Driving the Future: Evaluating a Training Concept for Advanced Driver Assistance Systems

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Abstract — With the widespread adoption of Advanced Driver-Assistance Systems (ADAS), the need for effective ADAS driver training increases. However, empirical evidence regarding the effectiveness of ADAS education remains limited. This study evaluated the effectiveness of an ADAS driver training program across four European countries. The training included classroom-based theoretical instruction and practical hands-on experience on test-tracks and open-roads. 166 participants completed a questionnaire measuring their knowledge, attitudes, and behavioral intentions towards ADAS pre- and post-training. Overall knowledge of system purpose, handling and limitations improved significantly with the training. However, some misunderstandings remained, and in some cases, misconceptions from before the training were not corrected. Perceived safety and trust remained unchanged while willingness to use ADAS systems, and the perceived ease of use and usefulness of ADAS increased. Future training should not only provide information for trainees but also identify misconceptions they may hold. Follow-up or feedback sessions are recommended to address potential misunderstandings.

Keywords: ADAS; driver training; evaluation

1. Introduction

It is expected that by 2025, more than 60% of vehicles sold globally will be equipped with partial driving automation, offering SAE Level 2 (SAE, 2021) functionality or higher (Statista, 2023). Currently, vehicles equipped with Advanced Driver Assistance Systems (ADAS) are already on the market, including SAE levels 1 and 2 (SAE, 2021). These systems offer lateral and/or longitudinal vehicle support and include features such as adaptive cruise control, lane keeping assistance and blind spot detection. While the aims of these systems are to improve vehicle safety and enhance driver comfort, these systems are currently not achieving their potential contribution to safety, with research from the Insurance Institute for Highway Safety in the U.S. finding little evidence that L2 systems provide any safety benefits (Cicchino, 2025). In addition, studies have shown that many drivers are either unaware of the existence of ADAS in their vehicles (Harms et al., 2020), or do not fully understand how they work (Nandavar et al., 2023). Thus, it is clear that while ADAS has the potential to greatly improve road safety, its benefits can be lost, or even reversed, if drivers misunderstand or misuse the systems. Therefore, establishing consistent and effective training programs to provide users with the necessary knowledge to engage and use these systems is an essential step to maintaining traffic safety.

Previous studies (Boelhouwer et al., 2020; Kaye et al., 2022; Lubkowski et al., 2021; Nandavar et al., 2023; Viktorová & Sucha, 2019) have shown that drivers learn about ADAS through a variety of methods, including manuals, trial and error, and dealership. Among these, trial and error has often been most frequently reported, leading to concerns about the risk of drivers' developing inaccurate mental models of system functionality (Nandavar et al., 2023). Although owners' manuals are commonly provided to drivers, and may offset this risk, many drivers do not read them. In the case of dealership responsibilities, drivers sometimes do not receive formal instruction from dealership staff (Boelhouwer et al., 2020), and even when they do, dealership staff may not be fully knowledgeable about the systems themselves (Abraham et al., 2017). As such, current methods of acquiring knowledge about ADAS are unstructured, posing risks of insufficient or inaccurate information acquisition, increasing the risks of system misuse or disuse (Parasuraman & Riley, 1997). Technologies that could make travelling safer and more comfortable when used as intended, can lead to more dangerous driving situations when misused.

Knowledge from decades of research in the aviation sector suggests that drivers need to have a certain level of technical understanding of the capabilities and limitations of the systems they are using (Casner & Hutchins, 2019), and ideally this should be delivered and evaluated in a consistent manner across jurisdictions to facilitate more comprehensive and effective implementation. Structured training approaches using driving simulators and incorporating video and demonstration-based materials (e.g. Manser et al., 2019), and audio-based triggers (Murtaza et al., 2023) have been shown to enhance driver competence and comfort with ADAS technologies. Such instruction not only boosts operational accuracy but also fosters a better understanding and greater trust in the systems. However, this simulator-based training may not be accessible for wide groups of society, and thus it is important to consider training techniques and platforms which allow greater societal reach.

Driving academies provide an opportunity to incorporate multiple training approaches as suggested in the organizational training literature, along with providing the potential to achieve more widespread and consistent ADAS training across populations and jurisdictions (e.g., Salas et al., 2012). They can offer both theoretical knowledge and practical training aimed at improving driving skills and safety. Basic education for novice drivers is also offered, while providing advanced courses for experienced drivers in areas such as defensive driving, eco-driving, and the operation of emerging vehicle technologies. A distinctive characteristic of driving academies, compared to other learning methods such as video-based learning or text materials, is the opportunity for direct interaction between instructors and (trainee) drivers. This face-to-face engagement promotes driver participation, allows for immediate feedback to correct misconceptions, and reinforces learning impact in a real-world driving environment. Research in the United States (Walshe et al., 2022) has shown that novice drivers who underwent mandatory driver education, including behind-the-wheel training, were less likely to be involved in crashes than those exempt from such training, highlighting the importance of behind-the-wheel instruction. Driving academies also have the potential to serve as effective channels for ADAS education. Kim et al. (Under review) found that many drivers viewed driving academies as a promising avenue for learning about ADAS. Furthermore, some institutions have already begun to implement ADAS driver training programs (Autotechtraining, 2025). Nevertheless, empirical evidence regarding the effectiveness of ADAS education in driving academies remains limited. Therefore, further research is needed to examine the impact of academy-based ADAS education on drivers' understanding, attitude, and experience with these systems.

Evaluating the training is a key element in understanding the usefulness and appropriateness of a training program, identifying strengths and weaknesses so that improvements can be made where necessary (Noe & Tews, 2008), and providing a vital step to ensure that any purported training benefits are realized. The evaluation process starts with the initial identification of the knowledge and skills to be addressed through training (Arthur Jr et al., 2003; Goldstein & Ford, 2002). By systematically identifying areas which the training aims to target, a clear evaluation process can be developed to

measure the success and potential impact of the training. Manser et al. (2019) identify five key knowledge and skill areas that drivers should be trained on to safely drive and operate a vehicle with ADAS functions. These are: 1) understanding the purpose of ADAS (risks and benefits); 2) Understanding levels of ADAS (capabilities and driver responsibilities); 3) transitioning between ADAS and manual driving and handling critical situations; 4) familiarity with system components and placement; and 5) understanding ADAS limitations. These five knowledge and skill areas provide a useful starting point for developing structured ADAS training which can be effectively evaluated. Training evaluation frameworks (e.g. Kirkpatrick, 1976) recommend measuring participants' reactions (e.g. enjoyment of the training), learning outcomes (e.g. knowledge gained), intended behaviors (e.g. system usage) and results (e.g. reduction in accidents). However, it is often difficult to capture long-term changes in behaviors, and thus, behavioral intentions are often used as a proxy measure for results. A large body of research has shown that a person's intention to engage in a behavior is the strongest predictor of that behavior (e.g., Ajzen, 2011), and thus it is anticipated that training which leads to intentions to use ADAS appropriately will translate into safer driving with these systems. In the Hi-Drive project (https://www.hi-drive.eu/) partners from automotive industry, research and mobility clubs work amongst other on spreading knowledge about ADAS in the population. This includes a large awareness campaign in social media but also the development and testing of an onsite training concept for ADAS. The developed structured and targeted ADAS driver training program conducted across four European sites is evaluated using measurement of participants' reactions, learning outcomes and intended behaviors after training.

1.3. Objectives

This study aims to evaluate an ADAS driver training program at a driving academy focused on educating drivers about SAE Level 1–2. The training program incorporated both theoretical instruction and practical experience using real vehicles, and to the author's knowledge is the first ADAS driver training program to incorporate structured and supported on-road experience. Through a questionnaire based on Kirkpatrick's (1976) training evaluation framework, we assessed the training program's efficacy in improving users' knowledge and understanding of these systems, and the impact of driver training on participants' attitudes and behavioral intentions toward ADAS. As a potentially impacting factor, the pre-experience of participants with ADAS was considered in the analysis to see if the impact of training impact was the same for experienced and inexperienced participants. In addition, we gathered information on participants' reactions to the training, as this has the potential to impact their willingness to engage with the materials, and recommend the training to others. Through this evaluation, we aim to derive conclusions regarding the effectiveness of such training initiatives and to identify possibilities for optimizing future program design to enhance knowledge transfer, attitudinal shifts, and behavioral adoption. A key aim of this training program was to develop a consistent approach across European countries, and therefore the training curriculum was delivered in four different European countries.

2. Methods

2.1. Training Material and Procedure

Within the Hi-Drive project, a common framework for ADAS training was developed and implemented at four different training sites. The curriculum focused mainly on systems categorized under SAE Levels 1 and 2 (SAE, 2021), while SAE Level 3 functions like motorway assist and traffic jam chauffeur were also shortly addressed. The training material was created in English language through a collaborative process involving mobility clubs, automotive companies, and academic institutions

involved in Hi-Drive. The training was conducted by the mobility clubs (ADAC (in Germany), AMZS (in Slovenia), RACB (in Belgium), RACC (in Spain)) on their premises, which are comparable to driving academies. The training material was translated by the mobility clubs in the respective languages, which were German, Slovenian, Spanish and French. The framework consisted of a theoretical part with an introduction to ADAS and a practical part in which the different ADAS could be experienced in the car on-track and on-road. For the theoretical training, all training sites used the same material. The practical training took place firstly on a test track, and was supplemented by the opportunity to test the systems under real traffic conditions on open roads. The instructors who led the theoretical training and accompanied the practical sessions on the test track and on the road were professional driving instructors who work for the mobility clubs and have expert knowledge of ADAS systems. To evaluate the training, a questionnaire was filled in by the trainees before and after the training. Table 1 provides an outline of the training and durations of each element.

Table 1 Outline of the training

Training parts	**Duration**
Pre Questionnaire	5 min
1. Theoretical training	30 min
2. On-track training	75 min
3. On-road training	90 min
Post Questionnaire + Debrief	10 min
Total	3h30min

Theoretical training

The theoretical training was designed to provide drivers with a foundational understanding of ADAS and their role in modern vehicles. The primary objective was to enhance participants' knowledge of ADAS functionalities, enabling them to use these systems effectively and adequately. The training employed a classroom-based approach. The instructors gave presentations and used multimedia resources from the Hi-Drive project to illustrate key concepts. This included videos and campaign materials that highlighted the capabilities and limitations of ADAS technologies (https://www.hi-drive.eu/uec/). The theoretical section was structured into three main modules. They were based on the above-mentioned key skill and knowledge areas (1, 2, 5) identified for an ADAS training concerning the understanding of ADAS purposes, ADAS levels, and their limitations (Manser et al., 2019):

1. **Introduction to Driving Automation Levels**:
   Participants learned about the six levels of driving automation defined by the Society of Automotive Engineers (SAE, 2021). The focus was on understanding the driver's role at each level, emphasizing that even advanced systems require human oversight and responsibility.

2. **Overview of ADAS Functions**:
   This module distinguished between support functions (e.g., adaptive cruise control, lane-keeping assist) and emergency systems (e.g., automated emergency braking). Drivers were trained to recognize the benefits of these systems while understanding their limitations and the importance of staying attentive.

3. **Function-Specific Modules**:
   Detailed explanations of key ADAS features, including Adaptive Cruise Control (ACC), blind spot monitoring (BSM), lane-keeping assist (LKA), emergency lane-keeping (ELK), and automated

emergency braking (AEB front and rear), were provided. Each module covered system activation, deactivation, operational range, and potential limitations or failure points. The focus of the training was on these specific functions, as they are most popular on European Roads (Neumann, 2024), providing examples for both support functions and emergency systems.

The practical parts further deepened knowledge and addressed the following skill areas: transitioning between ADAS and manual driving and handling critical situations as well as familiarity with system components and placement (Manser et al., 2019). The driving instructors accompanied the practical sessions in the cars, explaining how to handle the systems in accordance with instructions defined in the training curriculum.

On-track training

In this module, participants drove maneuvers on a closed track under the guidance of an instructor in a car. First, participants could familiarize themselves with the car's HMI and then four modules followed, covering the four ADAS functions: Adaptive Cruise Control (ACC), Lane Keeping Assist (LKA)/Emergency Lane Keeping (ELK), Blind Spot Monitoring (BSM) and (rear) Automated Emergency Braking (AEB). The track-based segments of the training program aimed to help drivers become more comfortable with core ADAS features by practicing in a secure, controlled setting under expert supervision. The closed course environment offered a safe space to explore how these systems perform and where their boundaries lie.

On-road training

The on-road components of the training were designed to let drivers apply what they had learned on the track in real traffic conditions, all while being closely guided by an instructor. During these sessions, multiple ADAS features were activated and experienced together, helping participants understand how they complement one another in everyday driving. Drivers practiced real-world driving tasks on public roads under the supervision of an instructor, sharing the vehicle in pairs and switching roles midway through. The on-road training included three modules, each focused on a specific ADAS feature: ACC, LKA/ELK and BSM.

Throughout the training, the central message was reinforced that, while ADAS can enhance safety, it cannot replace driver vigilance. The detailed procedure, training curriculum and specific driving instructions and exercises, core messages and learning objectives for all parts can be accessed openly in the Hi-Drive Deliverable D8.7 (https://www.hi-drive.eu/downloads/ ; Beckmann et al., 2025).

2.2. Questionnaire

To assess the effects of ADAS training, a questionnaire was developed that covered objective changes in knowledge about the ADAS included in the training as well as behavioral and attitudinal aspects and subjective evaluation of ADAS and the training. The survey was conducted both before the training (pre-questionnaire) and after the training (post-questionnaire), as shown in the appendix A and B.

The pre-questionnaire included sections on demographics, experience with ADAS, attitudes toward ADAS, and knowledge assessment. In the demographics section, participants responded with their age and gender. Next, in the section on ADAS experience, participants answered questions about their driving experience and whether they had used ADAS features, how frequently they used them, and their perceived level of knowledge.

Following that, participants completed the **attitude** toward ADAS section. This section included the following constructs: perceived safety (items adapted from Xu et al., 2018), trust, perceived ease of use, and perceived usefulness of ADAS (items adapted from Zhang et al., 2019). **Behavioral intentions** were measured with the willingness to use these systems, with items based on Ozturk et al. (2025). Notably, willingness to use was assessed not only for ADAS in general but also for specific features such as ACC, LKA, AEB, and BSM. All these questions were measured using a 5-point Likert scale ranging from "Strongly disagree" to "Strongly agree." Items for each of the attitudinal and behavioral constructs were taken from the Hi-Drive common questionnaire (Lehtonen et al., 2024). In the appendix A it is indicated which items represent which attitudinal or behavioral construct (question 6).

Lastly, participants responded to questions assessing their **knowledge** of ADAS features. The features in question were ACC, LKA, AEB, and BSM. This section was designed with reference to a questionnaire that evaluates knowledge of Level 3 automation (see Metz et al. (2024) for reference). For each ADAS feature, a set of statements about the system was presented. Participants had to indicate whether each statement was correct or incorrect, and how confident they were in their response. System knowledge was evaluated including items about the system's purpose, actual functioning, handling, capabilities, and limitations based on the concepts of Manser et al. (2019), see appendix A questions 9–10.

The post-questionnaire included a section on training experience. First, the training experience was evaluated using a 5-point Likert scale to assess the quality and quantity of the information provided. Additional statements were included to assess the participant's experience, subjective knowledge acquisition, and potential recommendations, measured on the 5-point Likert scale ranging from "Strongly disagree" to "Strongly agree." Afterwards, the same knowledge, attitude and behavioral questions regarding ADAS as in the pre-questionnaire followed.

2.3. Participants and ADAS experience

A total of 166 participants took part in the training and completed the training questionnaires across four European sites (see Table 2 and 3 for further details on the sample). Participants were recruited via invitation emails sent to members of the mobility clubs. They were told that they could participate in free ADAS driver training, which was presented as a valuable opportunity. There were no specific recruitment criteria, as the aim was to reach people interested in learning about these systems. As the focus of this evaluation is on the general impact of the developed training approach on participants' reactions, learning outcomes and intended behaviors, the data from the different training sites is taken together. It is acknowledged that there will always be differences between sites (different vehicles, different characteristics of used test track / public roads, different trainees, …) that are not easy to interpret or control for. However, a successful and robust training curriculum should be effective independent of the specific training site characteristics. Thus, this study focused on overall effects rather than looking at sites individually.

Table 2 Overview training sites

	Training site				
	1	**2**	**3**	**4**	**total**
Country	Germany	Spain	Slovenia	Belgium	all
N trainees	14	45	54	53	166

Table 3 Sample description

Total N	**Age**		**Gender**		**Driver's license (years)**		**Vehicle (years)**	
	M	SD	Female	Male	M	SD	M	SD
166	46.2	17.7	33	131	27.2	17.5	5.0	7.3

In order to establish trainees pre-existing experience with ADAS, participants were asked about the systems that they have in their vehicles and how often they used them (see Figure 1). 59% of participants used ADAS-systems daily, 14.5% weekly, 4.8% monthly and 7.2% less often. Table 4 shows the percentage of participants who knew how to turn these systems on and off.

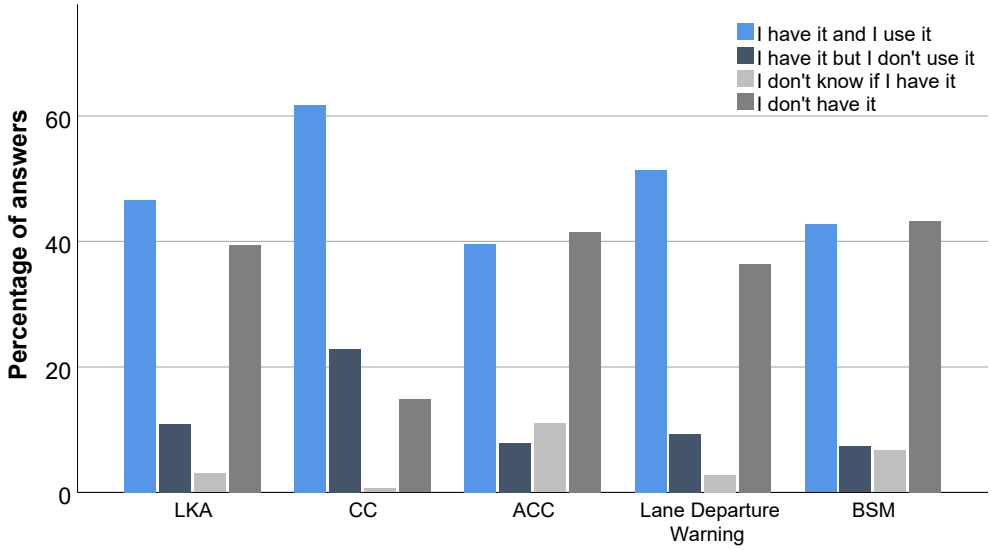


Figure 1 Pre-experience with ADAS per system.

Table 4 Percentage of answers regarding question on knowledge how to turn system on and off

	Yes	No	Not applicable*
LKA	53.5	10.7	35.8
CC	76.1	9.4	14.4
ACC	48.1	11.3	40.6

Note. *because system is not available in own car

2.4. Data Analysis

For all parts of the questionnaire, the focus is on the evaluation of the change between pre and post training. To see whether the impact of training differs between participants with and without ADAS experience, the pre-experience factor was included in the analysis of all parts of the questionnaire. For each system's specific experience, the 4-point 'experience' variable was dichotomized by classifying the response 'I have it and I use it' as 'previous experience', and all other responses as 'no experience' (see Figure 1 for the response categories). An overall ADAS experience item was also calculated, indicating whether participants had experience with at least one system or none.

The level of analysis (system-specific vs. general ADAS) was determined by the measurement design of the questionnaire and the conceptual specificity of the constructs. System-specific analyses were conducted for variables that were explicitly assessed at the system level (knowledge and willingness to use) reflecting the functional differences between the ADAS features and the system-dependent nature of these constructs. In particular, willingness to use was collected separately for each system to capture differentiated behavioral intentions toward individual ADAS functions. In contrast, attitudinal and general behavioral variables were assessed at an aggregated ADAS level and analyzed accordingly, as these constructs capture overarching perceptions that are not tied to individual systems.

The percentage of correct answers for the knowledge items were calculated for each trainee per system based on all given answers. To analyze confidence, the confidence ratings were averaged over all systems but separately for items answered correctly and incorrectly. For the behavioral and attitudinal concepts, the mean value for each construct (intention to use, safety, reliability, ease of use, and usefulness of ADAS) was calculated. The results section describes which specific analysis method and which experience item was used for each analysis.

Gender and age factors were not investigated, as the sample distribution was very unequal regarding these two aspects. Unfortunately, some data was missing for certain questions and participants. This was because the instructors did not check that the answers were complete. These participants were still included in analyses where the data was complete. Consequently, there are slight differences in sample sizes and degrees of freedom for analyses of different aspects.

The statistical assumptions for ANOVAs were tested. As the repeated-measures ANOVA is robust to violations of the normality assumption when n > 30 (Bortz, 2013), the violation of this assumption was not considered critical. Where the sphericity assumption was violated, the Greenhouse-Geisser correction was applied. Where extreme outliers were present, it was determined whether they were genuine outliers or measurement errors. Tests were then carried out to ascertain whether the same effects were present when the outliers were excluded. This was the case for all of them.

3. Results

3.1. System knowledge

First, a descriptive overview of the results regarding the knowledge items is provided. Figure 2 shows the percentage of correct answers about each system's purpose before and after training. Figure 3 compares the percentage of correct answers prior to and after training regarding how to handle each system. For each item, it is indicated whether the correct response was true (t) or false (f). For most participants (>75%), the purpose of all systems except ACC was clear pre- and post-training. (see Figure 2). However, for ACC, almost half of participants partly misunderstood its' purpose, as they indicated that ACC also has an automated emergency braking and speed limit function. In Figure 3, it is noticeable that for most items the percentage of correct answers was high (> 75%) pre- and post-training. However, for some items the percentage of correct answers regarding the system handling was very low, i.e. under 50%, even after the training. These are the following items:

- *ACC*: The system supports me when I need to brake in a critical situation.
  The system warns me when I drive faster than the speed limit.
  The system is always available.
- *LKA*: The system is always available.
  The lane departure warning system is available for all speeds.
- *AEB*: I can turn off the system.
  The system is always available.
  The AEB always brakes to a standstill.
- *BSM:* The system is always available.
  The BSM warns me with an audible signal.

With regard to the goals of the training, there was also a considerable decrease in the percentage of correct answers to the following items regarding the system handling:

- *LKA*: When the lane departure warning system is activated, I can take my hands off the steering wheel.
- *AEB*: The AEB always brakes to a standstill.

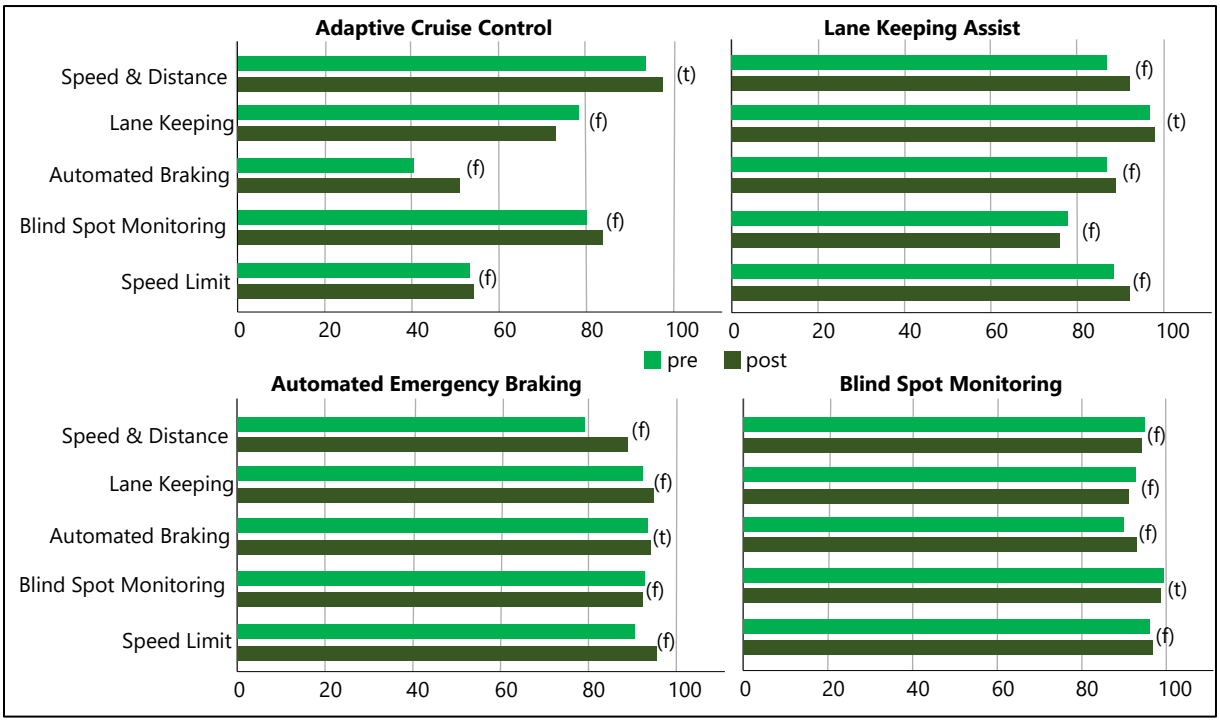


Figure 2 Percentage of correct answers regarding the system purpose (f = false item, t = true item)

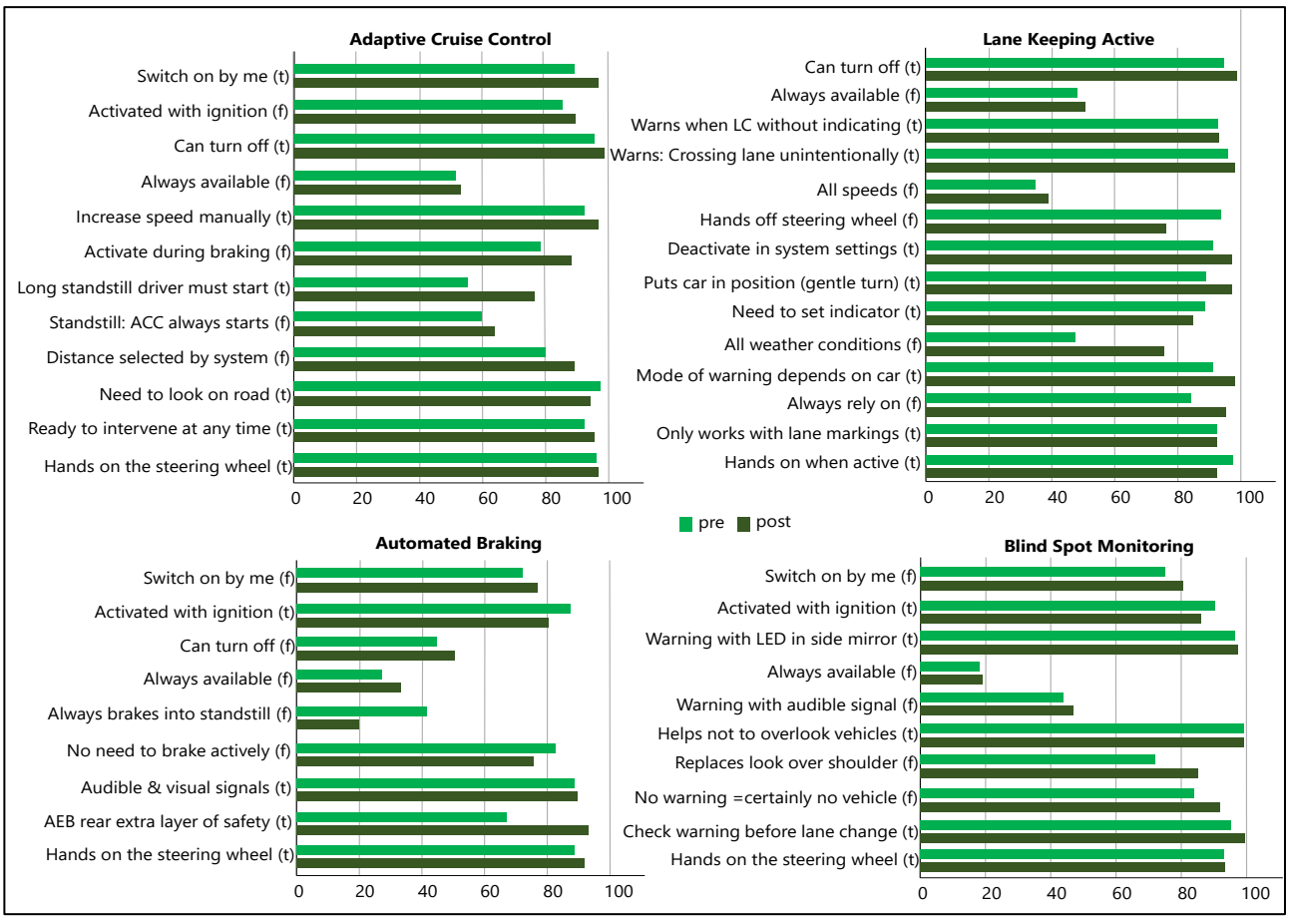


Figure 3 Percentage of correct answers regarding the system handling (f = false item, t = true item)

To investigate whether there was a significant difference pre- and post-training knowledge about the four trained systems, a 2x4 repeated measures ANOVA was conducted to investigate the effects of Questionnaire Time (pre vs. post training) and System Type (ACC, LKA, AEB, BSM) on the percentage of correct responses. The percentage of correct answers differed significantly between pre- and post-training [$F(1,130) = 17.521$, $p < .001$, $\eta^2 = .119$] and between systems [$F(2.605, 338.594) = 38.369$, $p < .001$, $\eta^2 = .228$]. For all systems, the percentage of correct answers was higher after the training compared to before. LSD post-hoc tests, that compare each system with each other show that all systems differ significantly in the percentage of correct answers ($p < .05$) except for LKA and BSM. There was no significant interaction effect. The mean values can be found in Figure 4.

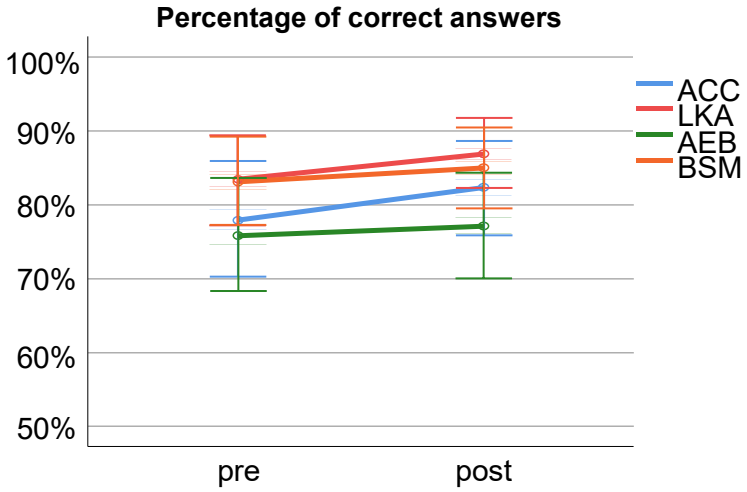


Figure 4 Mean percentage of correct answers per system and training (pre vs. post). Error bars = +/- 1 SD

To check whether the training effect differed depending on the participant's prior experience with the ADAS system, four 2x2 repeated measures ANOVAs were calculated for each system, with the factors of Questionnaire Time (pre- vs. post-training) and ADAS Pre-Experience (yes vs. no). The mean percentage of correct answers per system and factor is shown in Figure 5. For ACC, the ANOVA revealed a significant main effect of Questionnaire Time [$F(1,141) = 8.573$, $p = .004$, $\eta^2 = .057$], with participants having a higher percentage of correct responses after training. There was also a significant effect of pre-training experience [$F(1,141) = 5.549$, $p = .020$, $\eta^2 = .038$], whereby those with previous experience of ACC had a higher percentage of correct answers than those without. However, there was no significant interaction effect. For LKA, there was only a significant effect of Questionnaire Time [$F(1,138) = 13.665$, $p < .001$, $\eta^2 = .090$] but not LKA Experience, nor was there a significant interaction. There was no specific question to check participants' AEB pre-experience. Therefore, we used the overall ADAS Pre-Experience for this system. Here, there were no significant effects. For BSM, there was a significant effect of Questionnaire Time [$F(1,135) = 5.311$, $p = .023$, $\eta^2 = .038$] with a higher percentage of correct answers post-training.

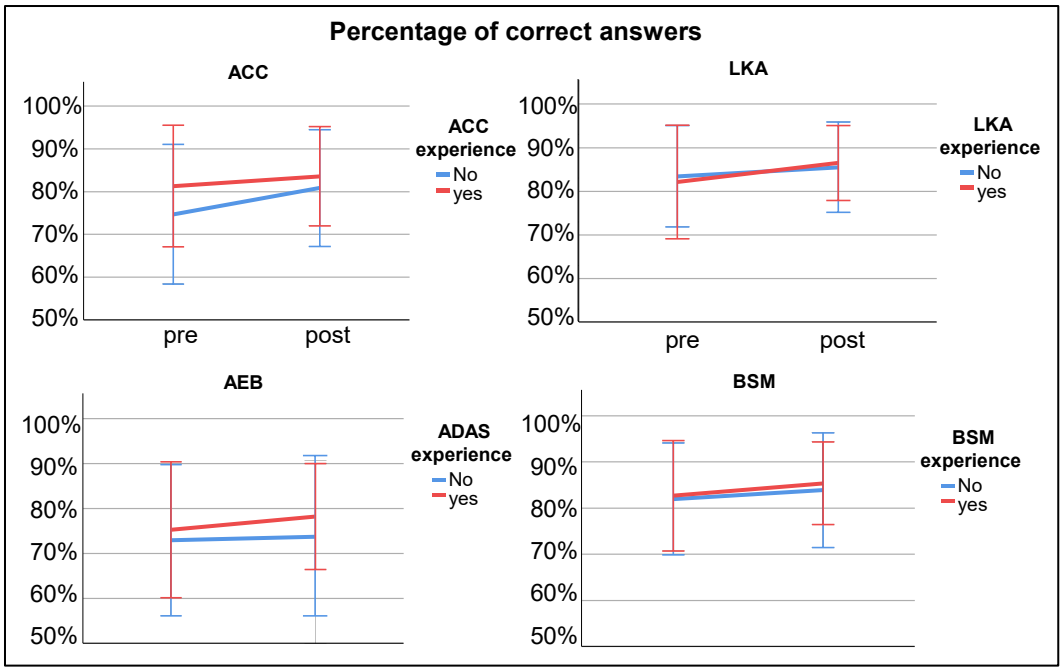


Figure 5 Mean percentage of correct answers per system and experience. Error bars = +/- 1 SD

3.2. Confidence in knowledge

A 2x2x2 repeated measures ANOVA was calculated with the factors of Questionnaire Time (pre- vs. post-training), Answer Accuracy (item correctly vs. incorrectly answered) and ADAS experience (yes vs. no) to see if confidence in answers changes with training and differs between different experience levels. The Answer Accuracy was included as a factor to check whether confidence changes differently for correct and incorrect items. Overall, confidence in the correctness of the answers was high. With the training, there was an increase in confidence [$F(1,112) = 40.9$, $p < .001$, $\eta^2=.27$], and the confidence was higher for items answered correctly [$F(1,112) = 82.1$, $p<.001$, $\eta^2=.42$]. There was a significant interaction between time and accuracy [$F(1, 112) = 6.0$, $p<.001$, $\eta^2=.05$]. The increase from pre to post was larger (0.4 scale points) for the incorrect items compared to the correct items (0.2 scale points). Post-hoc pairwise comparisons showed that after the training the confidence level for incorrect items is comparable to the pre level for correct items ($p > .999$), whereas all other pairwise comparisons were highly significant ($p < .001$). In other words, the increase in confidence through the training is more pronounced for incorrect answers. There was no significant main effect of ADAS experience nor any significant interactions with ADAS experience. Therefore, Figure 6 only displays the confidence levels for incorrect and correct items pre and post training without ADAS experience to ensure readability, as adding non-significant factors would unnecessarily complicate interpretation without adding meaningful insight.

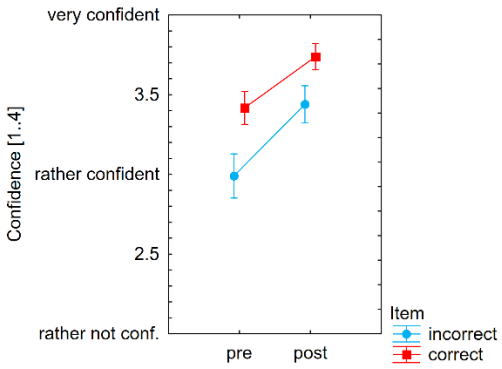


Figure 6 Confidence for pre- and post-training separated for correct and incorrect answers.
Note. For ease of interpretation, the confidence item was inverted so that higher values indicate higher confidence.

3.3. Attitude and Behavior towards ADAS

To understand whether the training led to any changes in attitude and behavioral intentions regarding ADAS, we compared the scales of willingness to use, perceived safety, trust, perceived ease of use and perceived usefulness. Table 5 shows the mean pre- and post- training values, as well as with and without experience values on a scale from 1 = strongly disagree to 5 = strongly agree. The results of a series of 2x2 repeated measures ANOVAs examining the impact of Questionnaire Time (pre- vs post-training) and ADAS Pre-Experience (yes vs. no) are also included. The interactions of Questionnaire Time and Pre-Experience were non-significant for all concepts.

Table 5 Descriptives and statistical values (rmANOVAs) for attitudinal and behavioral concepts

	Pre Training M (SD)	Post Training M (SD)	Without Exp. M (SD)	With Exp. M (SD)	Training effect			Experience effect		
					F	df	p	F	df	p
Willingness to use	4.15 (0.92)	4.23 (0.84)	3.26 (1.63)	4.42 (0.78)	6.140	1,143	**.014**	58.524	1.143	**<.001**
Perceived safety	4.11 (0.78)	4.07 (0.75)	3.51 (1.47)	4.24 (0.70)	0.104	1,143	.747	28.969	1,143	**<.001**
Trust	3.60 (0.73)	3.59 (0.71)	3.23 (1.44)	3.68 (0.67)	0.112	1,142	.738	11.492	1,142	**.001**
Perceived ease of use	3.65 (0.74)	3.96 (0.76)	3.58 (1.46)	3.87 (0.70)	13.767	1,143	**<.001**	4.698	1,143	**.032**
Perceived usefulness	3.81 (0.80)	3.95 (0.82)	3.31 (1.54)	4.01 (0.73)	6.043	1,143	**.015**	25.049	1,143	**<.001**

The willingness to use items were also asked separately per system. 2x2 repeated measures ANOVAs with the factor Questionnaire Time (pre v. post) as well as the system specific ADAS pre-experience (yes vs. no) were calculated. The results and mean values can be seen in Table 6. For all systems the willingness to use was significantly higher with experience compared to without. For ACC and LKA the willingness to use was also significantly higher after the training compared to before. For BSM, there was a significant interaction of questionnaire time and pre-experience [$F(1,141) = 4.951$, $p = .028$, $\eta^2 = .034$]. Post-hoc Bonferroni-adjusted pairwise comparisons showed that the willingness to use

increased significantly from pre- to post-test in the group without previous experience (p = .020), whereas no significant change was observed in the group with experience (p = .378).

Table 6 Descriptives and statistical values (rmANOVAs) for willingness to use per system

Willingness to use	Pre Training M (SD)	Post Training M (SD)	Without Exp. M (SD)	With Exp. M (SD)	Training effect			Experience effect		
					F	df	p	F	df	p
ACC	3.99 (1.00)	4.10 (0.93)	3.75 (1.06)	4.48 (1.28)	6.767	1,146	**0.10**	28.576	1,146	**<.001**
LKA	3.78 (1.13)	3.99 (1.02)	3.45 (1.26)	4.36 (1.29)	19.895	1,144	**< .001**	36.973	1,144	**<.001**
AEB	4.19 (0.85)	4.19 (0.98)	3.62 (1.76)	4.37 (0.85)	1.518	1,139	.220	20.652	1,139	**<.001**
BSM	4.35 (0.80)	4.35 (0.86)	4.19 (0.94)	4.62 (1.06)	0.813	1,141	.369	12.720	1,141	**<.001**

3.4. Evaluation of training experience

Finally, participants were asked to evaluate their experience of the training using several different criteria. Figure 7 shows the percentage of agreement per item. There was a difference between drivers with and without pre-experience for the items "I am aware of system capabilities and limitations" (U = 2706.00, z = 3.614, p < .001) and "I would recommend the training to others" (U = 2354.00, z = 2.322, p = .020). Trainees with no pre-experience of ADAS felt less aware of system capabilities and would recommend the training less. In further questions, 92.3% indicated the amount of information appropriate, 3.9% too much and 2.6% too little. 67.1% found the quality of information very good, 28.4% good and 3.9% neutral.

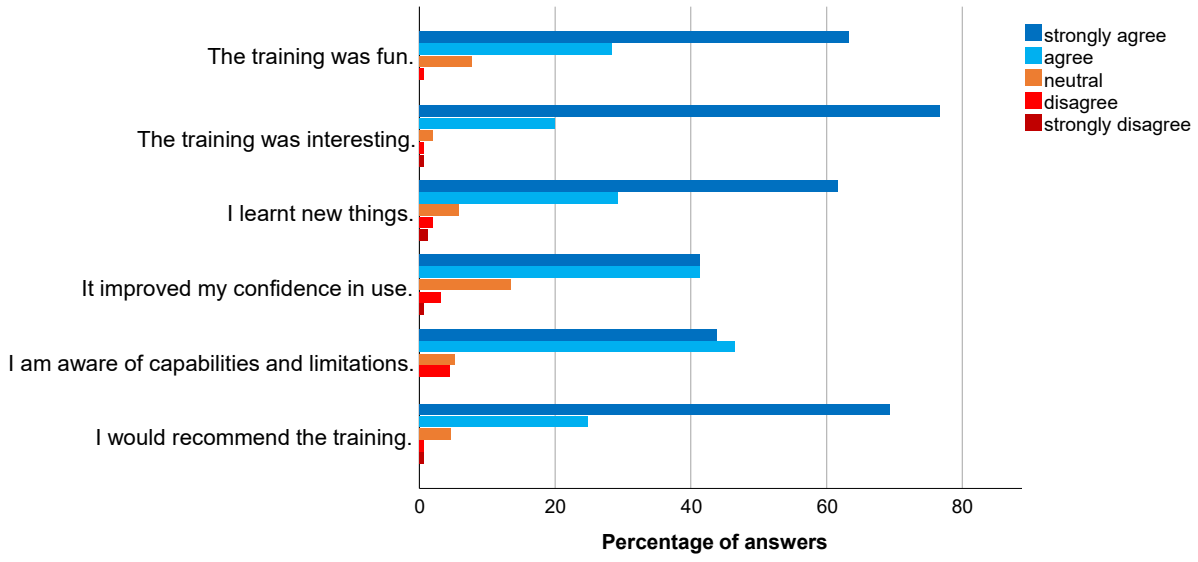


Figure 7 Percentage of answers in the different answer categories for each training evaluation item.

4. Discussion

The findings from this study provide valuable insights into the effectiveness of driver training programs focused on Advanced Driver Assistance Systems (ADAS). In this section, we discuss the results and reflect on this study.

4.1. Impact of ADAS training on ADAS knowledge and confidence

The overall results indicate a significant improvement in participants' knowledge for all systems except for AEB. Thus, the training program was effective in increasing participants' overall understanding of ADAS functionalities. This suggests that the training content was comprehensive and successfully conveyed key concepts about how these systems operate. A possible explanation why there was no increase in knowledge for AEB is that AEB is not used actively and it operates in a manner that is probably less noticeable during typical driving situations, reducing opportunities for drivers to apply their knowledge and thus limiting observable improvement.

Despite the overall improvement, there were items with less than 50% accuracy rate across participants, and there was a considerable decrease in the accuracy of responses for certain items after training. Surprisingly, more than half of the participants thought that all of the systems included are always available. This relatively poor performance on items stating that the systems were "always available" may indicate that these statements required a deeper understanding of the systems' operational logic than other knowledge items. Correctly rejecting such statements presupposes knowledge of the conditions under which a system may become temporarily unavailable, for example, due to environmental limitations or sensor constraints. Participants may not have developed a sufficiently detailed mental model of system operation to accurately judge these statements. Instead, some participants may have relied on a simplified assumption that a system installed in the vehicle is generally available at all times. This shows that system limits should be emphasized more. In addition, there were items with a lower percentage of correct answers. As an example, correct answers decreased from pre- to post-training for the item '*When the lane departure warning system is activated, I can take my hands off the steering wheel*'. This is actually a very undesirable outcome, as it can potentially lead to safety-critical situations when taking off the hands of the steering wheel. There are some potential causes of misinterpretations leading to wrong answers. Participants may have confused features across different ADAS systems, leading to misconceptions about what specific systems can or cannot do. Drivers with prior experience using similar systems may have carried over incorrect assumptions about how these technologies function, which the training did not adequately address. The training materials may not have explicitly clarified the limitations of certain systems, leaving room for ambiguity or confusion. With a wide range of ADAS features covered in the program, participants might have struggled to process and retain all the information, leading to selective retention or misinterpretation of specific details. In terms of training program design, these results indicate what aspects should be emphasized in future training content for this system. When evaluating the effectiveness of training, it is important not only to assess knowledge but also to consider potential misconceptions or risky behavioral changes that may arise after training, to inform future improvements of the training program. To address potential misconceptions or areas of confusion, future training programs should include follow-up assessments or feedback sessions. These mechanisms can help identify gaps in understanding and allow for targeted interventions to clarify misunderstandings. Further recommendations are that training materials should explicitly outline the limitations of each ADAS system. However, at the same time, training that solely emphasizes functional limitations could decrease the desire to use ADAS (DeGuzman et al., 2023). Therefore, the training

could be designed to introduce these limitations while highlighting the driver's responsibility, such as emphasizing that LKA requires driver oversight and does not allow hands-free operation.

Our evaluation method used explicit knowledge queries instead of objectively recording driver skills through behavioral observation, eye tracking, or reaction times, as is often done in simulator training for ADAS (Pełka & Rosiński, 2025; Zahabi et al., 2020). In such training, explicit knowledge is usually not queried directly afterward. We consider this an important part of training evaluation because pure behavioral observation does not allow one to conclude whether sufficient understanding is present.

Overall, the already high confidence in the correctness of the answers increased with the training. Although participants were more confident about correctly answered items, the increase in confidence through training was more pronounced for incorrect answers. This suggests a concerning disconnect between perceived understanding and actual knowledge. This phenomenon can be attributed to several factors, such as participants may feel more informed after training, leading them to overestimate their understanding of complex systems like LKA. Prior beliefs or experiences with ADAS systems could have been reinforced during training instead of being corrected, leading to misplaced confidence. Features from different ADAS systems might have been conflated with each other, causing confusion and misplaced confidence in functionalities that were misunderstood. Therefore, future training programs need to be designed not only to provide information but also to identify and challenge misconceptions actively.

Pre-experience with the system only had a significant impact on system knowledge for ACC. Drivers with pre-experience had higher system-knowledge not only before the training but also in the post-training questionnaire. This indicates that although drivers had already used ACC during daily drives, they still learned something knew in the training. For the other ADAS systems, there was no impact of pre-experience on the percentage of correct answers. Still, drivers with pre-experience were more confident in their answers, this being the case for both correct and incorrect answers. This highlights the need for such training, since people who already use these systems have the same level of knowledge as inexperienced users. Incorporating practical demonstrations or interactive exercises can help participants better understand and retain information about system functionalities and limitations. Training programs should be designed to actively address common misconceptions, particularly among drivers with prior experience using similar systems.

Previous research has identified gender differences in preferred learning styles (e.g., Wehrwein et al., 2007), which may also have influenced the effectiveness of our ADAS training given that our sample was predominantly male. There is currently limited research regarding possible gender differences in training responses in the context of ADAS driver training. For example, Zahabi et al. (2020) found that female participants benefited more from video-based training formats possibly due to the greater control they offered over pacing (e.g. pausing and repetition), whereas male participants performed better following demonstration-based training. Furthermore, male drivers were reported to activate ADAS features more quickly, consistent with the finding that males exhibit a greater willingness to engage with automated systems (Payre et al., 2014). As our sample was predominantly male, the observed training effects may reflect gender-specific preferences or behavioral tendencies, particularly favoring training modalities aligned with male participants. Consequently, the transferability of our findings to more gender-balanced populations is uncertain, and future research should explicitly examine gender as a moderating factor in the effectiveness of ADAS training.

4.2. Impact of training on attitude and behavior towards ADAS

Interestingly, perceived safety and trust remained unchanged post-training, yet willingness to use ADAS systems increased, along with perceived ease of use and usefulness. This suggests that

participants felt more confident in their ability to utilize ADAS effectively, though this newfound confidence did not translate to an enhanced sense of safety. However, the perceived safety was already high before training which is in line with other findings from surveys, that ADAS improves for most users the feeling of safety while driving (Neumann, 2024). System-specific analyses revealed divergent outcomes. For ACC and LKA, willingness to use increased across all participants, underscoring the training's broad effectiveness for these systems. However, for Blind Spot Monitoring (BSM), the interaction between prior experience and training was notable: while experienced users became more willing to use BSM after training, those without prior experience saw a decrease in willingness. This could be attributed to either an increased awareness of limitations or overwhelming complexity among novice users. For AEB, there was no change in willingness to use. AEB as an emergency system for collision avoidance, operates passively and only in critical situations, unlike other ADAS features that drivers can actively use daily. This could explain why willingness to use AEB remained unchanged after training, despite improvements in awareness. Its function is inherently limited to emergencies, making it less relevant for regular engagement or preference compared to systems like ACC or LKA.

4.3. Reactions to training content

The training was evaluated positively for the amount and quality of information, with more than 80% of trainees willing to recommend it. However, the analysis revealed significant variations based on participants' prior experience with ADAS systems. Drivers with prior experience demonstrated more positive perceptions of ADAS, suggesting that existing knowledge enhances the training's impact. Conversely, those without prior experience reported lower awareness of system capabilities and were less likely to recommend the training. This discrepancy suggests that, while the training content is effective for experienced users, it could have addressed the needs and concerns of novices more effectively. Therefore, future training design could benefit from a tailored approach that takes drivers' experience levels into account. For example, drivers without prior experience may require a focus on the basic features of the systems and opportunities to gain hands-on experience to reinforce initial understanding. In contrast, drivers with prior experience may benefit more from correcting knowledge errors and calibrating their trust in the systems. Overall, the positive evaluation of the training demonstrates its potential, but the differences in effectiveness across experience levels highlight the need for differentiated training design. Without additional strategies specifically addressing the needs of drivers without prior experience, the benefits of training are likely to remain unevenly distributed. In accordance with the positive feedback from our sample towards the theoretical and practical input, a survey study on the requirements for an ADAS training revealed that the most preferred option by drivers is a theoretical or practical training in a specialized unit, e.g. driving technique improvement center (Rodak & Pełka, 2023).

4.4. Limitations

This study has several limitations that need to be acknowledged. First, variations in training delivery across mobility clubs may have influenced the results. Even though the same training content was used, standardizing delivery methods across different training centers would help ensure consistency and allow for more reliable outcome comparisons. Regarding training content, this study primarily focused on the evaluation of the training program as a whole rather than on the effectiveness of its individual components or refining the instructional material. The training was developed based on a structured learning protocol encompassing key areas such as the purpose of the ADAS, user responsibility, transition management, system familiarity, and limitations (Manser et al., 2019). However, we did not assess the individual benefits of these elements or the specific impact of the theoretical, on-road, and

test-track components. Consequently, it remains unclear to what extent the theoretical sessions, on-road experiences, and test-track exercises each contributed to participants' knowledge gains, improved understanding, or remaining misconceptions regarding ADAS functionalities and limitations. In particular, although the practical driving components represent a novel aspect of the training concept, the current study design does not allow conclusions about their specific educational value or interaction with theoretical instruction. Furthermore, because the study investigated one specific training structure, the findings cannot necessarily be generalized to other ADAS training concepts or educational formats. Future research should therefore employ more differentiated evaluation strategies, including module-specific assessments and qualitative feedback after each training component, to better identify which elements are most effective for fostering accurate mental models and safe ADAS use, while also enabling comparisons across different training designs. Despite these limitations, the consistently positive participant feedback and the observed increase in knowledge indicate that the overall multimodal training structure represents a promising framework for ADAS education.

A further limitation of the present study is that post-training effects were only assessed directly after training. As the primary aim was to evaluate the immediate effectiveness of the training under controlled conditions, no follow-up assessments were conducted. Consequently, no conclusions can be drawn about how long the acquired skills are retained for. Future research should incorporate longitudinal follow-up assessments to examine the stability of training effects.

That the evaluation relied primarily on questionnaire-based measures and did not include objective behavioral or driving performance data can also be seen as a limitation. As such, the results may be subject to common biases associated with self-report measures, including social desirability and response tendencies (e.g., Paulhus & Vazire, 2007). Although knowledge was assessed via questionnaire, it still represents a performance-related construct, as it captures participants' understanding of system functionality and correct usage rather than purely attitudinal perceptions. Nevertheless, it remains an indirect measure and cannot fully substitute for objective indicators of driver behavior or system interaction in real driving contexts. However, as noted above, behavioral observation alone does not allow definitive conclusions about whether sufficient understanding has been achieved. Future research should therefore include both knowledge-based assessments and behavioral and performance-based measures to provide a more comprehensive evaluation of training effectiveness.

5. Conclusions

The findings of this study highlight both the successes and challenges of ADAS driver training programs. While the overall improvement in knowledge demonstrates the effectiveness of the training, the decrease in accuracy for specific items underscores the need for more nuanced and carefully designed educational interventions. By addressing potential sources of confusion, clarifying system limitations, and incorporating feedback mechanisms, future training programs can better equip drivers to safely and effectively utilize ADAS technologies. This approach will not only enhance driver confidence but also contribute to safer roads by reducing misunderstandings or misinterpretations of these advanced systems.

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Kim: Conceptualization, Methodology, Writing – Review & Editing. **Barbara Metz:** Conceptualization, Methodology, Formal Analysis, Writing – Review & Editing, Project Administration.

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6. Appendix

Appendix A: Pre-Questionnaire

1. What gender do you identify with?

☐Male
☐Female
☐Non-binary
☐Prefer not to say

2. How old are you? _____years

3. How long have you had a car driving license? _____years

4. How long have you driven the vehicle you normally drive? _____years

5. Advanced Driver Assistant Systems (ADAS) experience

a) Please indicate whether the vehicle you normally drive has each of the following Advanced Driver Assistant System (ADAS), and whether you use them.

Vehicle Control Systems	**I have it and I use it**	**I have it but I don't use it**	**I don't know if I have it**	**I don't have it,**
- **Lane keeping assistance**				
- **Cruise Control (CC)**				
- **Adaptive Cruise Control (ACC)**				
Vehicle Warning Systems:				
- **Lane Departure Warning**				
- **Blind Spot Monitoring**				

b) If you have any of the above: How often do you use it?

☐Daily ☐Weekly ☐Monthly ☐less often ☐not applicable

c) Do you know how to turn these systems on and off?

Lane keeping assistance: ☐Yes ☐No ☐not applicable
Cruise Control (CC): ☐Yes ☐No ☐not applicable
Adaptive Cruise Control (ACC): ☐Yes ☐No ☐not applicable

6. Please indicate how much you agree or disagree with the following statements about Advanced Driver Assistance Systems (ADAS), e.g. ACC, lane keeping assistant, blind spot monitoring etc.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
If I had ADAS in my car, I **would use it** regularly.[a]					
The next car I **buy**, should have ADAS[a]					
I expect to **feel safe** most of the time while using ADAS[b]					
I expect to **feel comfortable** most of the time while using ADAS[b]					
I expect to **feel anxious** most of the time while using ADAS[b]					
The ADAS is **dependable**[c]					
The ADAS is **reliable**[c]					
Overall, I can **trust** the ADAS[c]					
Learning to use ADAS will be **easy** for me.[d]					
I will find it **easy** to **get ADAS to do** what I **want it to do**.[d]					
It will be **easy** for me to become **skillful** at using ADAS.[d]					
I will find ADAS **easy to use.**[d]					
Using ADAS will be **useful** in meeting my **driving needs.**[e]					
Using ADAS will **decrease** my **accident risk.**[e]					
Using ADAS will **relieve** my **stress** of driving.[e]					

[a] willingness to use, [b] perceived safety, [c] trust, [d] perceived ease of use, [e] perceived usefulness

7. For each item regarding <u>Adaptive Cruise Control (ACC)</u>, please indicate whether you think the answer is <u>correct or not correct</u> for this system, and <u>how confident</u> you are in your answer.

	Correct	Not correct	Very confident	Rather confident	Rather not confident	Not confident at all
The system **must be switched on** for use (by pressing a button).						
The system is automatically **activated every time the ignition is turned on.**						
I can turn off the system.						
The system is **always available**.						
The system keeps **speed and distance** to the lead vehicle.						
The system helps to keep the vehicle in its' **lane**.						
The system supports me when I need to **brake** in a critical situation.						
The system informs me about other vehicles in the **blind-spot**.						
The system warns me when I drive faster than the **speed limit**.						
The driver can increase/decrease the speed manually.						
The distance is selected by the system itself and cannot be adjusted.						
The system can also be activated during braking.						
If the vehicle stands still for a longer time during Stop & Go, the driver must start off independently.						
During Stop & Go, the vehicle will start up automatically in any case.						
I do not need to look at the road and the vehicle in front, when ACC is active.						
I must be ready to intervene at any time, as the ACC might lose awareness of the vehicle in front.						
I need to keep my hands on the steering wheel when the system is on.						

a) Please indicate how much you agree or disagree with the following statements about ACC.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
If I had ACC in my car, I would use it regularly.					
The next car I buy, should have ACC					

8. For each item regarding <u>Lane Keeping Assistance (LKA) and Emergency Lane Keeping (ELK)</u>, please indicate whether you think the answer <u>is correct or not correct</u> for this system, and <u>how confident</u> you are in your answer.

	Correct	Not correct	Very confident	Rather confident	Rather not confident	Not confident at all
I can **turn off** the system.						
The system is **always available**.						
The system keeps **speed and distance** to the lead vehicle.						
The system helps to keep the vehicle in its' **lane**.						
The system supports me when I need to **brake** in a critical situation.						
The system informs me about other vehicles in the **blind-spot**.						
The system warns me when I drive faster than the **speed limit**.						
The system warns me if I cross the lane without indicating.						
The system warns me if I unintentionally cross the lane.						
The lane departure warning system is available for all speeds.						
When the lane departure warning system is activated, I can take my hands off the steering wheel.						
The lane departure warning system can be activated/ deactivated in the system settings.						
Active steering assist features help to bring the car back into position with a gentle turn.						
As soon as I set the indicator, I can change lanes without the intervention of the LKA.						
The system also works in adverse weather conditions like fog, heavy rain, or snow.						
It depends on the car model whether the system warns me visually, acoustically or with tactile warnings.						
I can always rely on the system, including all road types.						
The system only works reliably when there are lane markings.						
I need to keep my hands on the steering wheel when the system is on.						

a) Please indicate how much you agree or disagree with the following statements about LKA.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
If I had LKA in my car, I would use it regularly.					
The next car I buy, should have LKA					

9. For each item regarding <u>Automated Emergency Braking (AEB)</u>, please indicate whether you think the answer is <u>correct or not correct</u> for this system, and <u>how confident</u> you are in your answer.

	Correct	Not correct	Very confident	Rather confident	Rather not confident	Not confident at all
The system **must be switched on** for use (by pressing a button).						
The system is automatically **activated every time the ignition is turned on.**						
I can turn off the system.						
The system is **always available**.						
The system keeps **speed and distance** to the lead vehicle.						
The system helps to keep the vehicle in its **lane**.						
The system supports me when I need to **brake** in a critical situation.						
The system informs me about other vehicles in the **blind-spot**.						
The system warns me when I drive faster than the **speed limit**.						
The AEB always brakes to a standstill.						
If the AEB is activated, I no longer need to brake actively.						
The AEB warns me with audible and visual signals.						
AEB rear adds an extra layer of safety in situations where the driver may not have noticed an object behind the vehicle.						
I need to keep my hands on the steering wheel when the system is on.						

a) Please indicate how much you agree or disagree with the following statements about AEB.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
If I had AEB in my car, I would use it regularly.					
The next car I buy, should have AEB					

10. For each item regarding <u>Blind Spot Monitoring (BSM)</u>, please indicate whether you think the answer <u>is correct or not correct</u> for this system, and <u>how confident you are</u> in your answer.

	Correct	Not correct	Very confident	Rather confident	Rather not confident	Not confident at all
The system **must be switched on** for use (by pressing a button).						
The system is automatically **activated every time the ignition is turned on.**						
The system is **always available**.						
The system keeps **speed and distance** to the lead vehicle.						
The system helps to keep the vehicle in its **lane**.						
The system supports me when I need to **brake** in a critical situation.						
The system informs me about other vehicles in the **blind-spot**.						
The system warns me when I drive faster than the **speed limit**.						
The BSM warns me by illuminating an LED signal in the side mirror.						
The BSM warns me with an audible signal.						
BSM helps me not to overlook vehicles in my blind spot.						
The BSM replaces the look over the shoulder.						
When I do not receive a warning in the side mirror, I can be certain there is no vehicle in the blind spot.						
The warning must be confirmed by me before I change lanes.						
I need to keep my hands on the steering wheel when the system is on.						

a) Please indicate how much you agree or disagree with the following statements about BSM.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
If I had BSM in my car, I would use it regularly.					
The next car I buy, should have BSM					

Appendix B: Post-Questionnaire

1. **Please indicate how much you agree or disagree with the following statements about the training.**

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
The training was fun.					
The training was interesting.					
I learnt new things during the training.					
The training has helped to improve my confidence in how the system works e.g. activation and deactivation.					
I am aware of all of the system capabilities and limitations.					
I would recommend the training to others.					

2. **How do you feel about the amount of information provided during the training?**
   ☐far too little ☐too little ☐appropriate ☐too much ☐far too much

3. **How do you feel about the quality of information delivered during the training?**☐very poor ☐poor ☐neutral ☐good ☐very good

4. **If you have any of the following systems in your car: Do you know how to turn these systems on and off?**
   Lane keeping assistance: ☐Yes ☐No ☐not applicable
   Cruise Control (CC): ☐Yes ☐No ☐not applicable
   Adaptive Cruise Control (ACC): ☐Yes ☐No ☐not applicable

After this section the questions 6 to 10 from the pre-drive questionnaire followed.

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