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ACCIDENT ANALYSIS AND PREVENTION

Knowledge of and Trust in Advanced Driver Assistance Systems

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Abstract

Understanding what drivers know about state-of-the-art advanced driver assistance systems (ADAS), like adaptive cruise control (ACC) and lane keeping assistance (LKA) is important because such knowledge can influence trust in and reliance on the automation. We surveyed ADAS owners (*N*=102) and non-owners (*N*=262), with the primary objective of assessing knowledge and trust of ACC and LKA, and investigating the relationship between knowledge and trust among drivers who have not received special training. The survey contained demographic questions, ACC and LKA knowledge questionnaires (assessing knowledge of capabilities and limitations commonly found in owner's manuals), and ACC and LKA trust ratings. From the knowledge questionnaires, sensitivity (i.e., knowledge of the true capabilities of ACC and LKA) and response bias were assessed and used to predict trust. Results showed that owners did not have better knowledge of system capabilities/limitations than non-owners, in fact, owners had a stronger bias in favour of system capabilities. For non-owners, better knowledge of system capabilities was associated with lower trust, and those who were more biased towards endorsing system capabilities had higher trust. Neither knowledge nor response bias was associated with trust among owners. Further research is needed to confirm our results with a larger sample of owners, but given that it is also impractical to expect drivers to learn and remember all possible ADAS limitations, it may be beneficial to focus training efforts on improving drivers' overall understanding of the fallibility of ADAS and reinforcing their role when using ADAS to support appropriate trust and reliance.

Keywords: driving automation, SAE Level 2 automation, mental models, signal detection theory

1. Introduction

Advanced Driver Assistance Systems (ADAS) currently available to the public can control the lateral and longitudinal movement of the vehicle, via, for example, a lane keeping assistance (LKA) system and an adaptive cruise control (ACC) system, respectively. While drivers perceive these systems as beneficial for their safety (e.g., Eby et al., 2018; Hagl & Kouabenan, 2020), safety benefits depend on drivers using ADAS appropriately. ACC and LKA are only driver support systems, meaning that drivers are still responsible for the driving task; they should be monitoring the roadway at all times to determine when they need to take over full control of the vehicle (SAE International, 2018). However, 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, overreliance on ADAS, particularly ACC and LKA, has already contributed to several real-world collisions (National Transportation Safety Board, 2020). One approach to reduce overreliance on ADAS and related collisions is to improve drivers' understanding of system capabilities and how ADAS should be used.

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). Singer and Jenness (2020) found that after training on the capabilities and limitations of a test vehicle with ACC and LKA, most drivers were aware of some of the ADAS limitations (e.g., it does not work in heavy rain or snow, or when lane markings are “badly faded”). However, a majority of their participants thought that the ADAS in the test vehicle would probably or definitely “take action and avoid a collision” if the car ahead suddenly braked hard or if they were approaching a slow-moving motorcycle, which are limitations of ACC. Thus, while training may result in increased awareness of some of ADAS limitations, there were still dangerous misperceptions. In addition, these results may not reflect the knowledge of typical drivers who have not been trained by experimenters on ADAS capabilities and limitations. Research, using methods such as surveys, is needed to investigate the understanding of current ADAS systems among drivers who have not received any special training.

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 important because such knowledge can influence their trust in and reliance on the automation (Hoff & Bashir, 2015; Lee & See, 2004). 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, 28% of drivers did not take over in time to avoid a collision due to an ACC limitation (an inflatable stationary vehicle ahead), despite being trained on the automation’s limitations and seeing the hazard prior to impact. 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, Baseler, and Bengler (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 training to support appropriate reliance on ADAS. For example, if knowledge of ADAS limitations is found to have an indirect impact on reliance, training that aims to support appropriate reliance by improving driver knowledge of limitations would also benefit from assessing trust and considering its other influencing factors.

Drivers may also have biases in their mental model of the system, which may impact their trust and reliance intention. For example, when considering ADAS capabilities, some drivers may have a positive response bias, meaning that they are inclined to view the systems as capable. Signal detection theory is a useful framework to separate sensitivity (i.e., knowledge of the true capabilities of ADAS) from response bias and can be applied to confidence rating data (e.g., Macmillan & Creelman, 2005), which was collected in the current study (see Section 2.2.1).

The primary objective of the current study was to investigate drivers' knowledge of ACC and LKA, their self-reported trust in these systems, and the relationship between knowledge and trust. 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 the simulator studies that have provided participants with training. A secondary objective of this study was to investigate how knowledge of and trust in ADAS impact drivers' reliance intention. Since we could not observe reliance behavior, 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). We surveyed owners (drivers who own or lease a vehicle with ACC or LKA) and non-owners (drivers who do not own a vehicle with ACC or LKA and have 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.

2. 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). 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.

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 trust. In a previous paper, we reported a preliminary analysis of a subset of the ACC data from the current study (DeGuzman & Donmez, 2021). The results showed that the only learning method that was associated with a better understanding of ACC was trial-and-error. However, we did not investigate whether the different learning methods influenced trust in ACC. Although other learning methods (e.g., reading an owner’s manual) did not appear to influence drivers’ level of knowledge, information from certain sources may have a greater influence on trust (e.g., from a friend or dealership staff instead of a manual or website). This potential effect is explored in the current paper.

In terms of experience and demographics, experience with driving automation has been found to increase trust (e.g., Beggiato, Pereira, Petzoldt, & Krems, 2015). Findings regarding age-related differences on trust in driving automation are mixed. There is some evidence that older drivers trust driving automation more (e.g., Gold, Körber, Hohenberger, Lechner, & Bengler, 2015), and other research suggesting older drivers trust it less (Dikmen & Burns, 2017). Higher education and being an early adopter of technology were associated with greater acceptance of ACC (Lee, Seppelt, Reimer, Mehler, & Coughlin, 2019), but research is needed to explore whether these demographic variables also influence trust in ADAS.

2.1. 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 2.2.1).

Participants who were recruited through Mechanical Turk were compensated $4 for the main survey and $2 for the follow-up survey (all currency 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 1 and descriptive statistics for the owner and non-owner samples can be found in Table 1.

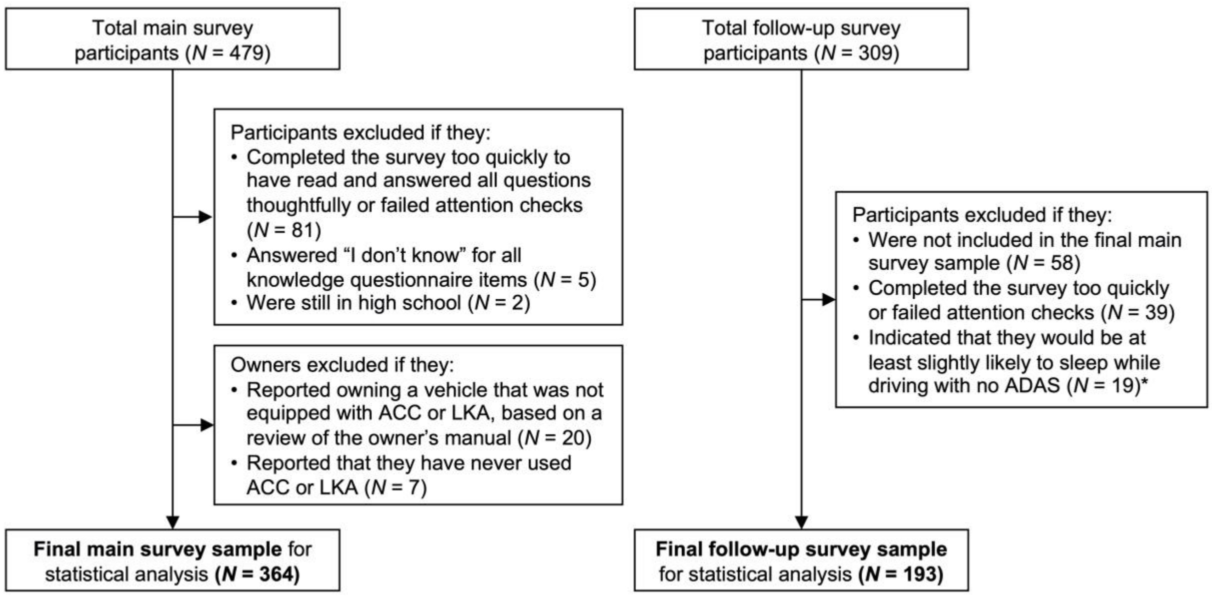

Fig. 1. Screening process to obtain final samples for the main survey and follow-up survey.
*We were unable to identify whether these responses were due to misunderstanding the item or not paying attention to the items, thus these participants were removed to be conservative.

Table 1. Descriptive statistics by ownership

	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

2.2. Survey design and procedure

2.2.1 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.

2.2.2 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 7). Likelihood was rated on a 5-point scale from “not at all likely” to “extremely likely”.

2.3. Analysis

2.3.1 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 an initial investigation of participants' performance on the knowledge questionnaires, we calculated a confidence weighted knowledge score for ACC and LKA. 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.

After this initial investigation, we 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). The models were built with the 'lm' function in R. 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 2. All predictors were entered into the model simultaneously and the full models are reported. 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.

Table 2. Explanatory variables for main survey and follow-up survey analyses

Predictor	Description
Main Survey: Regression Model Predicting Trust	
Predictor	**Description**
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).
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.
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).
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).
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.
Age	Self-reported age at the time that the survey was completed
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.
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)
Follow-up Survey: Mixed Linear Model Predicting Reliance Intention	
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 A (main survey) and Appendix B (follow-up survey)
* To calculate sensitivity and bias, items were recoded so that they reflected a system capability.

As presented in Table 2, 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.

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 were a relatively small proportion of owners (25%) who used fewer than 2 learning methods (see Table 1), 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.

2.3.2 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' packaged 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 2. 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.

3. Results and discussion

3.1. ADAS knowledge

3.1.1 Driver misperceptions

Owners and non-owners 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, $t(87.7) = -0.21$, $p = .8$.

When looking at individual questionnaire items, Figure 2 highlights that non-owners and owners have similar misperceptions about ACC; this information was previously reported in Figure 1 in DeGuzman & Donmez (2021), and a more detailed discussion of these findings can be found there. What we want to highlight in the current paper is that while most participants know 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 3 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.

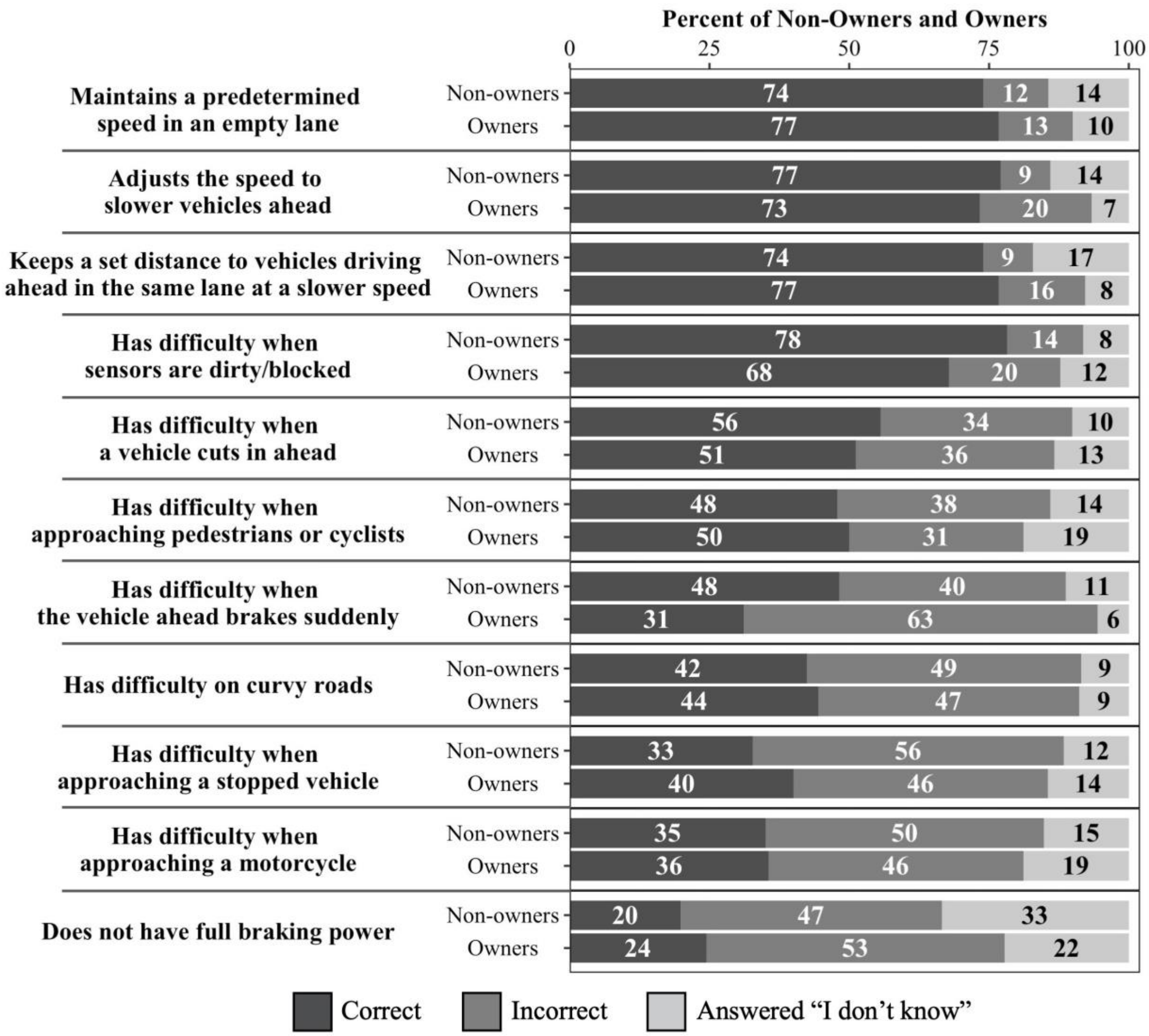

Fig. 2. Percent of non-owners and owners who answered correctly, incorrectly, and "I don't know" for a subset of ACC knowledge items. Note: this information was previously reported in Figure 1 in DeGuzman and Donmez (2021).

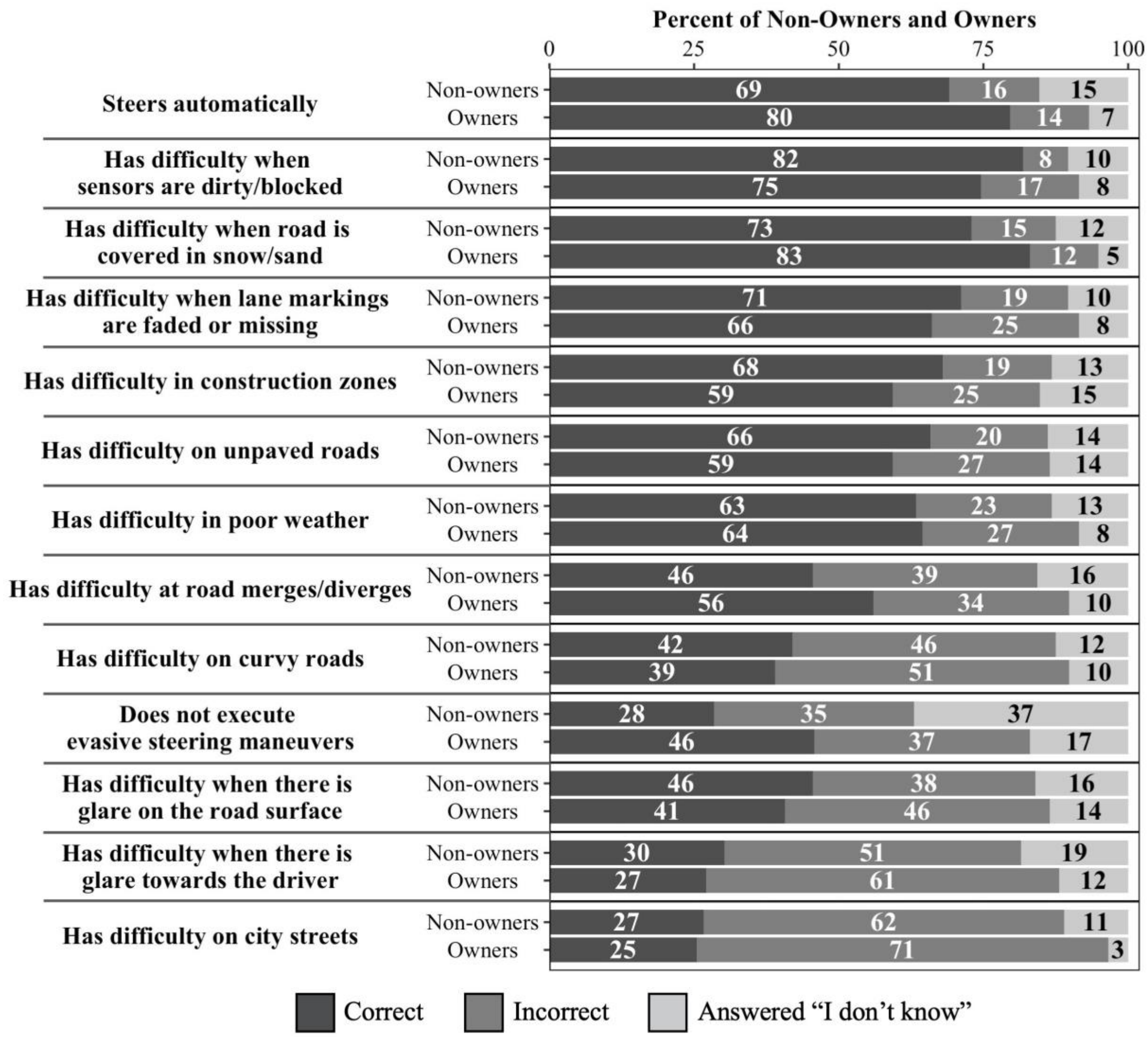

Fig. 3. Percent of non-owners and owners who answered correctly, incorrectly, and "I don't know" for a subset of LKA knowledge items.

Overall, these 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.

3.1.2 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 4). 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., National Transportation Safety Board, 2020).

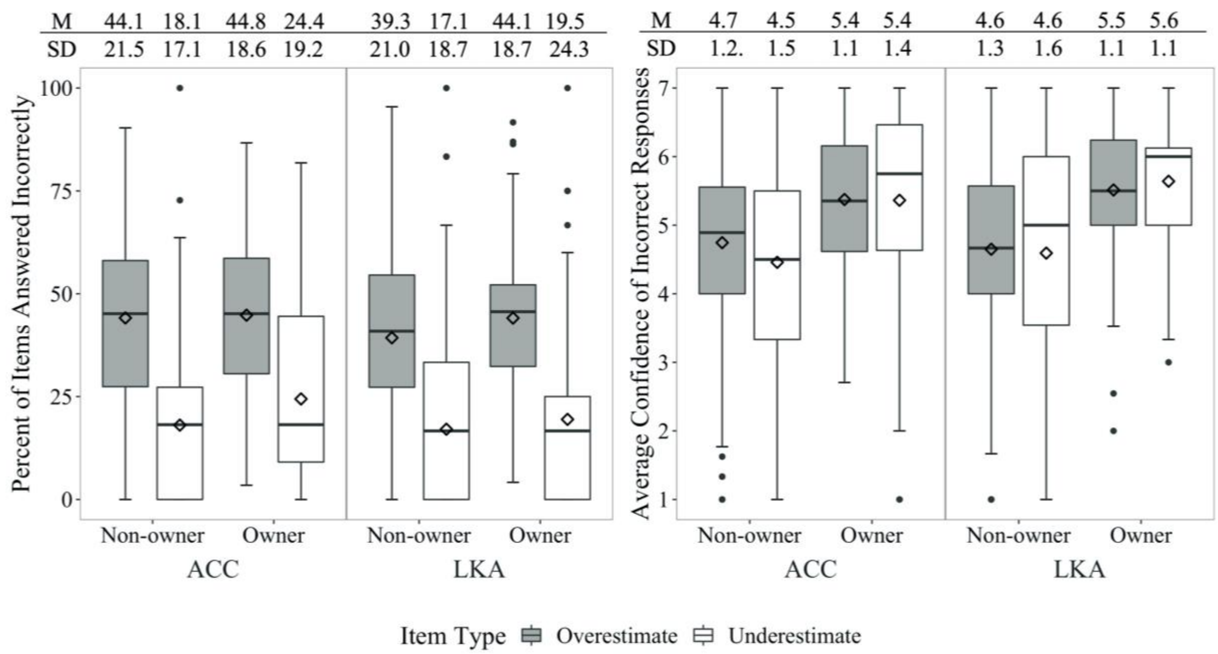

Fig. 4. Proportion of incorrect overestimate and underestimate items (left) and average confidence for the incorrect overestimate and underestimate items (right). Boxplots represent the five-number summary, the diamond indicates the mean. At the top, mean (M) and standard deviation (SD) values are provided.

3.1.3 Signal detection theory measures

Figure 5 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 2 and 3). However, consistent with the findings for confidence weighted scores, owners and non-owners did not differ in their sensitivity (Table 3). 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 3). 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 3). 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 3. Comparison of sensitivity and bias between owners and non-owners. 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)**

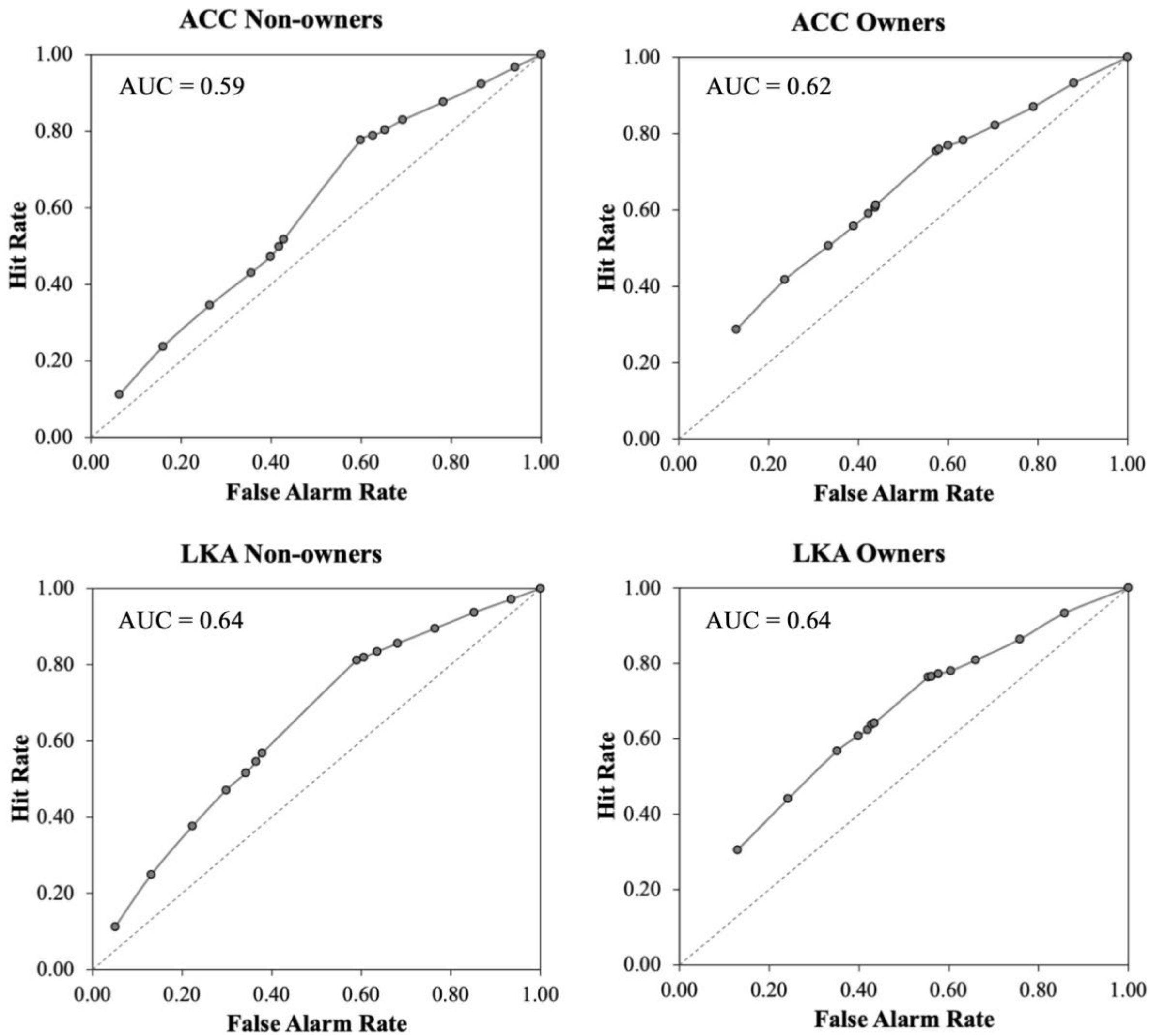

Fig. 5. Receiver operating characteristic curves and AUCs, averaged across participants within each group (i.e., ACC non-owners, ACC owners, LKA non-owners, LKA owners). Dots represent hit-false alarm pairs at each possible response level. The leftmost point is the hit-false alarm pair for a response 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).

3.2. 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 6) 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.

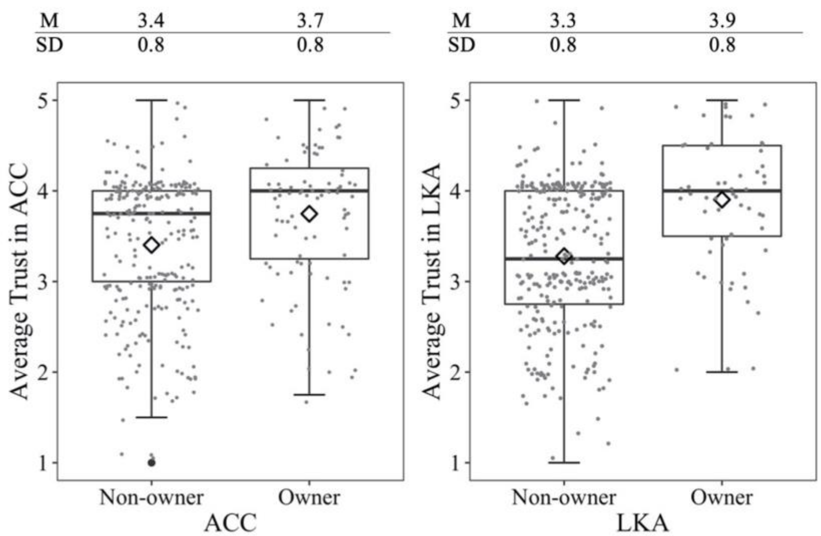

Fig. 6. Average trust in ACC and LKA for owners and non-owners. Trust items were rated on a scale from 1 (strongly disagree) to 5 (strongly agree), thus higher average values indicate higher trust. Boxplots represent the five number summary, the diamond indicates the mean. At the top, mean (M) and standard deviation (SD) values are provided.

3.2.1 What factors predict trust in ACC and LKA?

For non-owners, sensitivity predicted trust in ACC and LKA (see Table 4). 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 4). 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. The correlation between AUC and trust for non-owners was -.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. 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 4). 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 3.1.1, Figures 2 and 3) 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 4. Results for regression models predicting trust; significant (p < .05) and marginally significant 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
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

In a previous paper using the same dataset (DeGuzman & Donmez, 2021), we found that only demographic factors predicted the percent of correct responses on the ACC knowledge questionnaire for owners and non-owners. In the current study, 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.

3.3. Reliance intention

Based on inspection of the raw data (see Figure 7), 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.

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 5). 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 5), potentially due to sample size limitations.

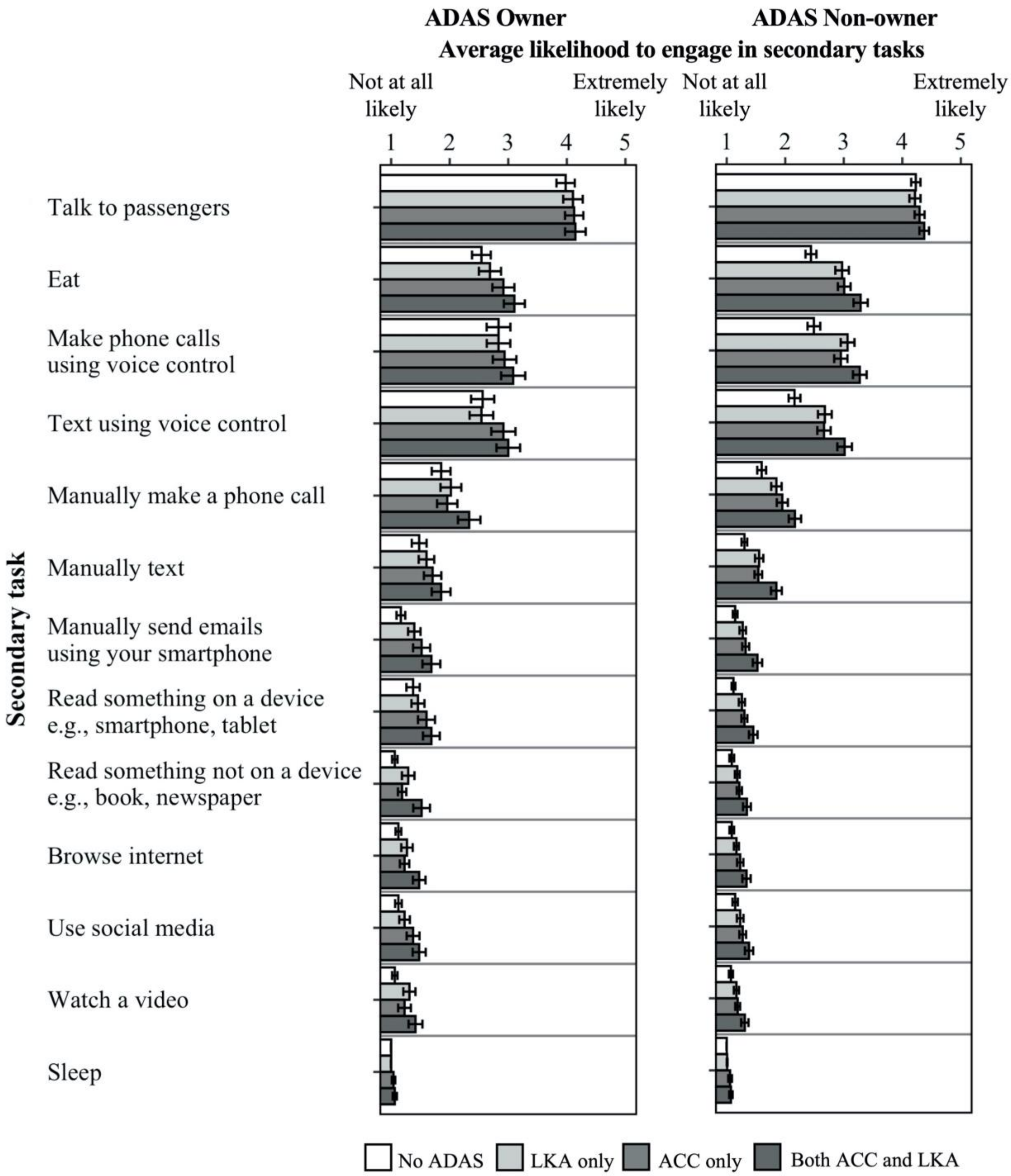

Fig. 7. Average likelihood to engage in secondary tasks by ADAS condition: 1 = not at all likely, 2 = slightly likely, 3 = moderately likely, 4 = very likely, 5 = extremely likely. Error bars represent standard error.

Table 5. Results for linear mixed models predicting reliance intention; significant ($p < .05$) and marginally significant 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.

3.4. Limitations

As described in Section 2.1, 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, 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.

4. 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. Owning a vehicle with ACC or LKA does not appear to result in a better understanding of system limitations.
2. For both owners and non-owners, participants tended to overestimate ADAS more than underestimate it.
3. 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.

4. 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.
5. 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.
6. 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.

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 to focus 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 such strategies to support appropriate trust in and reliance on ADAS.

These findings complement existing research on drivers' attitudes towards currently available ADAS and automated driving technologies that are not yet available in consumer vehicles in North America (e.g., Level 3 driving automation which controls lateral and longitudinal movement of the vehicle and does not require the driver to monitor the roadway while the automation is engaged; SAE International, 2018). Prior work has investigated drivers' acceptance and intent to use ADAS (e.g., Rahman et al., 2018) and Level 3 automated driving systems (e.g., Buckley, Kaye, & Pradhan, 2018; Schoettle & Sivak, 2014; Zhang et al., 2020), but it is also important to understand what drivers' know about the technology to improve the safety of drivers' interactions with automated vehicles. Our findings suggest that even though ACC and LKA have some market penetration, owners who use these systems lack a clear understanding of their capabilities. Further, there have been several collisions involving the use of ADAS that were at least partially a result of drivers' overreliance on the automation (e.g., National Transportation Safety Board, 2020). As higher levels of driving automation (e.g., Level 3) are implemented, similar problems will likely occur. Understanding how knowledge is related to trust and reliance with the ADAS systems currently emerging in the market can not only improve safety for ADAS users, but also serve as a foundation to improve the safety of drivers' interactions with more advanced automated driving systems.

CRediT Author Contribution Statement

Chelsea A. DeGuzman: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data curation, Writing - original draft, Visualization. **Birsen Donmez:** Conceptualization, Methodology, Validation, Writing - review & editing, Supervision, Funding acquisition.

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APPENDIX A: Main Survey

<u>Demographics</u>

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 highway or interstate, 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 highway or interstate. Please check all that apply to indicate why you do not use the technology when driving on the highway/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 Q20 = Yes OR Not sure] **Q23. When driving in stop-and-go traffic, 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 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 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 <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 or 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 Q26 = Yes] **Q31. When driving in <u>stop-and-go traffic</u>, 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 <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 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 stop-and-go traffic, 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 stop-and-go traffic, 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 stop-and-go traffic. Please check all that apply to indicate why you have not used the technology at the same time 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 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

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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 <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
	Non-owners	**Is the following statement about ACC 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
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 <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
	Non-owners	**Do you think <u>any ACC 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
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		

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

Part 1	**Owners**	**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
	Non-owners	**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
		Changes lanes automatically; Steers automatically; 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); 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; Deactivates if your turn signal is on; Deactivates if you are pressing the gas pedal; Can be deactivated by pressing the brake pedal; Can only be activated when Adaptive Cruise Control is also active; Can be deactivated by turning the steering wheel; Deactivates if you look away from the road for an extended period of time; Deactivates if you have your hands off the wheel or do not steer for an extended period of time; Alerts you when you are looking away from the road for too long; Alerts you when you have your hands off the wheel or do not steer for too long
Part 2	**Owners**	**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
	Non-owners	**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
		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; Heavy traffic; 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.; GPS data is unavailable; 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

Note: Items in each part were randomized

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 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

Table C.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**	