System attributes that influence reported improvement in drivers' experiences with adaptive cruise control and active lane keeping after daily use in five production vehicles

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ABSTRACT

Driving automation technology only will deliver safety benefits if drivers use it, but little is known about experiences with these technologies on actual roads. Fifty-one Insurance Institute for Highway Safety employees used an Audi A4 or Q7, Honda Civic, Infiniti QX60, or Toyota Prius as a personal vehicle for up to several weeks and completed surveys about their experiences. Each vehicle was equipped with adaptive cruise control (ACC), and the Audis and Honda had active lane keeping (ALK). Mixed-effects regression analysis found drivers agreed ACC improved the driving experience more than ALK on average, but this was not true for all vehicles. On average, drivers agreed that the Honda's ALK improved the driving experience more than its ACC, but the opposite was observed for the Q7. Drivers were most comfortable using automation on interstates with free-flowing traffic, and least comfortable using ACC on low-speed local roads and in stop-and-go traffic and ALK on curvy roads; manufacturer guidance in the owner's manual about use in these situations was inconsistent. Increased agreement that the technology made smooth and gradual changes to vehicle control significantly predicted increased agreement that ACC and ALK improved the driving experience. Based on these results, designers should strive to implement driving automation technology that drivers feel makes smooth and gentle changes to steering or speed because these attributes improve drivers' perceptions of the technology. Models of automation acceptance suggest that more positive perceptions of driving automation technology would encourage broader use and increase the technology's opportunity to provide safety benefits.

Keywords: adaptive cruise control; ACC; active lane keeping; ALK; automation acceptance model; driving automation technology; lane centering; lane support system; technology acceptance model

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INTRODUCTION

Driver assistance and collision warning technologies have the potential to prevent a significant proportion of crashes (Jermakian, 2011). Some of these systems, such as forward collision warning and automatic emergency braking, are reducing insurance claim frequency and police-reported crash rates (Cicchino, 2017a; Highway Loss Data Institute [HLDI], 2015, 2016a), but others, such as lane departure warning, are producing smaller benefits than expected (Cicchino, 2017b; HLDI, 2016b, 2016c). Some technologies may not be living up to their potential, in part because drivers are not using them (e.g., Reagan, Cicchino, Kerfoot, & Weast, 2018; Reagan & McCartt, 2016). Driver trust and annoyance vary among driver assistance technologies (Eichelberger & McCartt, 2014; Kidd, Cicchino, Reagan, & Kerfoot, 2017), and differences in the way drivers interact with and experience these technologies may influence their use.

Attitudes and perceptions of a technology's usefulness and ease of use are thought to influence intentions to use the technology and, ultimately, actual use. The Technology Acceptance Model (TAM) (Davis, 1989) has been widely used to characterize the relationship between perceptions of a technology and its use. Ghazizadeh, Lee, and Boyle (2012) adapted the TAM to describe the adoption of automation as a partner in completing a task, by including constructs from the cognitive engineering literature like trust, compatibility, external factors like prior use, and feedback loops that account for the influence of actual use on perceptions. Based on this model, drivers who trust driver assistance technologies less (e.g., Kidd et al., 2017) would use them less.

Driving automation technology builds on current driver assistance systems. Unlike crash avoidance technologies that intervene in safety-critical situations, driving automation adapts to developing situations and may prevent critical situations from happening altogether. Adaptive cruise control (ACC) and active lane keeping (ALK) are two forms of driving automation technology available in production vehicles.

ACC provides longitudinal vehicle control to maintain speed and headway. ACC may convey benefits similar to or in parallel with front crash prevention (Kessler et al., 2012). Field operational tests and simulator studies show increased following distance, gentler braking, or reduced speeds when ACC is engaged relative to when it is not (e.g., Kessler et al., 2012; Schleicher & Gelau, 2011).

ALK provides sustained steering input to keep the vehicle within its travel lane. Drivers may potentially find the increased functionality of this system more useful than lane departure warning, especially if it minimizes alerts that drivers find annoying (e.g., Eichelberger & McCartt, 2014). Reagan et al. (2018) examined the on or off status of lane departure warning, lane departure prevention, or ALK systems in 1,152 vehicles brought in for service at dealerships. A larger proportion of vehicles equipped with ALK (65%) had the system turned on than those equipped with lane departure warning (45%) or lane departure prevention (55%). Vehicles equipped with lane departure prevention were significantly more likely to have the system turned on than vehicles equipped with lane departure warning. However, the likelihood that these systems were on was not significantly different than the likelihood that ALK was on, because only 78 vehicles had ALK equipped, which limited statistical power.

The potential safety benefits of driving automation technology depend on how frequently and where it is used. Drivers may not use technologies like ACC and ALK often or may limit use to situations where there is little opportunity for the technologies to benefit safety. For example, drivers do not use ACC all the time and use tends to be highest during free-flowing traffic conditions on higher speed roadways, where forward conflicts are less frequent (General Motors Corporation, 2005; Kessler et al., 2012). Drivers may use driving automation technology even less if they think it lacks value, is unpredictable, or performs poorly (Beggiato & Krems, 2013; Jamson, Merat, Carsten, & Lai, 2013). Similarly, drivers who believe that driving automation technologies like ACC and ALK control the vehicle in a similar manner as they do, or have high compatibility, should view automation more positively and be more likely to use it in the future (Ghazizadeh et al., 2012; Rogers, 1995). The attributes of ACC and ALK systems that contribute to compatibility and positive perceptions of the technology are not well understood, but would be important for increasing use and acceptance.

The purpose of this study was to learn more about driver perceptions of the value and performance of ACC and ALK systems in production vehicles following on-road use, and to identify the system attributes that contribute to these perceptions. Drivers were asked if ACC and ALK systems, if equipped, improved their driving experience, about situations in which they felt comfortable using these technologies, and about performance characteristics of the automation. Systems that drivers perceived to perform better were expected to be associated with more positive attitudes regarding their contribution to the driving experience.

METHOD

Participants

Participants were Insurance Institute for Highway Safety (IIHS) employees in Arlington or Ruckersville, Virginia. Arlington is a densely populated area outside Washington, DC, and Ruckersville is a rural area about 20 miles north of Charlottesville, VA. Of the 108 employees who received an electronic invitation, 51 (28 men, 23 women) agreed to voluntarily participate (Table 1). Participants were 40 years old (*SD*=9.8) on average and ranged from 22–70 years old. No incentives were provided for participation.

Table 1. Sample demographics overall and by location.

Location	Age				Gender	
	Mean	SD	Min	Max	Men (n)	Women (n)
Arlington	42.2	8.4	28	70	11	13
Ruckersville	38.5	10.8	22	64	17	10
Overall	40.3	9.8	22	70	28	23

Vehicles

Participants drove up to five different vehicles. They were a 2017 Audi A4, 2017 Audi Q7, 2016 Honda Civic, 2016 Infiniti QX60, and 2016 Toyota Prius. All vehicles except the A4 were used in a previous study involving IIHS employees (Kidd et al., 2017). Every vehicle was equipped with multiple driver assistance systems, but only the driving automation technologies are discussed here. Each vehicle was equipped with an ACC system capable of bringing the vehicle to a complete stop and following vehicles ahead at low speeds. Each ACC system had controls to set and adjust the vehicle’s speed and headway to a vehicle ahead; however, the layout and location of these controls varied. A unique feature of the Audi ACC systems was a speed limit recognition function that adjusted the set speed based on the posted speed limit. The feature slowed the vehicle when ACC was engaged and set faster than the posted speed limit. Three (Audi A4, Audi Q7, and Honda) of the five vehicles were equipped with ALK. The Audi ALK systems operated at speeds over 40 mph, and the Honda system became available at 45 mph. Both Audis were equipped with a congestion assist feature that provided lane keeping and car following at slower speeds when dense traffic was detected. In addition to ALK, both Audis and the Honda had a lane departure prevention system that provided a haptic warning (vibrating steering wheel) and corrective steering when the vehicle departed the lane without the turn signal being used.

Procedure

Researchers contacted participants to schedule days to use a vehicle. Participants signed vehicle use agreements where they agreed to use the vehicle instead of their personal vehicle, follow traffic laws, avoid cellphone use, and drive with the technologies engaged as often as possible.

Participants completed a familiarization process before receiving the vehicle. First, a researcher showed participants where various controls (ignition, seat and mirror adjustment controls, windshield wipers) were and how to use them. Then the researcher summarized each crash avoidance and driver assistance technology equipped to the vehicle. The summary included descriptions of each system's purpose, operational boundaries, settings, and instruction about use (e.g., activate, deactivate, change settings). All drivers received vehicles with systems activated, except for those that required activation when the vehicle was moving. During this overview, the researcher also ensured that system settings were set to a middle sensitivity setting or the earliest, most sensitive setting if only two were available.

Next, participants used ACC and ALK during a 30-minute researcher-supervised drive on the highway. The researcher instructed the participant to engage ACC, modify the set speed, and adjust the headway setting. Each driver was encouraged to allow the ACC system to accelerate and decelerate the vehicle in response to prevailing traffic conditions. Participants were instructed to depart the travel lane in a controlled manner when neighboring traffic was absent and a wide, paved shoulder was present. This maneuver was intended to demonstrate the differences between ALK and the warnings and corrective steering from the lane departure prevention system. Status and indicator displays were highlighted during use.

Drivers completed an online daily-use survey every day they used a vehicle. This survey took about 5–10 minutes to complete and asked participants about their driving exposure (e.g., miles driven; percentage of driving time on higher speed roads, in free-flowing traffic, and during precipitation). After returning a vehicle, participants completed a post-use survey. This survey collected information about participants' experiences and opinions about the various vehicle technologies, by asking participants to indicate their level of agreement or disagreement with various statements. Participants indicated their level of agreement using a 5-point Likert scale that ranged from 1 (strongly disagree) to 5 (strongly agree).

The following three statements about ACC and ALK were intended to capture drivers' general sentiments of each system:

- Overall, I felt this [adaptive cruise control/active lane keeping] system improved my driving experience.
- I want this [adaptive cruise control/active lane keeping] system on my next car.
- This [adaptive cruise control/active lane keeping] system worked as I expected.

Participants also responded to additional statements about their comfort with using ACC or ALK in different roadway scenarios. These statements were based on feedback received in a previous study (Kidd et al., 2017) about situations where ACC and ALK systems were used, had difficulty, or behaved unexpectedly. Drivers rated their level of agreement with whether they felt comfortable using ACC in free-flowing traffic on interstates, free-flowing traffic on major arterial roads with signalized intersections, roads with moderate hills, heavy stop-and-go traffic, and low-speed local roads. Drivers rated their level of agreement with whether they would feel comfortable using ALK on winding, curvy roads; roads with moderate hills; on interstates with gentle to moderate curves; and in free-flowing traffic on interstates.

Finally, participants used a 5-point Likert scale to indicate their agreement with statements about various attributes of ACC and ALK. Attributes of ACC included if the system accelerated and decelerated smoothly, maintained constant following distance, made the system status clear to the driver, detected moving or stopped vehicles ahead, and continued to adjust vehicle speed even after the vehicle ahead had exited the lane. ALK attributes included if the system made it clear when lane lines were detected, consistently detected lane markings, made steering corrections that were smooth or too frequent, and kept the vehicle centered in the lane. The post-use survey took about 30 minutes to complete. Data for this study were collected from August 2016 to January 2017.

Analysis plan

Analyses only considered a driver's first experience with a vehicle during the study period. Responses to the three statements about drivers' general sentiments toward ACC and ALK were analyzed using mixed-effects linear regression. Each participant's reported level of agreement with each statement was modeled separately with the fixed-effects of vehicle (Audi A4, Audi Q7, Honda, Infiniti, Toyota), technology (ACC, ALK), and the interaction between vehicle and technology. Separate mixed-effects regression models were constructed to examine differences in the reported level of agreement with comfort using ACC and ALK in different driving situations. These models included the fixed effects of situation, vehicle, and the interaction between situation and vehicle.

Driver was included as a random effect in every mixed-effects regression model to account for within-subject variance from repeated observations. Type 3 tests were performed to determine whether a set of variables that made up a fixed effect was statistically significant at the 0.05 level. Least Square Means (LSM) estimates and 95% confidence intervals were computed to examine pairwise differences between each level within each fixed effect. Pairwise comparisons were adjusted using the Tukey-Kramer method to control for alpha inflation. Analyses were conducted using the PROC MIXED procedure in SAS 9.4.

Each driver's rating of the extent ACC or ALK improved the overall driving experience was modeled with their perceptions of various attributes of ACC and ALK using a general linear model. One model used responses to the six statements about attributes of ACC to predict the reported improvement in driving experience, and other models used the five statements about attributes of ALK to predict reported improvement in the driving experience. Driver was included as a random effect in each model to account for repeated observations from each driver. The models were created using the PROC GLM in SAS 9.4. The proportion of variance accounted for (R^2) by the set of predictors was calculated as well as the variance explained by each predictor (η_p^2) using the "effectsize" option.

RESULTS

Driving exposure

Fifty-one participants had 110 total experiences with the study vehicles, but some participants drove the same vehicle more than once. Repeated uses of a vehicle by a single participant within the study period were excluded, resulting in 104 unique experiences. In 32 of the 104 (31%) experiences, the participant indicated that they drove the vehicle in a previous study (Kidd et al., 2017). Data from these experiences were included, since the prior survey instrument was different from the one used in Kidd et al.

Twenty participants used only one study vehicle; 14 used two; 13 used three; 3 used four; and one driver used all five vehicles. Vehicle use ranged from 1–22 days and was 6 days (*SD*=3.4) on average. Drivers submitted 637 daily-use reports and reported driving 49,559 total miles. The number of drivers, daily reports, and total mileage reported for each vehicle is shown in Table 2.

Table 2. Number of drivers, daily reports, and self-reported miles by study vehicle.

Vehicle	Drivers (n)	Daily reports (n)	Reported miles driven
2017 Audi A4	22	156	12,522
2017 Audi Q7	24	173	14,611
2016 Honda Civic	16	83	4,886
2016 Infiniti QX60	24	139	12,857
2016 Toyota Prius	18	86	4,682

General sentiments about ACC and ALK

The extent that drivers, on average, strongly disagreed (1) or strongly agreed (5) with statements about general sentiments toward ACC and ALK are shown in Table 3. Across the five vehicles, drivers agreed that ACC improved their driving experience, that they wanted it on their next vehicle, and that it worked as expected. When asked about ALK, drivers' average level of agreement with these statements was lower and neutral, ranging from 3.39 to 3.58.

Table 3. Mean (SD) level of agreement (1=strongly disagree, 5=strongly agree) with general sentiments about ACC and ALK overall and by vehicle.

Vehicle	Improved my driving experience	Want on my next vehicle	Worked as I expected
Adaptive Cruise Control			
Audi A4	3.95 (0.84)	4.05 (1.13)	3.64 (0.95)
Audi Q7	4.08 (0.78)	4.29 (0.81)	4.42 (0.65)
Honda Civic	3.56 (1.09)	3.63 (1.09)	3.88 (1.26)
Infiniti QX60	3.88 (0.74)	4.08 (0.78)	4.04 (0.95)
Toyota Prius	4.11 (0.83)	4.11 (0.83)	4.17 (0.71)
Overall	3.93 (0.85)	4.06 (0.92)	4.04 (0.95)
Active Lane Keeping			
Audi A4	3.55 (0.96)	3.36 (1.26)	3.50 (1.01)
Audi Q7	3.21 (1.18)	3.13 (1.36)	3.46 (1.32)
Honda Civic	4.00 (1.15)	3.81 (1.28)	3.88 (1.20)
Overall	3.53 (1.13)	3.39 (1.31)	3.58 (1.18)

Driver responses to these three statements about ACC and ALK were similar, suggesting they provided similar information. Single-predictor mixed-effect regressions (one fixed effect and driver as a random effect) were constructed to assess separately the strength of association between these statements for ACC and ALK, while accounting for multiple observations from drivers. The proportion of variance that each statement accounted for in another statement (i.e., R^2) was estimated by computing the percentage reduction in the total residual variance observed in each model from a null model with the intercept and random effect of driver. The square root of the R^2 values was used to estimate the correlation between pairs of statements. The correlations between pairs of statements were all above 0.50, indicating a large effect size (Cohen, 1988), and were similar in strength and direction to Pearson product-moment correlation coefficients (ACC: Pearson's *r,* 0.54–0.78; ALK: Pearson's *r,* 0.74–0.85), which ignored the repeated nature of the data.

Given the collinearity between responses to these three statements, only the statement "Overall, I felt [adaptive cruise control/active lane keeping] improved my driving experience" was analyzed further. Seventy percent of participants agreed or strongly agreed (i.e., rated agreement a 4 or 5) that ACC improved their driving experience, and only 52 percent said the same about ALK. A mixed-effects regression did not indicate a significant main effect of vehicle ($F(4, 158)=0.44$, $p=0.78$) or main effect of technology ($F(1, 158)=3.2$, $p=0.08$), but there was a significant interaction between vehicle and technology ($F(2, 158)=5.49$, $p<0.01$). The Least Square Means estimate for the level of agreement with this statement for each vehicle with ACC and ALK is shown in Figure 1. Overall, drivers expressed greater levels of agreement that ACC improved their driving relative to ALK ($p=0.08$), and among vehicles with ACC and ALK, respondents agreed that the Audi Q7's ACC system improved their driving experience significantly more than its ALK system ($p=0.01$).

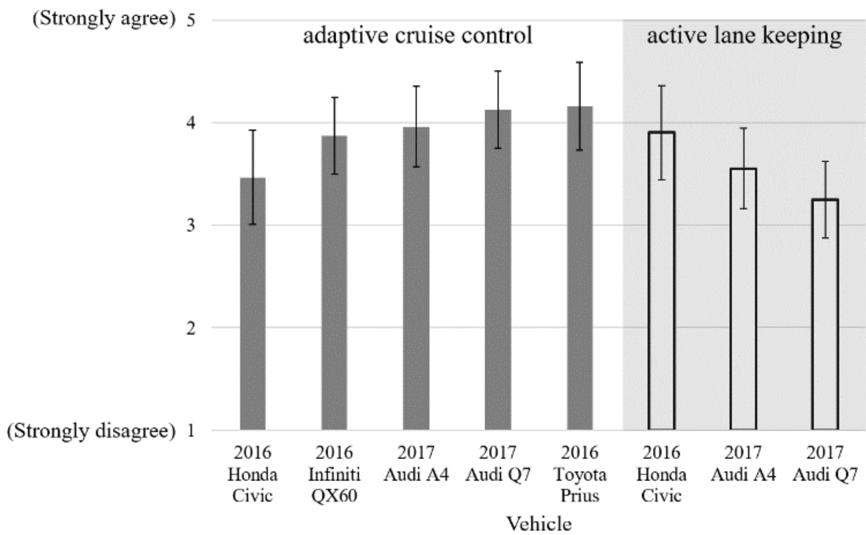

Figure 1. Least Square Means estimate for driver agreement that ACC or ALK improved their driving experience. Error bars indicate 95% confidence intervals.

Driver comfort with using ACC and ALK

Driver agreement with statements about comfort with using ACC in different driving situations was examined next. Eighty-nine percent of drivers agreed or strongly agreed that they would be comfortable using ACC in free-flowing traffic on interstates, but only 37 percent said the same about using ACC on low-speed, local roads. A mixed-effects regression analysis revealed a significant main effect of situation ($F(4, 495)=46.51$, $p<0.001$). On average, drivers agreed they were comfortable using ACC in free-flowing traffic on interstates (*LSM*=4.36, 95% CI[4.13, 4.59]) significantly more than arterial roads with intersections (*LSM*=3.63, 95% CI[3.40, 3.86]), roads with moderate hills (*LSM*=3.52, 95% CI[3.30, 3.75]), in heavy stop-and-go traffic (*LSM*=3.04, 95% CI[2.81, 3.27]), and on low-speed local roads (*LSM*=2.70, 95% CI[2.69, 3.16]). Drivers also agreed significantly more that they were comfortable using ACC on arterials with intersections and roads with moderate hills compared with low-speed local roads or in heavy stop-and-go traffic.

The main effect of vehicle also was statistically significant ($F(4, 495)=9.05$, $p<0.001$). On average, drivers indicated significantly more agreement that they were comfortable using the ACC system in the Audi Q7 (*LSM*=3.96, 95% CI[3.73, 4.19]) than the ACC systems in the Audi A4 (*LSM*=3.34, 95% CI[3.10, 3.58]) ($p < 0.001$), Infiniti QX60 (*LSM*=3.55, 95% CI[3.31, 3.78]) ($p < 0.05$), Toyota Prius (*LSM*=3.49, 95% CI[3.24, 3.75]) ($p < 0.01$), and Honda Civic (*LSM*=3.14, 95% CI[2.88, 3.41]) ($p < 0.001$). Drivers also expressed significantly less agreement that they were comfortable using ACC in the Honda than every other vehicle except the A4. The interaction between vehicle and situation was not statistically significant ($F(16,495)=0.98$, $p=0.48$).

Like ACC, the largest proportion of drivers agreed or strongly agreed that they would be comfortable using ALK on interstates with free-flowing traffic (66%); the smallest proportion agreed or strongly agreed they were comfortable using ALK on curvy, winding roads (42%). A mixed-effects regression analysis of drivers' level of agreement with being comfortable using the Audi A4, Audi Q7, and Honda ALK systems in different situations indicated a significant main effect of situation ($F(3, 236)=9.94$, $p<0.001$). Drivers indicated significantly more agreement that they were comfortable using ALK in free-flowing traffic on interstates (*LSM*=4.02, 95% CI[3.70, 4.37]) compared with interstates with gentle curves (*LSM*=3.70, 95% CI[3.37, 4.04]), roads with moderate hills (*LSM*=3.60, 95% CI[3.26, 3.94]), and curvy, winding roads (*LSM*=3.31, 95% CI[2.98, 3.65]). Drivers also reported significantly less agreement that they were comfortable using ALK on curvy, winding roads than in each other situation.

The main effect of vehicle also was significant ($F(2,236)=5.93$, $p<0.01$). Across the four driving situations, drivers' expressed significantly more agreement that they were comfortable using the Honda ALK system (*LSM*=3.94, 95% CI[3.58, 4.30]) than the Audi A4's system (*LSM*=3.41, 95% CI[3.07, 3.75]) ($p < 0.01$); the level of agreement for the Honda system also exceeded that of the Audi Q7 (*LSM*=3.63, 95% CI[3.30, 3.96]) but this difference was not statistically significant ($p = 0.13$). The interaction between vehicle and situation was not significant ($F(6,236)=0.59$, $p=0.74$).

Ratings of performance and interface characteristics of ACC and ALK

Participants' general sentiment towards ACC and ALK and their comfort with using these technologies varied across vehicles, so additional analyses were conducted to better understand how participants' opinions about various attributes of ACC and ALK explained variation in their overall sentiments towards each technology across vehicles. Table 4 presents the percent of drivers who agreed or strongly agreed with statements about attributes of ACC systems. Overall, most drivers agreed or strongly agreed that the five ACC systems changed vehicle speed smoothly, maintained desired following distances, informed drivers if the vehicle ahead was detected, and detected moving or stopped vehicles ahead. Most drivers also agreed or strongly agreed that the system slowed for vehicles ahead that had exited their travel lane.

Table 4. Percent of drivers who agreed or strongly agreed with various statements about attributes of ACC by vehicle.

Vehicle	Accelerated and decelerated smoothly	Maintained a constant, desired distance to vehicle ahead	Driver always knew if the vehicle ahead was detected	Detected moving vehicles ahead	Detected stopped vehicles ahead	Continued adjusting vehicle speed after vehicle ahead exited lane
2016 Honda Civic	25	75	63	88	44	69
2016 Infiniti QX60	63	75	75	92	63	58
2016 Toyota Prius	67	78	50	78	56	44
2017 Audi A4	64	82	73	86	64	45
2017 Audi Q7	75	88	67	96	63	54
Overall	61	80	66	88	59	54

Table 5 presents the results of a general linear model predicting drivers' reported level of agreement that ACC improved their overall driving experience based on their level of agreement with six statements about the attributes of the system. Drivers' responses to these six statements significantly predicted changes in the level of agreement that ACC improved the driving experience ($F(6,97)=9.9$, $p<0.001$, $R^2=0.38$). Specifically, one-point increases in the level of agreement that the ACC system accelerated and decelerated the vehicle smoothly and detected moving vehicles ahead were associated with significant 0.29- and 0.42-point increases, respectively, in the level of agreement that the system improved the driving experience.

Table 5. Model results predicting the level of agreement that adaptive cruise control improved the driving experience from agreement with statements about various system attributes.

Effect	Estimate	95% Confidence interval	p-value	η_p^2
Intercept	1.06			
Accelerated and decelerated smoothly	0.29	[0.13, 0.45]	<0.001	0.12
Maintained a constant, desired distance to vehicle ahead	0.03	[-0.19,0.26]	0.76	<0.01
Driver always knew if vehicle ahead was detected	0.03	[-0.16,0.23]	0.73	<0.01
System detected moving vehicles ahead	0.42	[0.14,0.70]	0.004	0.08
System detected stopped vehicles ahead	-0.04	[-0.17,0.09]	0.56	<0.01
System slowed for vehicles exiting my lane	-0.04	[-0.18,0.10]	0.61	0.00

Overall, most drivers agreed or strongly agreed that they understood when ALK systems had detected lane markings, and that the systems consistently detected the markings and kept the vehicle centered in the lane (Table 6). Less than half agreed or strongly agreed that that the ALK systems made smooth, gentle steering corrections, and 37 percent agreed or strongly agreed that the steering corrections occurred too frequently.

Table 6. Percent of drivers who agreed or strongly agreed with various statements about attributes of ALK by vehicle.

Vehicle	Driver always knew if lane markings were detected	System consistently detected lane markings	Made smooth, gentle steering corrections	Kept my vehicle in the center of the lane	Made steering corrections too frequently
2016 Honda Civic	94	44	63	75	31
2017 Audi A4	68	55	41	45	23
2017 Audi Q7	92	63	46	54	54
Overall	82	55	48	56	37

The results of a general linear model predicting drivers' reported level of agreement that ALK improved the overall driving experience, based on their level of agreement with five statements about the attributes of the system, are shown in Table 7. Drivers' level of agreement with the five statements significantly predicted their level of agreement that ALK improved the overall driving experience ($F(5,56)=26.8$, $p<0.001$, $R^2=0.71$). Specifically, a one-point increase in the level of agreement that the ALK system made smooth, gentle steering corrections was associated with a 0.32-point increase in the level of agreement that ALK improved the driving experience. Likewise, a one-point increase in the level of agreement that the ALK system made steering corrections too frequently was associated with a 0.39-point decrease in the level of agreement that ALK improved the overall driving experience.

Table 7. General estimating equation results of regressing subjective ratings about active lane keeping improving the driving experience on various ratings of system performance characteristics.

Effect	Estimate	95% Confidence interval	p-value	η_p^2
Intercept	2.55			
Driver always knew if lane markings were detected	0.15	[-0.06,0.37]	0.16	0.03
System consistently detected lane markings	0.08	[-0.12,0.27]	0.44	0.01
Made smooth, gentle steering corrections	0.32	[0.10,0.53]	0.004	0.14
Kept my vehicle in the center of the lane	0.06	[-0.19,0.31]	0.64	<0.01
Made steering corrections too frequently	-0.39	[-0.55,-0.23]	<0.001	0.30

DISCUSSION

This study evaluated factors that contribute to drivers' experiences with driving automation technology in five production vehicles following on-road use. Consistent with a prior study of trust in driver assistance and driving automation technology (Kidd et al., 2017), drivers' experiences with driving automation technology varied considerably among different driving technologies and implementations of the same technology in different vehicles. In general, there was more agreement that ACC improved the driving experience than ALK, but this was not the case for every vehicle. For instance, among ALK systems, drivers agreed that Honda's system improved the driving experience the most, but, among ACC systems, agreed that Honda's system improved the driving experience the least. The opposite pattern was found for Audi Q7.

Perceived differences in functionality and performance identified in previous research (Kidd et al., 2017) were shown to contribute to variation in drivers' experiences with the technology. In general, more agreement that ACC and ALK made smooth, gradual changes to vehicle control, that ACC detected moving vehicles ahead, and that ALK made infrequent steering corrections predicted increased agreement that the technology improved the driving experience. This suggests that compatibility plays a large role in the interaction with driving automation technology as posited by the Automation Acceptance Model (Ghazizadeh et al., 2012); that is, technologies that control the vehicle in a similar fashion to the driver are viewed more favorably and would be expected to be used more. However, additional research is needed to link functional differences in these attributes to actual use.

Another factor that may influence use of driving automation technology are the road types and traffic conditions on roads where drivers travel. Past research has found that drivers are more comfortable using driving automation technologies in some situations than in others (General Motors Corporation, 2005; Kessler et al., 2012). In the current study, drivers were most comfortable using ACC and ALK in free-flowing traffic on interstates, and least comfortable using ACC in stop-and-go traffic and on local roads and ALK on curvy, winding roads; these feelings were consistent across vehicles. Drivers may not be comfortable using ACC and ALK in every situation because of the functional limitations they encounter (e.g., Kidd et al., 2017).

Drivers are less likely to use some crash avoidance technologies than others (Reagan et al., 2018), and disparities in use could be one reason why these technologies are preventing fewer crashes than they could potentially prevent (e.g., Cicchino, 2017b; Jermakian, 2011). Similarly, drivers need to use driving automation technology more broadly than in free-flowing traffic on interstates to realize the full safety benefit of the technology. In 2015, only about 18% of all fatal crashes occurred on interstates, freeways, and expressways (National Highway Traffic Safety Administration [NHTSA], 2017). Technologies that can function well in a broader range of roadway situations conditions, like other arterial, collector, and local roads and around curves, need to be developed if the full crash-prevention potential of driving automation is to be realized.

Drivers need to develop an accurate understanding of the purpose, function, and limitations of a system to use it as intended by the manufacturer (Lee & See, 2004; Parasuraman & Riley, 1997). Owner's manuals can help drivers learn about the appropriate use and limitations of driving automation technology. However, the owner's manuals for current study vehicles inconsistently described the intended use of ACC and ALK, despite the technologies having similar capabilities. For example, the Honda manual explicitly stated that ACC should only be used on freeways in good weather conditions, but the Infiniti manual stated that ACC is for use on straight, dry, open roads with light traffic. Abraham, McAnulty, Mehler, and Reimer (2017) indicate similar issues with information provided by automotive retailers; some retailers even provided system descriptions that were explicitly inaccurate. Information about driving automation technology delivered to consumers needs to be accurate and consistent to support appropriate perceptions and proper use of the technology.

This study had several limitations. First, participants were employees of a nonprofit highway safety research organization in the United States, and their perceptions of technology intended to enhance safety may be more positive than typical drivers. Second, drivers had limited exposure to the technologies, and their opinions may have changed following extended use. Third, drivers were instructed to use ACC and ALK as often as possible while driving, but actual use was not measured. Thus, it is unclear the extent that actual use contributed to individual perceptions of the technology, or reflected self-reported comfort with using the technology in different situations.

Lastly, slightly less than one-third of study participants experienced a study vehicle in a previous study (Kidd et al., 2017), but were included in the current study since a different survey instrument was used. Prior experiences with a study vehicle may have influenced opinions of the equipped technologies. In both Kidd et al. (2017) and the current study, participants were given an accurate description of how each vehicle technology functioned and the limitations of each. Beggiato and Krems (2013) found that trust and acceptance of ACC increased over time and were less affected by system failures when the functionality and limitations of the technology were correctly described to drivers unfamiliar with the technology who used it during simulated driving on three separate occasions. Beggiato and Krems's findings suggest that opinions towards driver assistance technology endure when drivers have accurate information up front, so participants who drove a study vehicle in Kidd et al. (2017) would be expected to have similar feelings towards the technologies as reported in the current study.

In conclusion, highly automated vehicles are being promoted as a way to address the large number of crashes involving driver error (NHTSA, 2016). In the interim, existing driving automation technology may offer safety benefits (e.g., Kessler et al., 2012), but only if drivers use the technology and use it extensively. The current findings indicate that not all drivers strongly agreed that ACC and ALK improved their driving experience, which, according to models of technology acceptance, will reduce use. Furthermore, drivers were most comfortable using these technologies in free-flowing traffic on interstates. ACC and ALK systems that drivers felt made gradual and smooth changes in vehicle control, and detected moving vehicles (ACC) or made infrequent steering corrections (ALK) were most associated with reported improvements in the driving experience. Improving these attributes for these two driving automation technologies would be expected to increase use, and improvements that allow these technologies to perform better in more demanding roadway situations will increase the potential safety benefit.

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REFERENCES

Abraham, H., McAnulty, H., Mehler, B., & Reimer, B. (2017). Case study of today's automotive dealerships: introduction and delivery of advanced driver assistance systems. *Transportation Research Record: Journal of the Transportation Research Board, 2660,* 7–14.

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

Cicchino, J. B. (2017a). Effectiveness of forward collision warning and autonomous emergency braking systems in reducing front-to-rear crash rates. *Accident Analysis & Prevention, 99,* 142–152.

Cicchino, J. B. (2017b). *Effects of lane departure warning on police-reported crash rates*. Retrieved from Insurance Institute for Highway Safety website: http://www.iihs.org/frontend/iihs/documents/masterfiledocs.ashx?id=2142

Cohen, J. (1988) *Statistical power analysis for the behavioral sciences* (2nd ed.). Hilsdale. NJ: Lawrence Earlbaum Associates.

Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly, 13*(3), 319–340.

Eichelberger, A. H., & McCartt, A. T. (2014). Volvo drivers' experiences with advanced crash avoidance and related technologies. *Traffic Injury Prevention, 15*(2), 187–195.

General Motors Corporation. (2005). *Automotive collision avoidance system field operational test (ACAS FOT) final program report* (DOT HS 809 886). Washington, DC: National Highway Traffic Safety Administration.

Ghazizadeh, M., Lee, J. D., & Boyle, L. N. (2012). Extending the Technology Acceptance Model to assess automation. *Cognition, Technology & Work, 14*(1), 39–49.

Highway Loss Data Institute. (2015). 2013–2015 Honda Accord collision avoidance features. *HLDI Bulletin, 32*(33), 1–15.

Highway Loss Data Institute. (2016a). 2013–15 Subaru collision avoidance features. *HLDI Bulletin, 33*(6), 1–11.

Highway Loss Data Institute. (2016b). Buick collision avoidance features: an update. *HLDI Bulletin, 33*(18), 1–9.

Highway Loss Data Institute. (2016c). Mercedes-Benz collision avoidance features: a 2016 update. *HLDI Bulletin, 33*(23), 1–22.

Jamson, A. H., Merat, N., Carsten, O. M., & Lai, F. C. (2013). Behavioural changes in drivers experiencing highly-automated vehicle control in varying traffic conditions. *Transportation Research Part C: Emerging Technologies, 30*, 116–125.

Jermakian, J. S. (2011). Crash avoidance potential of four passenger vehicle technologies. *Accident Analysis & Prevention, 43*(3), 732–740.

Kessler, C., Etemad, A., Alessandretti, G., Heinig, K., Selpi, Brouwer, R., . . . Benmimoun, M. (2012). *European large-scale field operational tests on in-vehicle systems* (Deliverable 11.3: Final report). Retrieved from http://www.eurofot-ip.eu/download/library/deliverables/eurofotsp120121212v11dld113_final_report.pdf

Kidd, D. G., Cicchino, J. B., Reagan, I. J., & Kerfoot, L. B. (2017). Driver trust in five driver assistance technologies following real-world use in four production vehicles. *Traffic Injury Prevention, 18*(sup1), S44–S50.

Lee, J. D., & See, K. A. (2004). Trust in automation: Designing for appropriate reliance. *Human Factors, 46*(1), 50–80.

National Highway Traffic Safety Administration. (2016). *The road ahead: National Highway Traffic Safety Administration strategic plan 2010-2016*. (DOT HS 812 343). Washington, DC: National Highway Traffic Safety Administration.

National Highway Traffic Safety Administration. (2017). *Traffic safety facts 2015*. (DOT HS 812 384). Washington, DC: National Highway Traffic Safety Administration.

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

Reagan, I. J., Cicchino, J. B., Kerfoot, L. B., & Weast, R. A. (2018). Crash avoidance and driver assistance technologies – are they used? *Transportation Research Part F: Traffic Psychology and Behaviour, 52*, 176–190. doi:10.1016/j.trf.2017.11.015

Reagan, I. J., & McCartt, A. T. (2016). Observed activation status of lane departure warning and forward collision warning of Honda vehicles at dealership service centers. *Traffic Injury Prevention, 17*(8), 827–832.

Rogers, E. M. (1995). *Diffusion of innovations* (4th ed.). New York, NY: The Free Press.

Schleicher, S., & Gelau, C. (2011). The influence of Cruise Control and Adaptive Cruise Control on driving behaviour–A driving simulator study. *Accident Analysis & Prevention*, *43*(3), 1134–1139.