information; Sales staff at the dealership offered information (you did not specifically ask); Asked a friend or family member for information; Friends or family were talking about advanced driver assistance systems (you did not specifically ask); Looked for information on the internet; Searched for online videos; Saw a video or commercial by chance; Observed the advanced driver assistance systems as a passenger; Other - please specify; None of the above
[Each item from Q38a displayed] **Q40b. How much did information from each source contribute to your understanding of the advanced driver assistance systems in your vehicle? [Rated for each item]**
Not at all 1 – 2 – 3 – 4 – 5 – 6 – 7 A lot

Q41. How would you prefer to learn about advanced driver assistance systems? Select up to three answers.
Reading the vehicle manual; Learning by trial-and-error (driving the vehicle); From staff at the dealership, or car rental staff; Asking a friend or family member; Reading information on websites; Watching online videos; The car teaches you (for example, a tutorial on your dashboard or infotainment system); Other - please specify

Q42. Understanding advanced driver assistance technology is:
Very difficult 1 – 2 – 3 – 4 – 5 – 6 – 7 Very easy
Q43. Do you think your understanding of ACC is correct?
Not at all correct 1 – 2 – 3 – 4 – 5 – 6 – 7 Fully correct
Q44. Do you think your understanding of ACC is complete?
Not at all complete 1 – 2 – 3 – 4 – 5 – 6 – 7 Fully complete
Q45. Do you think your understanding of LKA is correct?
Not at all correct 1 – 2 – 3 – 4 – 5 – 6 – 7 Fully correct
Q46. Do you think your understanding of LKA is complete?
Not at all complete 1 – 2 – 3 – 4 – 5 – 6 – 7 Fully complete

ACC Knowledge Questionnaire

Part 1	**Owners**	**Is the following statement about ACC true for your vehicle?** Yes; No; I don't know **Please rate your confidence in this response** 1 = Very low confidence to 7 = Full confidence, or NA if they answered I don't know
	Non-owners	**Is the following statement about ACC true for any system?** Yes; No; I don't know **Please rate your confidence in this response** 1 = Very low confidence to 7 = Full confidence, or NA if they answered I don't know

Maintains a predetermined speed in an empty lane; Keeps a set distance to vehicles driving ahead in the same lane at a slower speed; Has full braking power; Allows you to choose how closely you would like to follow the vehicle ahead; Adjusts the speed to slower vehicles ahead; Works at very low speeds (under 30 km/h or 19 mph); Activates the brake lights when braking to slow the vehicle; Allows you to drive faster than the set speed by pressing the accelerator (gas) pedal; Can slow down to a complete stop; Can be deactivated by pressing the brake pedal; Returns to the predetermined speed after manually pressing the accelerator (gas) pedal; Deactivates if you are pressing the gas pedal; Can only be activated when Lane Keeping Assist is also active; Can be deactivated by turning the steering wheel; Alerts you when you are looking away from the road for too long; Deactivates if you look away from the road for an extended period of time; Alerts you when you have your hands off the wheel or do not steer for too long; Deactivates if you have your hands off the wheel or do not steer for an extended period of time; Warns when exceeding the current speed limit; Warns in case you need to intervene; Reacts to traffic lights and/or signs; Reacts to oncoming traffic; Adjusts speed before bends

Part 2	**Owners**	**Do you think the ACC in your vehicle might have difficulty in this situation?** Yes; No; I don't know **Please rate your confidence in this response** 1 = Very low confidence to 7 = Full confidence, NA if they answered I don't know
	Non-owners	**Do you think any ACC system might have difficulty in this situation?** Yes; No; I don't know **Please rate your confidence in this response** 1 = Very low confidence to 7 = Full confidence, NA if they answered I don't know

Dirty or blocked vehicle sensors; Curvy roads; Construction zones; Approaching pedestrians or cyclists in the same lane; Vehicle cutting-in ahead of you; Approaching a very slow-moving vehicle ahead in the same lane; Approaching a stationary vehicle in the same lane; Approaching a motorcycle in the same lane; Vehicle ahead brakes suddenly; Hills; Very narrow lane; Very wide lane; City streets; Lane markings are faded or missing; Highways/freeways; Unpaved roads; Road merges or diverges (for example, entrance or exit ramps); Approaching a vehicle partially in the lane ahead; Heavy traffic; Approaching cross traffic; When the front and rear of the vehicle are not level (for example, due to heavy weight in the trunk); Road is wet due to rain or puddles; Extremely hot or cold weather; Poor weather (for example, heavy rain, snow, fog, etc.); Road is covered in snow, sand, etc.; Glare on the road surface (for example, from the sun); Glare towards the driver (for example, from the sun or oncoming vehicle headlights); GPS data is unavailable

Note: Items in each part were randomized. Items that are underlined did ***not*** *have the same correct answer across all systems. These items were excluded when we compared scores between owners and non-owners.*

ACC Trust

Please rate your overall agreement with the following statements regarding ACC
Strongly disagree – Disagree – Neutral (neither agree nor disagree) – Agree – Strongly Agree

I am confident in the system; The system is dependable; The system is reliable; I can trust the system; I am familiar with the system

LKA Knowledge Questionnaire

<table>
<tr><td rowspan="2">Part 1</td><td>Owners</td><td>Is the following statement about LKA true <u>for your vehicle</u>?
Yes; No; I don’t know
Please rate your confidence in this response
1 = Very low confidence to 7 = Full confidence, or NA if they answered I don’t know</td></tr>
<tr><td>Non-owners</td><td>Is the following statement about LKA true <u>for any system</u>?
Yes; No; I don’t know
Please rate your confidence in this response
1 = Very low confidence to 7 = Full confidence, or NA if they answered I don’t know</td></tr>
<tr><td colspan="3"><u>Changes lanes automatically</u>; Steers automatically; <u>Works at low speeds (for example, below 60 km/h or 35mph); Works at high speeds (for example, above 60 km/h or 35 mph)</u>; Allows you to choose how abruptly you would like the vehicle to steer; Does not allow you to manually steer the vehicle; Warns in case you need to intervene; Executes evasive steering manoeuvres; <u>Deactivates if your turn signal is on</u>; Deactivates if you are pressing the gas pedal; <u>Can be deactivated by pressing the brake pedal</u>; <u>Can only be activated when Adaptive Cruise Control is also active</u>; <u>Can be deactivated by turning the steering wheel</u>; <u>Deactivates if you look away from the road for an extended period of time</u>; <u>Deactivates if you have your hands off the wheel or do not steer for an extended period of time</u>; <u>Alerts you when you are looking away from the road for too long</u>; <u>Alerts you when you have your hands off the wheel or do not steer for too long</u></td></tr>
<tr><td rowspan="2">Part 2</td><td>Owners</td><td>Do you think the LKA <u>in your vehicle</u> might have difficulty in this situation?
Yes; No; I don’t know
Please rate your confidence in this response
1 = Very low confidence to 7 = Full confidence, NA if they answered I don’t know</td></tr>
<tr><td>Non-owners</td><td>Do you think <u>any LKA system</u> might have difficulty in this situation?
Yes; No; I don’t know
Please rate your confidence in this response
1 = Very low confidence to 7 = Full confidence, NA if they answered I don’t know</td></tr>
<tr><td colspan="3">Curvy roads; Highways/freeways; City streets; Construction zones; Hills; Unpaved roads; Lane markings are faded or missing; Road merges or diverges (for example, entrance or exit ramps); Very narrow lane; Very wide lane; <u>Heavy traffic</u>; Dirty or blocked vehicle sensors; When the front and rear of the vehicle are not level (for example, due to heavy weight in the trunk); Poor weather (for example, heavy rain, snow, fog, etc.); Road is wet due to rain or puddles; Road is covered in snow, sand, etc.; <u>GPS data is unavailable</u>; Extremely hot or cold weather; Glare on the road surface (for example, from the sun); Glare towards the driver (for example, from the sun or oncoming vehicle headlights); Driving through a tunnel</td></tr>
<tr><td colspan="3">Note: Items in each part were randomized. Items that are underlined did not have the same correct answer across all systems. These items were excluded when we compared scores between owners and non-owners.</td></tr>
</table>

LKA Trust

Please rate your overall agreement with the following statements regarding LKA Strongly disagree – Disagree – Neutral (neither agree nor disagree) – Agree – Strongly Agree
I am confident in the system; The system is dependable; The system is reliable; I can trust the system; I am familiar with the system

Appendix B: Reliance Intention Items from Study 1 Follow-up Survey

If you were driving with NO advanced driver assistance systems (that is, you are in control of all aspects of driving), how likely would you be to do the following things? Not at all likely – Slightly likely – Moderately likely – Very likely – Extremely likely
Manually text on a smartphone; Text using a voice control system (for example, Siri, Apple CarPlay, Android Auto); Manually make phone calls using a smartphone; Make phone calls using voice control (for example, Siri, Apple CarPlay, Android Auto); Manually send e-mails using your smartphone; Use social media; Browse the internet; Watch a video; Read something on a device (for example, smartphone, tablet); Read something not on a device (for example, book, newspaper); Talk to passengers; Eat; Sleep
If you were driving with NO advanced driver assistance systems (that is, you are in control of all aspects of driving), how confident would you be in your ability to do the following things without significantly affecting your driving? Not at all confident – Slightly confident – Moderately confident – Very confident – Fully confident
Same list as the first item in Appendix B.

If you were driving with NO advanced driver assistance systems (that is, you are in control of all aspects of driving), how safe would you feel if you were to do the following things? Not at all safe – Slightly safe – Moderately safe – Very safe – Fully safe
Same list as the first item in Appendix B.

If you were driving with ONLY ACC engaged, how likely would you be to do the following things? Not at all likely – Slightly likely – Moderately likely – Very likely – Extremely likely
Same list as the first item in Appendix B.

If you were driving with ONLY ACC engaged, how safe would you feel if you were to do the following things? Not at all safe – Slightly safe – Moderately safe – Very safe – Fully safe
Same list as the first item in Appendix B.

If you were driving with ONLY LKA engaged, how likely would you be to do the following things? Not at all likely – Slightly likely – Moderately likely – Very likely – Extremely likely
Same list as the first item in Appendix B.

If you were driving with ONLY LKA engaged, how safe would you feel if you were to do the following things? Not at all safe – Slightly safe – Moderately safe – Very safe – Fully safe
Same list as the first item in Appendix B.

If you were driving with BOTH ACC and LKA engaged, how likely would you be to do the following things? Not at all likely – Slightly likely – Moderately likely – Very likely – Extremely likely
Same list as the first item in Appendix B.

Are there any other tasks that were not listed above that you would be more likely to engage in while using both ACC and LKA than if you were driving with no advanced driver assistance systems? (Optional)
[Text entry field]

If you were driving with BOTH ACC and LKA engaged, how safe would you feel if you were to do the following things? Not at all safe – Slightly safe – Moderately safe – Very safe – Fully safe
Same list as the first item in Appendix B.

Are there any other tasks that were not listed above that you would feel more safe performing while using both ACC and LKA than if you were driving with no advanced driver assistance systems? (Optional)
[Text entry field]

Appendix C: ADAS Owner Vehicles from Study 1

Vehicles owned by ADAS owners

Vehicle Make	Number of Owners	Percent of Owners
Acura	2	2%
Audi	1	1%
BMW	7	7%
Cadillac	1	1%
Chevrolet	2	2%
Ford	4	4%
Honda	14	14%
Hyundai	4	4%
Infiniti	1	1%
Jeep	2	2%
Kia	3	3%
Lexus	5	5%
Lincoln	1	1%
Mazda	3	3%
Mercedes Benz	3	3%
Nissan	3	3%
Subaru	4	4%
Tesla	2	2%
Toyota	34	33%
Volkswagen	3	3%
Volvo	3	3%
Total	**102**	

Appendix D: Study 2 Demographic Questions

Q1 What is your age?
[text entry field]

Q2 Highest level of education completed:

( ) Some high school
( ) High school degree or equivalent
( ) Some college
( ) College degree
( ) Bachelor's degree
( ) Master's degree
( ) Professional degree (for example, JD, MD, DDS)
( ) Doctorate

Q3 Current yearly household income:

( ) Less than $50,000
( ) $50,000 to $99,999
( ) $100,000 to $149,999
( ) $150,000 or more

Q4 On a scale of 1 to 10, with 1 being very inexperienced and 10 being very experienced, how would you rate your level of experience with technology (for example, cell phones, automatic teller machines, digital cameras, and computers)?

Very inexperienced 1 2 3 4 5 6 7 8 9 10 Very experienced

Q5 Some people prefer to avoid new technologies as long as possible while others like to try them out as soon as they become available. In general, how would you rate yourself as being an avoider or an early adopter of new technology?

Avoid new technology as long as possible	1	2	3	4	5	6	7	8	9	10	Try new technologies as soon as possible

Q6 I find learning new technology to be:

Very easy 1 2 3 4 5 6 7 8 9 10 Very difficult

Q7 How many times have you used Adaptive Cruise Control when driving on highways or interstates?
( ) Once
( ) 2-4 times
( ) 5-10 times
( ) More than 10 times

Q8 How many times have you used Lane Keeping Assist when driving on highways or interstates?
( ) Once
( ) 2-4 times
( ) 5-10 times
( ) More than 10 times

Appendix E: Study 2 ADAS Questionnaire

Q1 Please rate your interest in using ACC and LKA in the future.

( ) Not at all interested
( ) Somewhat interested
( ) Moderately interested
( ) Very interested

Q2 Please indicate whether you agree or disagree with each of the following statements. Mark one response for each row.

	Strongly disagree	**Disagree**	**Somewhat disagree**	**Neither agree nor disagree**	**Somewhat agree**	**Agree**	**Strongly agree**
I expect that ACC and LKA will increase my safety	○	○	○	○	○	○	○
I expect that ACC and LKA will reduce my stress	○	○	○	○	○	○	○
I expect that ACC and LKA will improve my physical comfort	○	○	○	○	○	○	○

Q3 How likely are you to drive in the following situations with **no driver support systems**?

	Not at all likely	**Slightly likely**	**Moderately likely**	**Very likely**	**Extremely likely**
Driving while drowsy	○	○	○	○	○
Driving after having three alcoholic drinks	○	○	○	○	○
Driving after taking a medication that warns you not to drive	○	○	○	○	○
Driving while having a hands-free cell phone conversation (for example: using Bluetooth headset or connection to car)	○	○	○	○	○
Driving while having a handheld cell phone conversation (for example: holding the phone to your ear)	○	○	○	○	○
Driving while having a text message conversation (typing with your hands)	○	○	○	○	○
Driving while eating	○	○	○	○	○
Driving while browsing the internet or watching a video	○	○	○	○	○

Q4 How likely are you to drive in the following situations **while using both ACC and LKA**?

	Not at all likely	**Slightly likely**	**Moderately likely**	**Very likely**	**Extremely likely**
Driving while drowsy	○	○	○	○	○
Driving after having three alcoholic drinks	○	○	○	○	○
Driving after taking a medication that warns you not to drive	○	○	○	○	○
Driving while having a hands-free cell phone conversation (for example: using Bluetooth headset or connection to car)	○	○	○	○	○
Driving while having a handheld cell phone conversation (for example: holding the phone to your ear)	○	○	○	○	○
Driving while having a text message conversation (typing with your hands)	○	○	○	○	○
Driving while eating	○	○	○	○	○
Driving while browsing the internet or watching a video	○	○	○	○	○

Q5 For each situation below, indicate whether or not you expect ACC and LKA to successfully control vehicle speed and keep the vehicle in its lane **without the driver doing anything**. If you're not sure, take your best guess. If you feel like you have no way of even guessing, you may select "I have no idea." Mark one response for each row. [Excluded for Session 1 pre-training]

	Definitely will work	**Probably will work**	**Probably will not work**	**Definitely will not work**	**I have no idea**
Driving in a work zone where lanes have shifted from their usual location	○	○	○	○	○
Driving in heavy rain or snow	○	○	○	○	○
Driving into direct sun glare at sunset	○	○	○	○	○
Driving where lane lines are badly faded	○	○	○	○	○
Driving on city streets	○	○	○	○	○
Driving on an undivided highway (no median or barrier separating traffic traveling in the opposite direction)	○	○	○	○	○
Driving on a divided highway (has a median or barrier separating traffic traveling in the opposite direction)	○	○	○	○	○
Driving on a rural highway without stop signs or traffic lights	○	○	○	○	○
Driving on a cloudy day	○	○	○	○	○

Q6 For each situation below, please indicate whether or not you expect ACC and LKA to brake and/or steer, **without the driver doing anything**. If you're not sure, take your best guess. If you feel like you have no way of even guessing, you may select "I have no idea." Mark one response for each row. [Excluded for Session 1 pre-training]

	Definitely will work	**Probably will work**	**Probably will not work**	**Definitely will not work**	**I have no idea**
Approaching stopped traffic ahead due to a traffic jam	○	○	○	○	○
Approaching a bed mattress on the road in your lane	○	○	○	○	○
Car in front of you in your lane suddenly brakes hard (in other words, they "slam on the brakes")	○	○	○	○	○
Car in lane directly next to you starts changing into your lane	○	○	○	○	○
Approaching a highway construction worker standing in your lane	○	○	○	○	○
Approaching a slower moving motorcycle ahead in your lane	○	○	○	○	○
Approaching a slight curve	○	○	○	○	○
Car merges into your lane, 2 seconds ahead of you, driving 5 km/h slower than you	○	○	○	○	○
Approaching a slower moving car ahead in your lane (for example, a car driving 15 km/h slower)	○	○	○	○	○
Car in front of you in your lane brakes lightly (for example, slows down by 5 mph)	○	○	○	○	○

Appendix F: Participant Suggestions for Training from Study 2

Participant suggestions on ways to improve the training (first column) and the number of participants who provided each suggestion.

		Responsibility-focused		**Limitation-focused**	
Suggestions for Improving the Training	**Total # of mentions**	**No Experience**	**Experienced**	**No Experience**	**Experienced**
Add information	9	4	2	3	
More detail about how LKA works	2		1	1	
Differences compared to lower level ADAS	1	1			
How system determines hands on wheel	1	1			
Misconceptions	1	1			
More example scenarios	1	1			
Speed limit changes	1	1			
Whether it is universal	1		1		
Legal precedence	1			1	
Longer explanations	1			1	
Improve visuals	3	2	1		
Could improve to support memory	2			1	1
Increase pace	2			1	1
Less information per slide	2			1	1
Add more excitement	1		1		
Including specific sensor range could have negative consequences	1	1			
Add animations or video examples	1			1	
Reduce pace	1				1
Total # of respondents	20	7	4	6	3

Appendix G: Study 3 Post-Drive Questionnaires

Perceived Workload (modified NASA TLX; Hart & Staveland, 1988)
The purpose of this questionnaire is to assess your subjective workload for the scenario you just completed. While providing your ratings, **please consider both the driving and the non-driving tasks that you performed**.

If you need clarification on a question, please do not hesitate to ask the experimenters.
[Participants rated each question using a slider from 0 to 20]

Mental Demand - How much mental or perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching etc.?) Was the task easy or demanding, simple or complex?
Question: How mentally demanding was the task?

Very Low *Very High*
0 ________________________[x]_____________________________ 20

Physical Demand - How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating etc.?)
Question: How physically demanding was the task?

Very Low *Very High*
0 ________________________[x]_____________________________ 20

Temporal Demand - How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
Question: How hurried or rushed was the pace of the task?

Very Low *Very High*
0 ________________________[x]_____________________________ 20

Performance - How stressful do you think you were in accomplishing the goals of the task? How satisfied were you with your performance in accomplishing these goals?
Question: How successfully were you in accomplishing what you were asked to do?
(Be careful, for this question, the bar is from PERFECT to FAILURE from LEFT to RIGHT)

Perfect *Failure*
0 ________________________[x]_____________________________ 20

Effort - How hard did you have to work (mentally and physically) to accomplish your level of performance?
Question: How hard did you have to work to accomplish your level of performance?

Very Low *Very High*
0 ________________________[x]_____________________________ 20

Frustration Level - How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?
Question: How insecure, discouraged, irritated, stressed and annoyed were you?

Very Low *Very High*
0 ________________________[x]_____________________________ 20

Trust (adapted from Jian et al., 2000)
Please fill out the questionnaire below for the driver support systems you used in the last scenario (i.e., combined adaptive cruise control and lane keeping).

Please mark the point that best describes your feeling or your impression on the following statements.

Please mark one response for each row.

	Not at all 1	2	3	4	5	6	Extremely 7
I am confident in the system	◯	◯	◯	◯	◯	◯	◯
The system is dependable	◯	◯	◯	◯	◯	◯	◯
The system is reliable	◯	◯	◯	◯	◯	◯	◯
I can trust the system	◯	◯	◯	◯	◯	◯	◯

Acceptance (adapted from van der Laan et al., 1997)
For each row, please mark the point that best describes your feeling or your impression of the driver support systems you used in the last scenario (i.e., combined adaptive cruise control and lane keeping).

Please mark one response for each row.

Useful	◯	◯	◯	◯	◯	Useless
Pleasant	◯	◯	◯	◯	◯	Unpleasant
Bad	◯	◯	◯	◯	◯	Good
Nice	◯	◯	◯	◯	◯	Annoying
Effective	◯	◯	◯	◯	◯	Superfluous
Irritating	◯	◯	◯	◯	◯	Likeable
Assisting	◯	◯	◯	◯	◯	Worthless
Undesirable	◯	◯	◯	◯	◯	Desirable
Raising Alertness	◯	◯	◯	◯	◯	Sleep-inducing

Appendix H: Study 3 ADAS Knowledge Questionnaire

* Asterisks indicate situations where ADAS may have difficulty

1. Not considering unforeseen malfunctions, please check all the situations where you think the advanced driver assistance systems in your vehicle **may have difficulty controlling speed and/or steering**. Check all that apply.

   [ ] Driving in a work zone where lanes have shifted from their usual location*
   [ ] Driving in heavy rain or snow*
   [ ] Driving into direct glare at sunset*
   [ ] Driving where lane lines are badly faded*
   [ ] Driving on city streets*
   [ ] Driving on an undivided highway (only a yellow line separating traffic travelling in the opposite direction – no median or barrier)
   [ ] Driving on a divided highway (has a median or barrier separating traffic traveling in the opposite direction)
   [ ] Driving on a rural highway without stop signs or traffic lights
   [ ] Driving on a cloudy day
   [ ] Lane markings for your lane change from dashed lines to solid lines

2. Not considering unforeseen malfunctions, please check all the situations where you think the advanced driver assistance systems in your vehicle **may have difficulty avoiding a collision without the driver adjusting the speed or steering**. Check all that apply.

   [ ] Approaching a bed mattress on the road in your lane*
   [ ] Car in front of you brakes hard (in other words, they "slam on the brakes")*
   [ ] Car in the lane directly next to you starts changing into your lane*
   [ ] Approaching a highway construction worker standing in your lane*
   [ ] Approaching a slight curve in the road
   [ ] Approaching a slower moving car ahead in your lane (for example, a car driving 10 km/h slower)
   [ ] Car in front of you brakes slightly (for example slows down by 5 km/h over 3 seconds)
   [ ] Car in front of you brakes moderately (for example slows down by 10 km/h over 3 seconds)

Appendix I: Study 3 Participant Demographics

	No training	**Limitation-focused**	**Responsibility-focused**
Highest level of education completed (*N*)			
High school degree or equivalent	0	0	1
Some college or university	1	3	1
College degree	1	0	4
Bachelor’s degree	3	3	3
Some graduate education	2	2	0
Master’s degree	4	5	2
Doctorate	1	0	1
Professional degree	2	0	1
Yearly household income (*N*)			
Less than $35,000	0	0	3
$35,000 to $69,999	3	5	4
$70,000 to $99,999	3	3	0
$100,000 to $149,999	6	1	1
More than $150,000	0	3	5
Technology familiarity (*M*, *SD*)	7.69, 1.62	7.64, 1.45	7.19, 2.03