Effects of training and display content on Level 2 driving automation interface usability

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Highlights

- Training improves detection of Level 2 notifications for lane centering but not for adaptive cruise control (ACC).
- Information used to identify Level 2 activity varies with training and display content.
- System status recognition improves with use of appropriate display information.
- Training only moderately improves comprehension of system limitations.
- Persistent system statuses are better understood than changes that may require action.

Abstract

Introduction: Advanced driver assistance systems have the potential to improve safety, but as they become increasingly sophisticated there is a growing risk for drivers to misunderstand their functionalities and limitations. Level 2 driving automation features, such as adaptive cruise control (ACC) combined with lane centering, primarily communicate their operating statuses to the driver through the instrument cluster. It remains an open question how interface-specific training and display content influence a driver's use and comprehension of Level 2 automation in production vehicles.

Methods: A total of 80 participants viewed videos recorded from the driver's point of view under a variety of driving conditions with level 2 automation activity displayed in the instrument cluster of a model year 2017 Mercedes-Benz E-Class. Half of the sample viewed one of two instrument cluster layouts (simple or complex), and half received a brief orientation to the interface of their experimental group prior to the experiment. Participants viewed videos recorded from the driver's point of view under a variety of driving conditions with Level 2 automation activity displayed in the instrument cluster. After each video they were asked about the scenario they had just seen. We then examined what information in the instrument cluster participants used to identify Level 2 automation activity and their perceived usability of the displays.

Results: Training improved the ability to detect when lane centering was temporarily inactive and improved understanding of why the system was inactive. Neither training nor instrument cluster content affected the ability to identify when ACC had adjusted the vehicle's speed or detected a vehicle ahead, which all participants were highly accurate at detecting regardless of condition. The experimental factors also had no effect on the identification of when ACC initially did not detect a lead vehicle and the understanding of why it had not detected it, on which performance was universally poor. Both factors, however, influenced which sources of information in the display participants relied on to determine Level 2 automation activity. In turn, accuracy of system activity detection improved when participants relied on the correct sources of information. Training, but not instrument cluster content, also influenced the perceived usability of lane centering but not of ACC.

Discussion: Basic training improves detection of some system notifications that potentially require further driver action, but not of those that display persistent status information, where understanding without training is high. Even so, training does not result in full understanding of all system notifications or functional limitations, which reinforces the need for vehicle interfaces to saliently communicate pertinent system behavior and its limitations intuitively to naïve users.

Keywords: Advanced driver assistance system; adaptive cruise control; lane centering; active lane keeping; education; instrument cluster

1.0 Introduction

Advanced driver assistance systems are evolving in sophistication with the intention of reducing driving-related workload and, ideally, keeping drivers safer on the road. Level 2 driving automation (SAE International, 2018) integrates multiple driver assistance systems to provide sustained lateral and longitudinal vehicle control and represents some of the more advanced features that are currently available in mass market vehicles. One of the driver assistance subsystems is adaptive cruise control (ACC), which is similar to conventional cruise control except that it modulates its pre-set speed to maintain a pre-set following distance when a vehicle is in front. Another subsystem is lane centering, also known as autosteering, steering assistance, or active lane keeping assistance, which automatically steers the vehicle to keep it in the center of the lane. Although Level 2 driving automation does not require continuous driver input to control the vehicle's path under certain situations and environments, it does require the driver to constantly monitor both the road for hazards and the vehicle interface for system-related notifications in order to recognize when additional driver action is required should any of the assistance systems encounter conditions they cannot handle.

The degree to which a driver can understand a vehicle's operating status has critical safety implications. On-road testing of vehicles with Level 2 features has demonstrated that currently available systems can disengage when encountering challenging situations, such as curves, hills, intersections, added or dropped lanes, or losing sight of a vehicle that it is following when lane lines are not available (American Automobile Association [AAA], 2018; Consumer Reports, 2018; Insurance Institute for Highway Safety, 2018), and drivers need to be aware of when system status changes occur in order to respond appropriately. However, a challenge is that the ability to maintain attention diminishes as workload decreases, especially as the automation's reliability increases but remains imperfect, thus impairing a driver's ability to promptly detect notifications and respond when necessary (Carsten & Martens, 2019; Gold, Körber, Hohenberger, Lechner, & Bengler, 2015; Merat, Jameson, Lai, Daly, & Carsten, 2014). Drivers often misunderstand the functional capabilities and limitations of advanced driver assistance systems, which increases the risk of misuse and overreliance (McDonald, Carney, & McGehee, 2018). Accordingly, the potential safety consequences for drivers failing to understand vehicle interface communication are growing as these systems are becoming more functionally sophisticated and widely available across manufacturers and models (McDonald, Reyes, Roe, & McGehee, 2017).

Knowledge about Level 2 features appears to affect a user's understanding of the various system notifications, but while many drivers report seeking additional information about the technology equipped in their vehicles from the owner manual, some drivers do not or instead report learning through trial and error (McDonald et al., 2018). Llaneras, Cannon, and Green (2017) showed that receiving a general orientation to Level 2 features prior to operating a vehicle equipped with them improves a driver's compliance with requests from the vehicle to return attention to the road while performing secondary tasks. However, although the authors found that the training improved most of their participants' understanding for why the interface gave the attention prompts in the first place, not all of their trained participants understood or were certain about what the alerts signified. Their findings raise the question of whether training specific to vehicle interface content improves a driver's comprehension of the Level 2 driving automation's communication methods and how those notifications relate to system functionality.

While Level 2 features in production vehicles communicate to drivers through various modalities, most notifications are delivered visually. Numerous design recommendations have been made for vehicle visual interfaces based on subject matter expert evaluation, basic visual attention research, and driving-simulator testing (e.g., Campbell et al., 2018; Consumer Reports, 2018; Naujoks, Wiedermann, Schömig, Hergeth, & Keinath, 2019; Normark & Gärling, 2015). Few of these principles have been tested using interfaces of production vehicles with Level 2 features, however, and there remain idiosyncrasies among manufacturers in terms of the amount of information the interfaces contain. Vehicle manufacturers have the difficult task of designing interfaces that minimize visual burden while keeping system operation-relevant information available to the driver and presenting driver takeover demands in ways that do not require continuous monitoring (Naujoks et al., 2019).The visual complexity, clutter, and density of Level 2 feature-specific information displayed have the potential to adversely affect how users interpret and utilize the interface content and likewise may result in dangerously long glances and inefficient visual searches (Campbell et al., 2018; Naujoks et al., 2019; Yoon, Lim, and Ji, 2015). Furthermore, incorporating information that is only broadly related to each subsystem's activity status risks confusing or distracting the user from the most pertinent information needed to understand changes in overall Level 2 driving automation activity (Carsten & Martens, 2019).

Driver misuse of and overreliance on of Level 2 features (e.g., Boelhouwer , van den Beukel, van der Voort, & Martens, 2019) demonstrates mismatches among a designer's intent for how systems should be used, what the interfaces should communicate to drivers about those systems, and how drivers should use that information when operating the vehicle. Confusion about interface content may be further exacerbated if there is ambiguity or misunderstanding about the Level 2 driving automation's notification methods. For example, although notifications should direct the driver to what and where to attend (Naujoks et al., 2019), Petermeijer, Bazilinskyy, Bengler, & de Winter (2017) found that multimodal (auditory and vibrotactile) takeover requests from ACC with implied direction about where in the roadway the driver needs to attend were not intuitive to participants without training. Given that drivers are prone to misunderstanding the functionalities of their vehicle technologies (McDonald et al., 2018), it is possible that drivers may not understand Level 2 notifications as they relate to what the system is doing based on the roadway situation if they do not understand the system's limitations.

The goal of the current study was to examine whether Level 2 interface-specific training and the amount of information about advanced driver assistance systems shown in the instrument cluster influence the interpretability and usability of a vehicle's visual interface. To accomplish this aim, we used a production vehicle to capture how Level 2 features communicate through the instrument cluster under real-world circumstances. Videos were collected from the driver's point of view of the instrument cluster of a model year 2017 Mercedes-Benz E-Class and of the forward roadway in different driving situations with the Level 2 driving automation, known as Drive Pilot, turned on. The instrument cluster content level was manipulated by presenting one of two displays that varied in complexity. Participants viewed the videos showing the instrument cluster and roadway after either receiving an orientation to the Level 2 system's display prior to the experimental session or receiving no prior training, and they were asked a series of questions concerning their understanding of the activity of the ACC and lane centering systems.

2.0 Methods

2.1 Sample

The sample was comprised of 80 drivers who were randomly assigned to one of four conditions (n = 20 each) in a 2 x 2 between-subjects design: 1) no training with a simple instrument cluster display, 2) no training with a complex display, 3) training with a simple display, or 4) training with a complex display. Experimental conditions were balanced for gender (n = 10 male and 10 female per group) and age (M = 40.75 years, SD = 13.59). All participants had valid driving licenses, drove at least once a week (M = 5.76 days a week, SD = 1.56), had been driving for a minimum of 3 years (M = 22.35, SD = 13.48), were fluent in English, were proficient with using a computer, and had never received a diagnosis for colorblindness. Participants were recruited from Craigslist and Westat's intranet site (employees were ineligible, but family and friends were eligible to participate). They provided informed consent and were reimbursed $75 for their participation. Two individuals were replaced in the sample, one due to technical issues during the experiment and the other due to limited English fluency. The study protocol was approved by Westat's Institutional Review Board.

2.2 Materials

2.2.1 Video stimuli. Videos displayed two points of view taken from the driver's perspective showing the instrument cluster and the forward roadway (see Figure 1). The two video feeds were synchronized, with the instrument cluster video overlaid at the bottom of the forward roadway video, to show system-related changes in the instrument cluster corresponding with events on the road. Videos of the instrument cluster and forward roadway were collected simultaneously on public roadways in Virginia. ACC and lane centering were turned on for the duration of every video, with speed and following distance set prior to each video's start. The same driving scenarios were captured for the simple and complex instrument cluster groups, and special care was taken to ensure that the videos were equivalent for a given scenario.

Figure 1. Still frame from one of the experimental videos.

Two types of instrument cluster displays were presented. Like many vehicles, the E-Class allows for drivers to change the type of information shown in the center of the instrument cluster. The complex display groups viewed the driver assistance display, which showed detailed digital graphical elements that depict lane line detection, lead vehicle detection, and the following distance setting in the center of the instrument cluster. A blank image was postprocessed over the center of the instrument cluster for the simple display groups. As shown in Figure 2, both displays contained basic information about the status of the Level 2 features.

Figure 2 shows the simple and complex instrument cluster displays with the icons relevant to the Level 2 features highlighted with arrows and numbers for description purposes here, but the numbers and arrows were absent in the experimental videos. The displays updated in real time when conditions changed. In both displays, the vehicle icon marked with #1 turned green when a lead vehicle was detected and grey when no lead vehicle was detected. The speed to which ACC was set was displayed through #2. The red highlighted flag against the speedometer gauge is marked with #3 and displays the vehicle's current speed relative to the set speed. If a lead vehicle was present and driving slower than the set speed, that red flag against the speedometer would extend down to ACC's adjusted speed, thereby displaying the speed differential of the lead vehicle relative to the participant's vehicle set speed. Lane centering activity was represented through the steering wheel icon denoted by #4. The steering wheel icon would turn green when the lane centering system was actively controlling steering, sometimes flash yellow briefly when transitioning from active to inactive, and turn grey when it was temporarily inactive due to road conditions.

Figure 2. Instrument cluster layout in the simple (top) and complex (bottom) conditions.

The complex instrument cluster contained additional information. The following distance to which ACC was set was denoted by an orange line (#5) and remained on screen regardless of whether a lead vehicle was present. Lane line detection was shown through #6, with the lane lines highlighted in green when the vehicle detected them and grey when it did not detect them. Because the lane centering system could be active without detecting lane lines (i.e., by following a lead vehicle) and lane lines could be detected when the system was temporarily inactive, this display was not a completely reliable indicator of lane centering operating status. Similar to icon #1, a lead vehicle was also represented through #7 when it was detected by ACC, and #8 represented the participant's vehicle, which was displayed at all times.

Eleven videos were presented, the first of which was a practice trial. Videos were 30 to 50 seconds long, and each equivalent video was the same duration between the two instrument cluster conditions. All but one of the remaining videos were recorded in a variety of driving situations where the status of ACC (the vehicle's speed changed or the system detected/dropped a lead vehicle), lane centering (the system became temporarily inactive), or both systems changed. Scenarios are described in Table 1.

Table 1. Description of driving scenarios.

Scenario	ACC status changes	Lane centering status changes
[Practice scenario] PV drove at set speed with no LV. Lane lines always present.	No	No
1. PV drove at set speed with LV in front. Lane lines always present.	No	No
2. PV drove behind LV, which initially drove at set speed, and then reduced speed. Lane lines always present.	Yes (speed)	No
3. PV drove behind LV, which was initially slower and then sped up to near set speed. Lane lines always present.	Yes (speed)	No
4. PV drove at set speed with no LV. No lane lines were present for the first half of the drive, then the drive was interrupted by an intersecting road, and then lane lines were present for the second half.	No	Yes
5. PV drove at set speed with no LV. Lane lines were present for the first half of the drive, then interrupted by an intersecting road, then absent for the second half.	No	Yes
6. PV drove at set speed with no LV. Lane lines were present initially, then absent (a curve and hill occurred shortly after), and resumed at the end.	No	Yes
7. PV initially drove at set speed, with a vehicle present ahead in the adjacent lane, which then merged in front of PV. LV then slowed down. Lane lines always present.	Yes (speed and LV detection)	No
8. PV drove behind LV, which drove slower than set speed. LV then sped up and merged into adjacent lane, causing PV to speed up to near set speed. Lane lines always present.	Yes (speed and LV detection)	No
9. PV driving at set speed with LV far enough ahead that it was initially undetected. As PV approached at faster speed, LV was then detected. Once PV approached at a certain distance, it slowed down to keep set distance. Lane lines always present.	Yes (speed and LV detection)	No
10. PV drove near set speed behind LV. Lane lines were initially present, then absent (a curve and hill occurred shortly after), and resumed at the end. Both vehicles sped up and slowed down over the curve and hill.	Yes (speed)	Yes

Note. PV denotes participant vehicle and LV denotes lead vehicle.

2.2.2 Questionnaire on the video stimuli. Questionnaires were delivered online via SurveyMonkey.com with a research assistant present. After watching each video, participants were asked questions about their comprehension of the statuses of the ACC and lane centering systems. The same questionnaire was delivered for each video to compare responses among the different driving scenarios.

Survey items asked if participants understood system statuses and functional limitations. Specifically, ACC status identification questions asked whether the system had detected a vehicle in front at any point during the video, whether it ever did not detect a vehicle when it was in front, and whether it ever changed the participant's vehicle speed in response to a vehicle in front. A single lane centering status identification question asked whether it was not working at any point during the video.

Comprehension of system limitations was assessed with one question for each system type. The limitation comprehension question for ACC asked why it had not detected the vehicle in front. Possible responses included that the vehicle in front was too far ahead, the vehicle in front changed lanes, the participant's vehicle passed and overtook the vehicle that was initially in front, it was unclear why it did not detect the vehicle in front, this situation did not occur during the video, and other. The analogous question for lane centering asked why it was not working, and the six possible responses included that the lane lines were absent or faded, the lane lines were interrupted by an intersecting road, the system could not use the vehicle in front because of a curve or hill, it is unclear why it was not working, this situation did not occur during the video, and other. Participants could select as many responses as applied to both questions. The lists provided to participants of the possible limitations of each system were generated based on the information provided in the owner manual and our experience using Mercedes-Benz's Drive Pilot system.

2.2.3 Questionnaire on instrument cluster utilization strategies. Participants were surveyed about where in the instrument cluster they looked for information about ACC and lane centering. Participants were presented with an image of the instrument cluster belonging to their experimental condition. As shown in Figure 2, the image of the instrument cluster shown to participants had various locations marked numerically. Participants were asked to select the locations they had used to determine whether their vehicle had detected a vehicle in front, what ACC's speed was set to, and whether their vehicle was autosteering. Three additional false items were marked as possible information sources in both the simple and complex conditions: outside temperature, engine temperature, and gear selector.

2.2.4 Questionnaire on the usability of the instrument cluster display. Participants were asked about their opinions on the ACC and lane centering notifications in the instrument cluster. This survey collected responses on a 5-point Likert scale using the following anchors: 1 = strongly disagree, 2 = disagree, 3 = neither agree nor disagree, 4 = agree, and 5 = strongly agree. Some survey items asked about the ease with which participants could locate information about ACC and lane centering in the instrument cluster. Others asked how easy it was for participants to determine when ACC was controlling the vehicle's speed and distance to the vehicle ahead, when ACC had changed the vehicle's speed or detected a vehicle ahead, when the vehicle was autosteering, and when lane centering was not controlling the vehicle's position on the road. Additional items asked about how well participants felt they understood the color coding of the ACC and lane centering icons, how useful notifications were about when lane centering was or was not autosteering, how useful notifications were about whether ACC had detected a vehicle in front or changed the vehicle's speed, how much they trusted the vehicle to notify them when ACC had detected a vehicle ahead or changed the vehicle speed, and how much they trusted the vehicle to notify them when lane centering was or was not working.

2.3 Procedure

After providing informed consent, all participants were given a general introduction to ACC and lane centering systems using information in the owner manual. They were informed that ACC maintains the desired set driving speed and will automatically speed up and slow down the vehicle to keep a desired following distance from the vehicle ahead, once the system has detected that vehicle. Lane centering was described as a system that automatically helps to keep the vehicle centered within the lane. Participants were informed that normally the lane centering system uses the lane lines around the vehicle to control its position; however, if it is unable to detect the lane lines and there is a vehicle in front, it can autosteer by using the vehicle ahead as a reference rather than the lane lines.

Participants in the two trained groups were given an orientation to the interface using one of the two images of the instrument cluster in Figure 2. During the orientation, the research assistant described the icons used by ACC and lane centering, their potential states (e.g., color changes), and their meanings, as described in the 2.2.1 Video Stimuli section. The information provided during the orientation was from the owner manual. Participants in the untrained groups were allowed to view the image of the instrument cluster belonging to their condition to orient themselves to the information and icons present, but the research assistant did not provide any information about what information was relevant to ACC or lane centering, nor did the research assistant explain what any of the information or icons meant.

The experimental session was conducted using a desktop computer to present the videos and collect the questionnaire responses. The research assistant played a video, the order of which was randomized, after which the participant completed the associated questionnaire. Participants were not allowed to rewatch any of the videos. Once all the videos were shown and the corresponding questionnaires were completed, participants were allowed to take a short break. Finally, they completed questionnaires on information sources in the instrument cluster used to monitor ACC and lane centering activity, usability, and demographics.

2.4 Analysis

2.4.1 Video questionnaire analysis. As seen in Table 1, all but one of the experimental videos encompassed scenarios where there was a status change for ACC, lane centering, or both systems. Six of the 10 videos involved ACC-related status changes, where the participant's vehicle detected and/or adjusted speed in response to a vehicle in front. Four out of 10 videos had lane centering-related status changes, where the system deactivated due to the loss of lane lines with no vehicle ahead or the lost line of sight of a lead vehicle when no lane lines were present, and/or where the system reactivated when lane lines or a lead vehicle were present. The practice video and one experimental video without a status change were excluded from the analysis.

Accuracy was calculated for responses to the ACC- and lane centering-related status detection and system limitation comprehension questions for videos where there was a change in the system activity of interest. Due to the general reliability of ACC under the conditions tested, only one video showed an ACC limitation where the lead vehicle was initially too far ahead in front of the participant's vehicle for ACC to be able to detect it. Four videos showed lane centering limitations where the system temporarily deactivated. Participants were considered to have answered questions on system limitation comprehension accurately if they both detected what happened in the video (i.e., ACC did not detect a vehicle ahead or lane centering was not working) and correctly identified why it happened. Response accuracy per question type was averaged across videos that contained relevant system activity changes.

2.4.2 *Instrument cluster source utilization questionnaire analysis*. Responses were analyzed per question concerning the icons used to determine whether ACC had detected a vehicle in front, what ACC's speed was set to, and whether the participant's vehicle was autosteering. We assessed whether participants selected one or more correct icons in the instrument cluster.

2.4.3 *Questionnaire on the usability of the instrument cluster display analysis.* The responses were averaged across questions for ACC and lane centering, separately.

2.4.4 *Statistical analyses.* All statistical analyses were conducted using SAS software (version 9.4 of SAS System for Windows; copyright © SAS Institute, Inc., 2019, Cary NC). Accuracy on video comprehension questions, correct instrument cluster icon use, and usability scores were each analyzed in separate 2(training) x 2(instrument cluster content) ANOVAs per question (video comprehension and instrument cluster use) or per system (usability). Additionally, video comprehension accuracy by type of instrument cluster icon used was analyzed with *t* tests.

3.0 Results

3.1 Video Questionnaire Accuracy

Table 2 displays mean accuracy scores on system status identification and functional limitation comprehension questions by condition in scenarios where the system attribute in question changed. Outcomes from ANOVA models testing accuracy on each item as a function of training and instrument cluster content are summarized in Table 3. Most participants correctly identified when ACC detected a lead vehicle or modified its speed in response to the vehicle ahead, but few recognized when ACC initially did not detect a vehicle ahead or both noticed the lack of detection and understood the reason for it. Accuracy on questions pertaining to ACC status did not statistically significantly vary by training, instrument cluster content, or an interaction between the two.

Table 2. Mean accuracy scores (%) in scenarios with status changes per question type.

Question type	Condition			
	Untrained simple display	Untrained complex display	Trained simple display	Trained complex display
	Mean % (*SD*)	*Mean %* (*SD*)	*Mean %* (*SD*)	*Mean %* (*SD*)
ACC				
Detected lead vehicle	90.00 (21.90)	95.00 (16.31)	96.67 (10.26)	91.67 (14.81)
Speed change	86.67 (19.94)	82.50 (18.32)	78.33 (23.63)	87.50 (21.54)
Did not detect lead vehicle	10.00 (30.78)	10.00 (30.78)	20.00 (41.04)	25.00 (44.43)
Why system did not detect lead vehicle	10.00 (30.78)	10.00 (30.78)	15.00 (36.63)	25.00 (44.43)
Lane centering				
System was temporarily inactive (“not working”)	38.75 (38.45)	31.25 (34.29)	75.00 (31.41)	68.75 (34.29)
Why system was temporarily inactive (“not working”)	28.13 (31.90)	17.50 (22.36)	40.63 (25.29)	38.13 (28.52)

Table 3. Summary of testing main effects of training and instrument cluster content, and interactions between the variables, on mean accuracy scores for scenarios with status changes per question type.

Survey item type	Training	Instrument cluster content	Training x instrument cluster content
ACC			
Detected lead vehicle	F (1, 76) = 0.21, p = 0.65	F (1, 76) = 0.00, p = 1.00	F (1, 76) = 1.87, p = 0.18
Speed change	F (1, 76) = 0.13, p = 0.72	F (1, 76) = 0.28, p = 0.60	F (1, 76) = 2.02, p = 0.16
Did not detect lead vehicle	F (1, 76) = 2.25, p = 0.14	F (1, 76) = 0.09, p = 0.76	F (1, 76) = 0.09, p = 0.76
Why system did not detect lead vehicle	F (1, 76) = 1.54, p = 0.22	F (1, 76) = 0.38, p = 0.54	F (1, 76) = 0.38, p = 0.54
Lane centering			
System was temporarily inactive (“not working”)	**F (1, 76) = 22.58, p <0.0001**	F (1, 76) = 0.78, p = 0.38	F (1, 76) = 0.01, p = 0.94
Why system was temporarily inactive (“not working”)	**F (1, 76) = 7.39, p = 0.008**	F (1, 76) = 1.16, p = 0.28	F (1, 76) = 0.44, p = 0.51

Note. Bold text indicates statistically significant effects.

Although training had no significant influence on status detection or functional limitation comprehension for ACC, it did influence how well participants recognized status changes for the lane centering system when it temporarily deactivated and understood why deactivations occurred. As shown in Figure 3, participants who received an orientation prior to the experiment were more than twice as accurate at detecting when the lane centering system had stopped working than those who were untrained. Similarly, training increased comprehension of why system deactivations occurred. Performance was unaffected by instrument cluster content or the interaction between instrument cluster content and training.

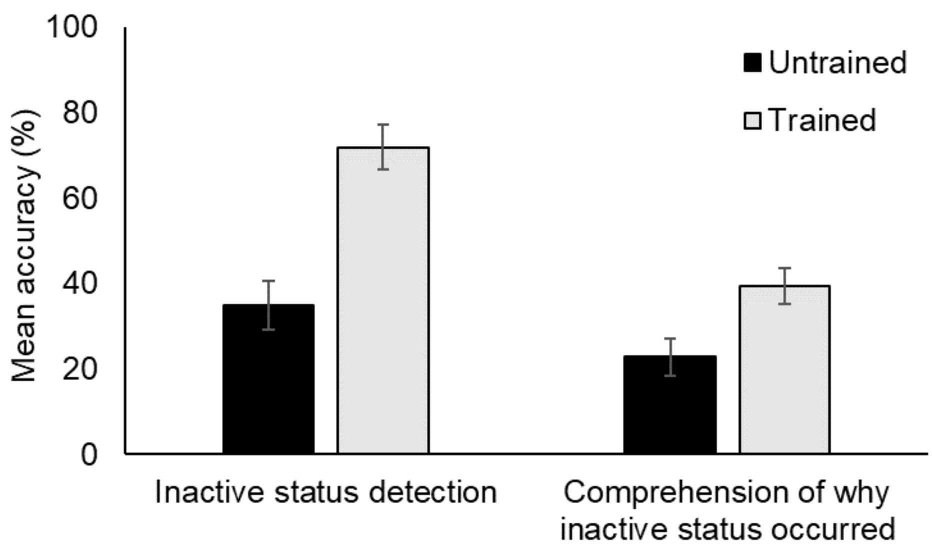

Figure 3. Effect of training on mean (%) accuracy of lane centering inactive status detection and functional limitation comprehension. Error bars are ± SE.

3.2 Instrument Cluster Source Utilization

Different sources of information were available to choose from between the instrument cluster content conditions, as shown in Figure 2. To determine whether the ACC system had detected a vehicle ahead, participants in the simple display group had only one reliable source to use, the green car icon in the upper left of the instrument cluster (#1), whereas those in the complex display group had two reliable sources available: the green car icon (#1) and the lead vehicle in the center of the display (#7) (see Table 4). There was a significant effect of training, F (1, 76) = 5.68, p = 0.02, in that more trained participants selected at least one correct source of information than untrained participants, but not of instrument cluster content, $F\ (1, 76) = 0.36$, $p = 0.55$, and there was no significant interaction between the variables, $F\ (1, 76) = 0.00$, $p = 1.00$.

Table 4. Percent of participants per condition who used available sources of information in the instrument cluster, as shown in Figure 2, to determine whether ACC had detected a vehicle ahead.

Information source	Condition			
	Untrained simple display	Untrained complex display	Trained simple display	Trained complex display
Correct icons				
Small green car (#1)	70	20	90	65
Lead vehicle in center of instrument cluster (#7)	n/a	75	n/a	85
Either correct response (#1 or #7)	70	75	90	95
Misleading icons				
Speedometer flag (#3)	50	15	40	25
Following distance setting (#5)	n/a	70	n/a	45
Other incorrect icons				
Set speed (#2)	25	5	0	0
Ego vehicle (#8)	n/a	10	n/a	15
Lane lines (#6)	n/a	35	n/a	35
Steering wheel (#4)	10	20	10	10
Other	10	5	5	0

Note. N/a indicates that this icon was not present on the instrument cluster in the simple display conditions.

The most commonly used incorrect sources of information, referred to as "misleading icons" in Table 4, were related to the ACC system's activity but did not reliably inform the driver about whether ACC had detected a vehicle ahead: the following distance setting in the complex display (#5 in Figure 2), which was present regardless of whether there was a lead vehicle, and the flag in the speedometer that marked the differential between the set speed and the vehicle's current speed (#3).

Participants in both instrument cluster content groups had two available sources to use to identify the speed to which ACC was set: the set speed in the upper left of the instrument panel (#2 in Figure 2) and the speed differential flag in the speedometer (#3). As summarized in Table 5, more trained participants selected at least one correct source of information than untrained participants, $F(1, 76) = 4.22$, $p = 0.04$, regardless of instrument cluster content, $F(1, 76) = 0.00$, $p = 1.00$, and there was no interaction between the variables, $F(1, 76) = 0.00$, $p = 1.00$. Almost all participants in both groups selected at least one correct source, which suggests that the practical significance of this training effect is small.

Table 5. Percent of participants per condition who used available sources of information in the instrument cluster, as shown in Figure 2, to determine the speed to which ACC was set.

Information source	Condition			
	Untrained simple display	Untrained complex display	Trained simple display	Trained complex display
Correct icons				
Set speed (#2)	80	65	75	100
Speedometer flag (#3)	35	55	60	45
Either correct response (#2 or #3)	90	90	100	100
Incorrect icons				
Small green car (#1)	5	10	15	20
Lead vehicle in center of instrument cluster (#7)	n/a	0	n/a	5
Following distance setting (#5)	n/a	5	n/a	10
Ego vehicle (#8)	n/a	0	n/a	0
Lane lines (#6)	n/a	0	n/a	0
Steering wheel (#4)	0	0	0	15
Other	15	0	0	5

Note. N/a indicates that this icon was not present on the instrument cluster in the simple display conditions.

All participants had one information source available to determine whether the lane centering system was actively steering the vehicle: the steering wheel icon at the bottom of the instrument cluster (#4 in Figure 2). As shown in Table 6, there were significant main effects of training, $F(1, 76) = 18.67$,

$p < 0.0001$, in that more trained participants selected the correct source of information than untrained participants, and of instrument cluster content, $F(1, 76) = 10.04$, $p = 0.002$, as more participants who viewed the simple display selected the correct source of information than those who viewed the complex display. These main effects should be interpreted in light of the significant interaction between training and instrument cluster content, $F(1, 76) = 4.07$, $p = 0.047$. Specifically, instrument cluster content had a significant effect among untrained participants, $t(38) = 9.68$, $p = 0.004$, as more untrained participants used the correct source of information in the simple display than untrained participants with the complex display; however, instrument cluster content had no significant effect among trained participants, $t(38) = 1.09$, $p = 0.30$.

Table 6. Percent of participants per condition who used available sources of information in the instrument cluster, as shown in Figure 2, to determine whether lane centering was active.

Information source	Condition			
	Untrained simple display	Untrained complex display	Trained simple display	Trained complex display
Correct icon				
Steering wheel (#4)	75	30	95	85
Misleading icon				
Lane lines (#6)	n/a	55	n/a	40
Other incorrect icons				
Small green car (#1)	10	20	10	10
Lead vehicle in center of instrument cluster (#7)	n/a	10	n/a	15
Speedometer flag (#3)	0	5	5	0
Set speed (#2)	15	0	5	5
Following distance setting (#5)	n/a	20	n/a	25
Ego vehicle (#8)	n/a	15	n/a	15
Other	15	15	5	5

Note. N/a indicates that this icon was not present on the instrument cluster in the simple display conditions.

The lane lines in the center of the instrument cluster (#6 in Figure 2), which were present only in the complex display, were an unreliable source of information to use when determining whether the lane centering system was actively steering because the vehicle could detect lane lines while the lane centering system was temporarily inactive and vice versa. Nevertheless, this was a commonly used source of information for participants who viewed the complex display, regardless of training.

3.3 Video questionnaire accuracy as a function of instrument cluster source use

We further explored status detection accuracy based on whether participants selected correct or incorrect sources of information that were available in the instrument cluster of their respective conditions (see Table 7). Participants who used the correct source of information to determine if the lane centering system was actively steering the vehicle had much higher accuracy in identifying when the lane centering system was not working. Participants who used at least one correct source of information to determine whether ACC had detected a vehicle ahead similarly were more accurate in identifying when ACC detected a lead vehicle in scenarios where a lead vehicle appeared or disappeared, although accuracy was still high among participants who did not use a correct source. Accuracy was low for detecting when ACC had initially did not detect a lead vehicle, but only participants who used the correct information sources detected the lack of detection. Accuracy in detecting when ACC changed the speed in response to the lead vehicle was not examined because participants were not asked about the information source used to detect changes in speed.

Table 7. Mean accuracy scores (%) in scenarios with status changes as a function of information sources used that were available in the instrument cluster, and results of unpaired *t* tests comparing accuracy by sources used.

Accuracy question type	Information source used		*t* test result
	At least one correct source used	Only used incorrect sources	
	Mean % (*SD*) [*N*]	*Mean %* (*SD*) [*N*]	
ACC detected lead vehicle	95.45 (14.19) [66]	83.33 (21.68) [14]	t (78) = 6.90, p = 0.01
ACC did not detect lead vehicle	19.70 (40.08) [66]	0 (0) [14]	t (78) = 3.35, p = 0.07
Lane centering system was temporarily inactive ("not working")	67.54 (33.06) [57]	18.48 (29.40) [23]	t (78) = 38.36, p < 0.0001

3.4 Display usability

Various aspects about participant perceptions of the display's usability were captured using Likert scales with anchors ranging between 1 (strongly disagree) to 5 (strongly agree). We averaged responses across those items to create a general indicator of how positively participants felt about the displays. The higher the scores, the more positively participants felt about the usability of the displays. As shown in Table 8, average usability ratings for the ACC interface were relatively consistent across conditions with only a small effect of training, F (1, 76) = 3.95, p = 0.05, but no significant effect of instrument cluster content, F (1, 76) = 0.17, p = 0.68, and there was no interaction between the two variables, F (1, 76) = 0.21, p = 0.65. There was an effect of training on lane centering interface usability ratings, as trained participants gave higher (i.e., more positive) ratings than untrained participants, F (1, 76) = 23.05, p < 0.0001; there was no effect of instrument cluster content, F (1, 76) = 0.66, p = 0.42, and there was no interaction between the two variables, F (1, 76) = 0.05, p = 0.83.

Table 8. Mean ratings (1=strongly disagree, 5=strongly agree) for ACC and lane centering display usability.

	Untrained simple display	Untrained complex display	Trained simple display	Trained complex display
	Mean (*SD*)	*Mean* (*SD*)	*Mean* (*SD*)	*Mean* (*SD*)
ACC	3.96 (0.78)	4.09 (0.57)	4.31 (0.57)	4.30 (0.56)
Lane centering	3.43 (1.04)	3.33 (0.59)	4.28 (0.64)	4.10 (0.67)

4.0 Discussion

Timely and appropriate feedback about the operating status of an automated system is critical for the user to monitor and understand what is happening when sharing control with it, because automation is imperfect and unanticipated events will occur outside of its capabilities (Norman, 1990). Campbell (2018) recommended that the best practice for vehicle interface communication is for the modality of the status display to supplement, or be consistent with, the nature of the information presented; for example, visual displays should be used for persistent status information, whereas auditory or tactile alerts should signify changes in system status. It could be argued that lane centering becoming temporarily inactive is a status change that could potentially require further driver action, whereas ACC's detection of a lead vehicle and speed information are "persistent" status information. ACC not detecting a lead vehicle when one is present could similarly potentially require braking from the driver in the event that the lack of detection occurs when the lead vehicle is too close ahead.

All of the system activity-related information communicated through the vehicle interface in this study was relatively inconspicuous. The fact that participants were worse at detecting status changes that could potentially require driver action than information not requiring a response suggests that status changes requiring a response ought to be communicated more saliently. Multimodal alerts are more effective in capturing driver attention and tend to elicit more rapid responses than single modality notifications (Bondi, Strayer, Rossi, Gastaldi, & Mulatti, 2017; Naujoks, Kiesel, & Neukum, 2016; Naujoks, Mai, & Neukum, 2014; Politis, Brewster, & Pollick, 2013). Such strategies are used by some vehicle manufacturers to communicate certain status changes; for example, when losing detection of lane lines, Nissan's ProPilot Assist system currently provides the option to receive both audible and visual alerts.

Despite the efficacy of multimodal notifications for eliciting driver takeover responses, there is a need to strike a balance between the salience of system communication and user acceptance. This is especially the case for systems, such as lane centering, that frequently encounter conditions that exceed their operational thresholds, including situations in which the system is not confident enough with the data it has or when some threshold of its algorithm has been exceeded. There is the risk that the frequent notifications of such systems will lead drivers to ignore or turn them off altogether, particularly if drivers perceive the alerts as false or unnecessary when, for example, system disengagements are brief or takeover responses are not required. Furthermore, the issue of notification acceptability is critical as it determines likelihood of use. Reagan, Cicchino, Kerfoot, and Weast (2018) showed that vehicle owners are more likely to turn lane departure warning systems off when those systems utilize alerts that are perceived as distracting and unnecessary, thereby eliminating any safety benefit the systems would otherwise have.

In an effort to combat misuse as a result of misunderstanding vehicle system communication and functionality, the National Highway Traffic Safety Administration (2018) has called for initiatives to improve public training with driver assistance systems. Our data show that interface-specific training improved status detection, use of the correct icons to infer status, and overall interface usability for the lane centering system and suggests that minimal training could also help drivers better understand other notifications that are not intuitive or salient. The implications of the effects of training are relevant for all drivers operating vehicles equipped with driver assistance systems, given that most do not receive formal training on these technologies (McDonald et al., 2018). Most drivers report that they learn how to use these systems using their owner manuals and/or trial and error, but they also indicate a general preference to learn from staff members at dealerships upon taking delivery of a vehicle (Abraham, Reimer, & Mehler, 2018). The discrepancy between the strategies utilized versus those desired to learn from highlights an ideal training opportunity that is evidently underused. Although the issue is complicated by the fact that dealership staff are often ill equipped to educate owners about their vehicles (Abraham, McAnulty, Mehler, & Reimer, 2017), our results suggest that minimal training may still be beneficial to help inform drivers about their vehicle technologies.

An important caveat our study revealed is that training does not universally improve the usability of the Level 2 vehicle interface. While it did improve detection of changes in lane centering activity, training had no effect on the overall poorer detection accuracy for when ACC did not initially detect a lead vehicle. Other ACC activity detection was also unaffected by training, yet that performance was considerably better than for lane centering activity detection among all participants. Similarly, although we observed the same pattern of the mixed effects of training on system limitation comprehension, performance was poor across all conditions for both systems. In light of these findings and because most owners do not receive training on the systems in their vehicles, it is imperative that system interfaces be designed to be as intuitive as possible to naïve users. Intuitive interface design will help minimize the opportunities for misuse of Level 2 features and confusion about their functional capabilities and limitations.

Related to interface design, the current study demonstrated that while having more information available in the instrument cluster changed the sources of information participants used, it did not inherently influence status detection accuracy or system limitation comprehension. Nevertheless, we found that the relevance of the interface content to the Level 2 feature's activity affected the ability to identify system statuses. The impact of using incorrect or unreliable sources of information on status detection accuracy was especially pronounced for lane centering compared with ACC's lead vehicle detection.

The fact that some participants relied on the lane line detection notification instead of the steering wheel icon to determine whether the vehicle was actively steering itself underscores the issue of partial functionality overlap between systems. When systems share some similarities, there is the risk that the interface content will lead to confusion about how it relates to each system's activity and its role for driver assistance (Larsson, 2012). Given that both ACC and lane centering limitations were poorly understood across the sample, these results emphasize the importance of minimizing information in the interface that has the potential to confuse users about a Level 2 feature's activity status.

Few participants correctly identified when ACC did not detect a lead vehicle or when lane centering became temporarily inactive without using the correct sources of information in the instrument cluster, but a large percentage were able to identify when ACC detected a lead vehicle while using incorrect sources. This suggests that many participants may not have relied on the vehicle interface to make this determination about ACC activity at all. Instead, it is likely that they assumed ACC had detected a lead vehicle based on the presence of a vehicle ahead in the forward roadway video. Such an interpretation would explain the small number of participants who both detected and understood why ACC did not initially detect the lead vehicle as well as why there was no effect of training or instrument cluster content. Moreover, the vehicle never drifted out of its lane when lane centering stopped working and therefore participants had to rely more on the instrument cluster to determine that system's operation status, as lane lines disappearing or being interrupted by an intersecting lane were less obvious in the forward roadway videos than the participant's vehicle speed changing or the presence of a lead vehicle. It is also possible that this finding arose because the ACC system is more reliable in the study scenarios, with few false positives and disengagements, which also might explain why we observed a different pattern of effects on the detection accuracy for lane centering inactivity.

4.1 Limitations

This study represents a novel approach to investigating interface usability of Level 2 features. With the focus on the instrument cluster display, our methodology utilized a desktop presentation of videos taken from the driver's point of view on the road while operating a vehicle equipped with Level 2 features; however, participants did not physically operate the vehicle themselves and thus did not have access to tactile cues through, for example, steering wheel movement. Although this method limited the fidelity of the Level 2 driving automation experience, it allowed our investigation to concentrate on the interface itself without external distraction and uncontrollable factors that would be inevitable with operation of the vehicle on public roads. The next step for research on this subject will be to explore the interface usability of Level 2 features within the broader context of using driving automation on the road.

Another limitation of this study is that we used only one production vehicle, and there are Level 2 interface differences between manufacturers and models that our stimuli were unable to capture. We had a limited number of scenarios exemplifying the real-world functionality and limitations of the Level 2 features that were specific to the year, make, and model of the vehicle used in this study, which may not generalize to other vehicles and manufacturers. Nevertheless, it was beyond the scope of this study to make comparisons between manufacturers. Our paradigm and results lay the groundwork for future research on vehicle interface design, given the many open questions about the effects of user and Level 2 vehicle interface characteristics (for a review see Noy, Shinar, & Horrey, 2018).

4.2 Conclusions

This study demonstrates that interface-specific training improves a user's detection of Level 2 feature activity as communicated through the vehicle interface. Both training and the amount of information presented in the interface influence what users rely on to determine system activity. Our data support concerns that unreliable or uninformative notifications will be used if presented continuously on display (e.g., Campbell, 2018; Carsten & Martens, 2019; Naujoks et al., 2019; Yoon et al., 2015). Relying on inappropriate sources of information in the interface increases the risk of a driver failing to detect changes in system activity that require driver intervention. Our findings underscore the importance of using brief presentations for information that does not communicate the operating status of a driver assistance system. In addition, we have shown that it is necessary to minimize confusion about notifications for systems that are partially related but have significantly different functionalities with respect to driver assistance, such as lane centering as compared to lane departure warning or prevention systems, as it may not be clear to the driver that they are separate systems.

Despite the impact that training appears to have on understanding interface content, we found that interface-specific education only moderately improves one's understanding of a system's limitations. Poor system limitation comprehension appears to hinder the ability to detect system inactivity when the system encounters situations that it cannot handle, which emphasizes the need for more intuitive interface communication strategies about system functionality and when drivers need to intervene. Altogether, our study highlights some of the challenges with designing interfaces for vehicles with increasingly sophisticated driver assistances systems and underscore the importance for designers to incorporate human factors recommendations.

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