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Design intent gets lost in translation: cooperative steering expectations and consumer willingness to steer with partial driving automation

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Abstract

Introduction: Partially automated (Level 2) systems have design factors that may influence driver behavior, such as shared steering control (i.e., cooperative steering). A fundamental characteristic of cooperative steering is that the lane-centering support remains on while the driver steers within the lane. At the time this study was conducted, Ford and Nissan systems had this cooperative design philosophy, whereas Tesla and General Motors (GM) systems did not.

Method: An online multimedia survey of 1,260 owners of Tesla, GM, Ford, and Nissan vehicles equipped with partial automation gave us insight into their understanding of their systems' cooperability.

Results: We found that automaker design intent does not always translate into consumer understanding because most respondents, from all owner groups, thought their systems were cooperative. Likewise, many drivers with hands-on-required systems thought they could be used hands-free for extended periods, whereas some people with hands-free-capable systems thought they could not use their systems that way. Nevertheless, after presenting video-based driving situations that varied in hazardousness, we found that cooperability has a situation-specific influence. Specifically, cooperative-system owners were more likely to want to steer to the side of the lane in all scenarios and have their hands on the wheel than noncooperative-system owners in scenarios with a large vehicle present in the adjacent lane.

Conclusion: Given the growing concern around driver disengagement and system misuse, our findings suggest that cooperative steering is not only a relatively intuitive design philosophy, but it also may help to maintain driver engagement.

Keywords: shared control; Level 2; collaborative; engagement; safeguards

Introduction

Automakers create unique relationships with their customers to produce a complex ecosystem of driver-vehicle interactions often involving driver assistance technology—the most advanced of which is known as driving automation. The Society of Automotive Engineers (SAE International, 2021) has a classification scheme for different levels of automation based on what it can do and what the driver is responsible for. The highest level that most production systems currently fall under is Level 2, meaning that they are only partially automated and provide sustained lane centering, speed, and headway support.

Although the term "automation" tends to evoke expectations that the vehicle can drive itself, your responsibility for safe driving is the same while driving with and without the automation's support. These systems can do things that are unsafe or unexpected, such as abruptly drifting out of the lane (Insurance Institute for Highway Safety [IIHS], 2018), and so drivers must pay attention to intervene in time. Unfortunately, a driver's attention tends to wane with system use over time with a corresponding uptick in distracting activities, such as texting (e.g., Dunn et al., 2021; Noble et al., 2021; Reagan et al., 2021). Many people believe that the technology can compensate for when they are distracted, impaired, or drowsy (Mueller et al., 2023, 2024). Some implementations may encourage these misconceptions with increased functionality, such as by performing complex maneuvers like lane changes on their own.

The industry has been grappling with lessons from deploying this unregulated technology rapidly in the market. High-profile crashes have intensified public scrutiny around lax designs that fail to safeguard proper system use (National Transportation Safety Board, 2017, 2019, 2020), and there is now a global appetite for data-driven guidance around such safeguards (e.g., European New Car Assessment Programme [Euro NCAP], n.d.; IIHS, 2024). The available evidence recommends using multiple approaches together (for a review, see Mueller et al., 2021). Some safeguards respond to driver behavior in real time, such as through escalating alerts (i.e., attention reminders), whereas others proactively shape behavior by keeping the driver physically in the loop. Steering is one of the most fundamental control actions that a driver can do in a vehicle, and it is often the basis for intervention when the partial automation does something unexpected. If the lane-centering feature encourages the driver to steer together with it, that driver's interventions should be more immediate because they are already involved in the vehicle's control (Garbacik et al., 2021; Gershon et al., 2023; Schneider et al., 2022). Lane centering that shares control is called cooperative steering, and it was the subject of interest for this study.

To be considered cooperative, at a minimum, the lane-centering function must stay on while the driver steers within the lane. A simple example of this is when the driver wants to overtake a large vehicle on a high-speed roadway, such as those known as highways or freeways in North America. The driver might want to move over to one side of their lane (known as lane line hugging) to give the large vehicle extra room while they drive past it in case it behaves erratically. If they are using a cooperative partially automated system in this scenario, the lane-centering support will remain on while they do this maneuver. This allows the driver to feel what the lane centering is doing from moment to moment through minor adjustments in the steering wheel, which can be too small to identify by sight alone. Steering response time tends to be shorter, with smaller adjustment magnitudes, when hands are already on the wheel (de Winter et al., 2023; Gershon et al., 2023; Schneider et al., 2022; Wang et al., 2019). People are also more likely to drift farther from the centerline during the intervention if they were using the partial automation hands-free beforehand, similar to what is seen with distracted or inattentive drivers (Larsson et al., 2022). Although it has been suggested that cooperative steering can incentivize drivers to stay physically involved in the driving (Marcano et al., 2021), it remains to be seen how well the automaker's design intent corresponds with a driver's willingness to be engaged.

At the time of this study, the Tesla Autopilot and General Motors (GM) Super Cruise systems deactivated their lane-centering support whenever the driver steers, and Super Cruise would only automatically reactivate if certain conditions were met. It has been argued that these noncooperative designs are meant to avoid mode confusion, which is when the driver confuses one operating status for another (de Winter et al., 2023; Wilson et al., 2020). An example of this mode confusion would be if the system makes steering adjustments before the driver is ready because they thought the support was off. It is unclear whether noncooperative designs have that intended effect on consumer understanding, though.

Drivers tend to exhibit greater hand-on-wheel readiness when the driving demands increase (De Waard et al., 2010; Thomas & Walton, 2007; Walton & Thomas, 2005), and so any influence of system cooperability may depend on what is happening on the road (Mars et al., 2014). Drivers who use cooperative systems may exhibit greater driver readiness (i.e., hands on wheel and steering) than those with noncooperative systems in a potentially hazardous situation, but there may be little difference between them when nothing is happening. In fact, there may be little difference between driving with the automation and without it in an uneventful driving situation. An alternate hypothesis is that lane-centering behavior might be too difficult for people to recognize. People may not understand how their systems respond to, for example, a driver's lane-line-hugging maneuver. This in turn may correspond with misaligned expectations between an automaker's design intent and their customer's interpretation of how they should use the technology (de Winter et al., 2023). This study sought to answer these questions through an online survey of vehicle owners who regularly use cooperative or noncooperative systems in their personal vehicles.

Method

Sample

An online survey was completed by 1,260 owners of vehicles equipped with partial driving automation between August 2023 and March 2024. To capture a range of vehicles with systems of interest offered by each automaker, we set quotas so that each owner group was split between people who owned larger and smaller vehicles from their automaker's vehicle lineup. The automakers of interest were Tesla (n = 316), GM (n = 316), Ford (n = 314), and Nissan/Infiniti (n = 314).

The partial automation in the Tesla vehicles is called Autopilot, Super Cruise in GM vehicles, BlueCruise in Ford vehicles, and ProPILOT Assist in Nissan/Infiniti vehicles. The Ford and Nissan systems stay on while the driver steers, which satisfies our criterion of being cooperative. At the time of the study, Tesla and GM lane centering deactivates whenever the driver steers, and the GM system will only reactivate if the driver first re-centers the vehicle and the system can detect the lane lines. We therefore classified the GM and Tesla systems as noncooperative. Unlike the Tesla and Nissan systems, the GM and Ford systems offer hands-free driving capability under certain road conditions.

Each owner group had a survey tailored to their system using their automaker's brand names as well as images and videos taken from vehicles from the same automaker. On average, the survey took 34 minutes to complete. This study was determined to be exempt from review by an institutional review board . Some vehicles are equipped with multiple partially automated systems, and while some of our respondents may have had them, we restricted the survey to Autopilot, Super Cruise, BlueCruise, and ProPILOT Assist. Furthermore, Nissan's ProPILOT Assist 2.0, Tesla's Navigate on Autopilot and Full Self Driving, or Ford's Co-Pilot360 systems were not included in this study.

Screening

Individuals were recruited from the Lucid Marketplace, which is an online community of panels and databases from sources likely to include our target population. Consenting U.S. residents aged 21 years or older who drove an eligible vehicle (see Table 1) at least once a week could participate.

Table 1

Vehicle ownership per automaker, model year, and model

Automaker	Model year(s)	Model	(*n*)
Tesla	2017 to 2023	Model 3	66
	2020 to 2023	Model Y	92
	2016 to 2023	Model X	64
	2015 to 2023	Model S	94
		Total	316
GM	2021 to 2023	Cadillac CT4	36
	2021 to 2023	Cadillac CT5	81
	2018 to 2020	Cadillac CT6	30
	2023	Cadillac XT6	11
	2021 to 2023	Cadillac Escalade	52
	2022 to 2023	Chevrolet Silverado	56
	2023	Chevrolet Suburban	8
	2023	Chevrolet Tahoe	25
	2023	GMC Sierra	12
	2023	GMC Yukon	5
		Total	316
Ford	2021 to 2023	Mustang Mach-E	157
	2022 to 2023	F-150 Lightning	157
		Total	314
Nissan/Infiniti	2019 to 2023	Nissan Altima	30
	2018 to 2023	Nissan Rogue	62
	2019 to 2023	Infiniti QX50	40
	2022 to 2023	Infiniti QX55	25
	2022 to 2023	Nissan Pathfinder	65
	2022 to 2023	Infiniti QX60	92
		Total	314

Potential respondents were further screened to ensure they used a partial automation system of interest. We defined partial driving automation and its subsystems (lane centering and adaptive cruise control, or ACC), and respondents who reported they had it and used it at least sometimes could continue. We then presented a visual search task corresponding with a series of questions that people unfamiliar with these systems would struggle to answer correctly. Automakers typically use the same iconography for their automation's communication across their vehicle lineup, and so images of instrument clusters belonging to a 2021 Tesla Model 3, 2020 Cadillac CT6 (GM), 2021 Ford Mustang Mach-E, and 2019

Nissan Altima were presented to the respective owner groups, as shown in Figure 1. Respondents were asked to select where one would look for information about (1) what their system's speed was set to, (2) whether their system had detected another vehicle in front, and (3) whether their system was helping steer to keep the vehicle centered in the lane. Drivers had to select one element correctly per question to move forward in the survey.

Figure 1

Instrument cluster/display images belonging to the Tesla Model 3 (top left), Ford Mustang Mach-E (top right), Cadillac CT6 (GM, bottom left), and Nissan Altima (bottom right)

Ineligible contacts. Out of the 7,051 people contacted to participate, 1,260 were included in the final sample. Of the 5,560 individuals who were ineligible, 151 refused to participate at the introduction, 3,207 had an ineligible vehicle, 435 did not have or know if they had a system of interest, 23 drove less than once a week or less than a few times a month, 179 drove rarely or never with their system on, 74 were under 21 years of age, and 1,491 failed the visual search screener task. Of the 1,491 who were eligible to complete the survey, 22 were unable to watch the required videos, 95 did not complete the entire survey, and 114 were removed due to quality control concerns.

Survey instrument

Steering wheel use. Respondents then watched a video recorded from the driver's point of view on the test track at the IIHS Vehicle Research Center. It was explained that the video's purpose was to show the range of hands-on-wheel behavior applicable to this survey: hands touching but not moving the steering wheel, followed by subtle corrections to keep the vehicle straight between the lane lines; then a mild sine wave maneuver within the lane and an effortful sine wave maneuver within the lane. Using 5-point Likert response options, questions were asked around preferences for specific aspects of driving support and how much respondents prefer to be involved when it comes to steering the vehicle.

Cooperative system behavior. A second video was presented using the same recording setup as the previous video. It demonstrated a gentle lane-line-hugging maneuver using a sine wave motion to go from one side of the lane to the other and back again on the test track (Figure 2). The video concluded with the vehicle offset to one side of the lane. Respondents were asked how their system responds whenever they steer their vehicle within the lane like this. Earlier research using the same maneuver (IIHS, 2024) has shown that it fully deactivates both Tesla's and GM's centering support—the vehicle must be re-centered before the GM system can reactivate—whereas the Ford and Nissan systems remain active the whole time. Respondents were asked how much they like the way their system responds, what it is like to drive with their system, and whether they feel their system drives better or worse than they do.

Figure 2

Still frames from the lane-line-hugging demonstration video

Using the system hands-free. In an effort to understand whether the design intent around hands-free capability or hands-on-required operation translates into consumer understanding, we asked respondents about the design of their systems in this respect, habitual hands-free use of these systems, and whether system performance is affected by the driver's hands on or off the wheel.

Situation-specific willingness to be involved. We hypothesized that a driver's willingness to be physically involved with the driving, for example with respect to hands on the wheel and steering behavior, may depend on the hazardousness of the driving situation (see Mars et al., 2014). Three videos representing three driving scenarios were presented with their own corresponding set of questions. Henceforth, we will refer to these videos as the baseline, uncomfortable, and hazardous scenarios. Each owner group only saw videos of a vehicle belonging to the same manufacturer of their personal vehicle (2021 Tesla Model 3, 2020 Cadillac CT6 [GM], 2021 Ford Mustang Mach-E, or 2019 Nissan Altima). Every video showed the partial driving automation actively providing support on the same stretches of road on Interstate 64 in Charlottesville, Virginia, on dry sunny days, as shown in Figure 3. Videos contained two camera angles. The upper half of the screen showed the forward roadway, and the bottom half showed the instrument panel/display. The vehicle from which the three videos were captured always traveled in the left lane at the speed limit—hereafter that vehicle will be called the test vehicle.

Figure 3

Still frames recorded from the Tesla Model 3 (top left), Ford Mustang Mach-E (top right), Cadillac CT6 (GM, bottom left), and Nissan Altima (bottom right)

In the baseline scenario, the test vehicle traveled in free-flowing traffic without any other vehicles nearby. In the uncomfortable and hazardous scenarios, the test vehicle drove in the left lane for a few seconds before coming up to another vehicle in the right lane with no other vehicles nearby. Drivers of both vehicles coordinated the maneuvers via hands-free shortwave radio. As shown in Figure 3, the vehicle in the right lane was a black 2016 Ford F-250 crew cab pickup towing a trailer with a white 2023 Kia Telluride on top. In the uncomfortable scenario, the pickup with trailer hugged the inner lane line closest to the test vehicle. The pickup traveled at a slightly slower speed than the test vehicle and it stayed on the lane line, within its lane, while the test vehicle overtook it. Once the test vehicle completed the overtake of the pickup, the video ended. In the hazardous scenario, the pickup truck and trailer combo quickly veered in and out of its lane several times, mimicking fishtailing (a loss of control). Just as in the uncomfortable scenario, when the test vehicle had closed the gap and was ready to overtake the pickup, the pickup stopped fishtailing and hugged the inner lane again on top of the lane line without further departure from its lane while the test vehicle overtook it. The video ended once the test vehicle completed the overtake maneuver. As nothing noteworthy happened in the baseline scenario, those videos were 20 seconds whereas the uncomfortable and hazardous scenario videos were 29 seconds.

Every respondent was first shown an example of the baseline scenario using a 2023 Hyundai Palisade, and then they were presented with (1) their automaker-specific baseline video followed by its question set, (2) their automaker-specific uncomfortable scenario followed by its question set, and (3) their automaker-specific hazardous scenario followed by its question set.

The baseline scenario's question set began with whether people would steer while using their automation and how many hands they would have on the wheel. Respondents were asked how comfortable they would be with their system steering in this situation and whether they thought they or their system would be better able to steer the vehicle in this situation. Lastly, they were asked to imagine driving without their system and what they would do in this situation. The uncomfortable and hazardous scenarios' question sets were identical and began asking respondents what they would do in that situation with respect to passing and steering. They were then asked if they were to let their system pass the other vehicle, what would they do in terms of steering and having hands on the wheel, how comfortable they would be with their system steering in this situation, who would be better able to steer in this situation, and what they would do in the same situation if they were driving without their system.

Demographics. The survey concluded after respondents provided demographic information.

Analysis

Logistic regression was used to investigate whether system cooperability predicts a driver's willingness to be involved in the driving in the baseline, uncomfortable, and hazardous video scenarios. Regression models were constructed independently for each combination of the three scenarios and two outcome measures (steering or hands on wheel), resulting in a total of six models. The independent variable of interest was system cooperability, for which GM and Tesla owners were grouped as noncooperative-system owners, and Ford and Nissan owners were grouped as cooperative-system owners. The outcome measure for the steering analyses was if the respondent reported they would steer to one side of the lane versus not steering at all or staying centered. The outcome variable for the hands-on-wheel analyses was the reported intention to have no hands on the wheel versus one or two hands on the wheel.

All hand-related regressions controlled for how often drivers said they use their system hands-free in general (all the time, most of the time, sometimes, never). All steering-related analyses controlled for what drivers said they would do in that scenario without system support. What drivers would do without system support in the baseline scenario fell either into a combined category of "not steer at all" and "steer to keep centered in the lane" or the category of "steer to one side of the lane". For the uncomfortable and hazardous scenarios, manual-driving responses combined "pass the other vehicle and steer to keep centered in the lane" and "remain behind the other vehicle" into one category and "steer to one side of the lane" was the other category.

Because the outcomes of interest were not always rare, odds ratios (ORs) were transformed into relative likelihoods using the formula developed from Zhang and Yu (1998):

$$Relative\ likelihood = OR/[(1 - P_o) + (P_o \times OR)]$$

P_o represents the probability of respondents in the reference group for a particular outcome. For example, in the steering analyses, P_o represents the probability of respondents who own noncooperative systems that said they would steer to one side of the lane (vs. not steer/stay centered). In the hands analyses, P_o represents the probability of respondents who own noncooperative systems that said they would have no hands on the wheel (vs. one or two). Percentage differences were calculated by subtracting 1 from the relative likelihood values and then multiplying by 100.

Most questions had "I don't know" and "I prefer not to answer" as response options; however, very few people selected either response for any of the survey questions and therefore those responses were omitted from the analyses.

Results

As shown in Table 2, the age distribution and education were similar among groups, but male drivers were overrepresented in the Tesla and Ford groups. Driving frequency was slightly higher among Ford owners than the others, whereas system use was somewhat higher among Ford and Nissan owners. On average, Tesla owners had the longest ownership and Ford owners had the shortest, which corresponds with their time on the market. Most people (but least of all Ford owners) said they would want to buy or lease another vehicle with their system again.

Table 2

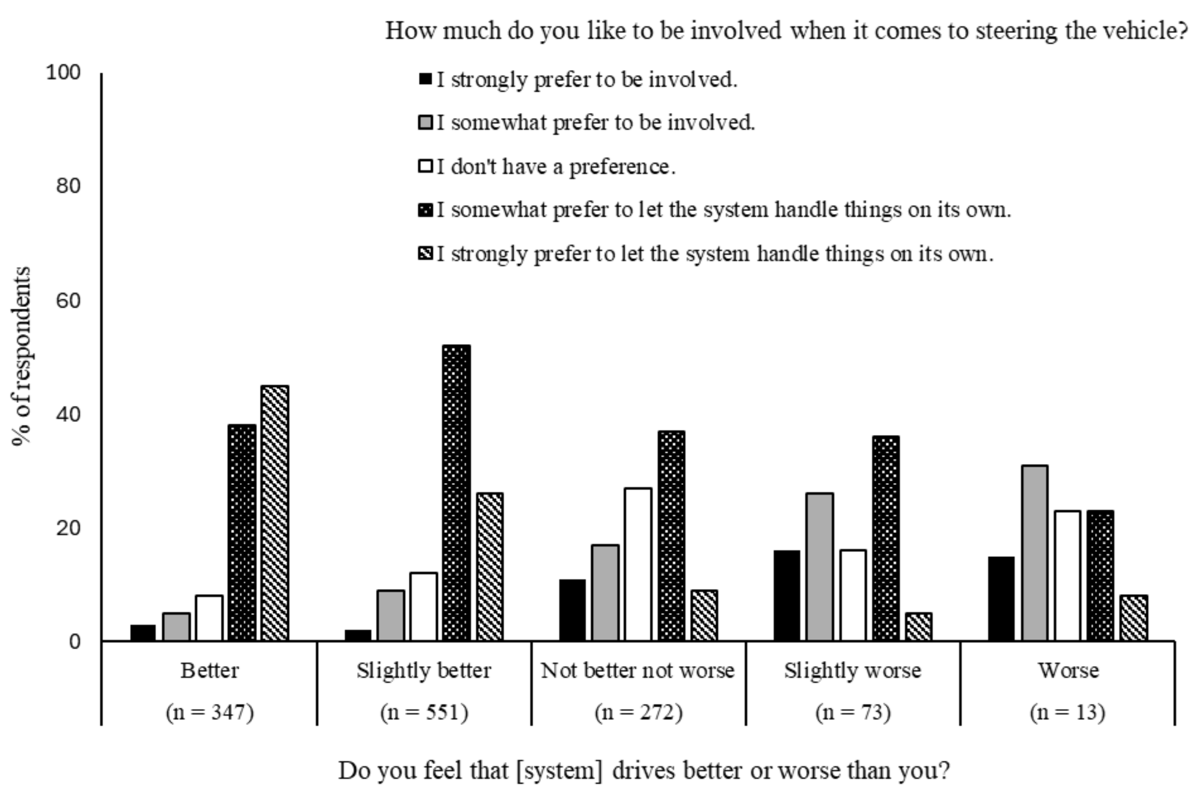
Demographic, vehicle ownership, driving and system exposure information

	Tesla (n = 316)	GM (n = 316)	Ford (n = 314)	Nissan (n = 314)
Age (*years*)				
	M = 39 SD = 8 Min = 22 Max = 87	M = 39 SD = 8 Min = 23 Max = 82	M = 38 SD = 7 Min = 21 Max = 67	M = 38 SD = 8 Min = 21 Max = 67
Gender (*n, %*)				
Males	204 (65%)	184 (58%)	206 (66%)	168 (54%)
Females	112 (35%)	132 (42%)	108 (34%)	146 (47%)
Highest level of education completed (*n, %*)				
High school diploma or less	34 (11%)	37 (12%)	25 (8%)	35 (11%)
Some college education, associate degree, or trade school	87 (28%)	106 (34%)	86 (27%)	92 (29%)
Bachelor's degree	92 (29%)	72 (23%)	90 (29%)	104 (33%)
Some graduate education	35 (11%)	31 (10%)	39 (12%)	21 (7%)
Graduate or professional degree	68 (22%)	70 (22%)	74 (24%)	61 (19%)
How frequently they drive per week (*n*, %)				
Every day	208 (66%)	212 (67%)	236 (75%)	218 (69%)
A few times a week	106 (34%)	99 (31%)	72 (23%)	88 (28%)
Once a week	2 (0.6%)	5 (2%)	6 (2%)	8 (3%)
How frequently they use the system when they drive (*n*, %)				
Every time	94 (30%)	85 (27%)	124 (39%)	128 (41%)
Almost every time	140 (44%)	143 (45%)	130 (41%)	140 (45%)
Sometimes	82 (26%)	88 (28%)	60 (19%)	46 (15%)
How long they have owned their vehicle (months)				
	M = 21 SD = 13 Min = 2 Max = 99	M = 14 SD = 10 Min = 1 Max = 66	M = 13 SD = 6 Min = 1 Max = 35	M = 17 SD = 10 Min = 2 Max = 60
Willing to purchase or lease another vehicle with the system again (*n*, %)	291 (92%)	288 (91%)	266 (85%)	284 (90%)

Most drivers in each group at least somewhat agreed that they liked their system's steering assistance (Tesla: 91%, GM: 85%, Ford: 90%, Nissan: 87%). Only a minority said they at least somewhat prefer to be involved in steering the vehicle (Tesla: 13%, GM: 16%, Ford: 18%, Nissan: 18%), whereas the majority at least somewhat preferred to let their system handle things on its own (Tesla: 76%, GM: 66%, Ford: 68%, Nissan: 68%). As shown in Figure 4, people who thought they were a better driver than their system were more likely to want to be involved in the steering. Those who thought their systems were better were instead more likely to want to let their system handle things.

Figure 4

Distribution of attitudes around wanting to be involved in the driving as a function of impressions of system steering competence



Cooperability perceptions

After watching the lane-line-hugging demonstration, respondents were asked how their system responds when they steer within the lane in the same way. As shown in Figure 5, the majority of each owner group thought their systems stay on while the driver steers, followed by a smaller percentage of those who thought their systems automatically reactivate after the driver stops steering, and only a small minority of owners in each group thought their system fully deactivates. Although a greater percentage of Ford owners correctly identified their system's response, all four groups had similar distributions of responses. Drivers were more likely to say they at least somewhat like how their system responds to them steering in a lane-line-hugging maneuver if they thought the automation's support was continuous during the maneuver or that it automatically reactivated immediately after than if they thought the support fully deactivated whenever they would begin to steer (see Figure 6). Moreover, similar to the lane-line-hugging-response perceptions, most respondents thought their systems drive with them together at the same time, regardless of how those systems are actually designed to respond to driver steering input. Distribution of responses was fairly consistent across the vehicle owner groups, as shown in Figure 7.

Figure 5

Distribution of perceptions around system response to a driver-initiated lane-line-hugging maneuver per vehicle owner group

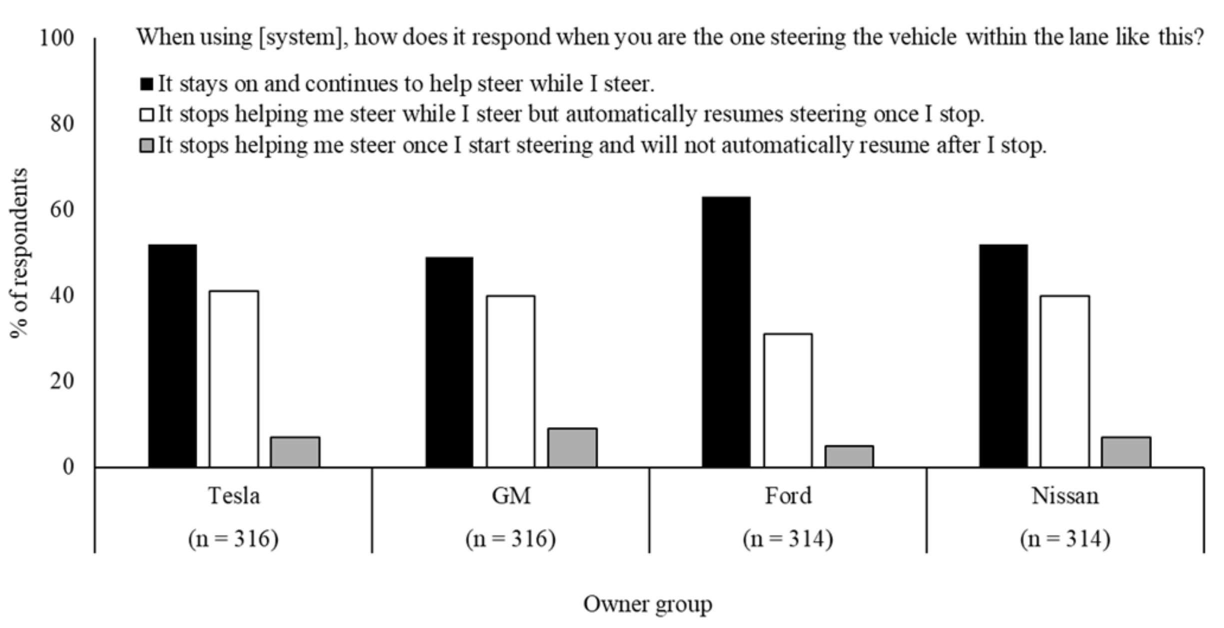


Figure 6

Distribution of attitudes around the likeability of how a system responds to the driver performing a lane-line-hugging maneuver as a function of how people think their system responds to driver-initiated lane-line-hugging

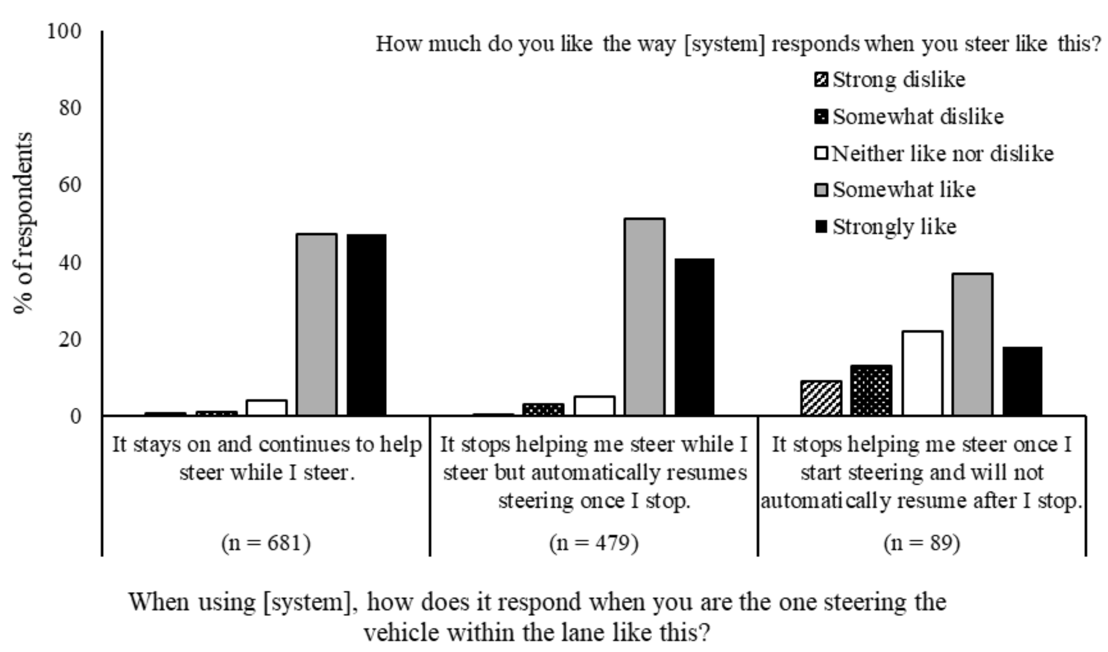
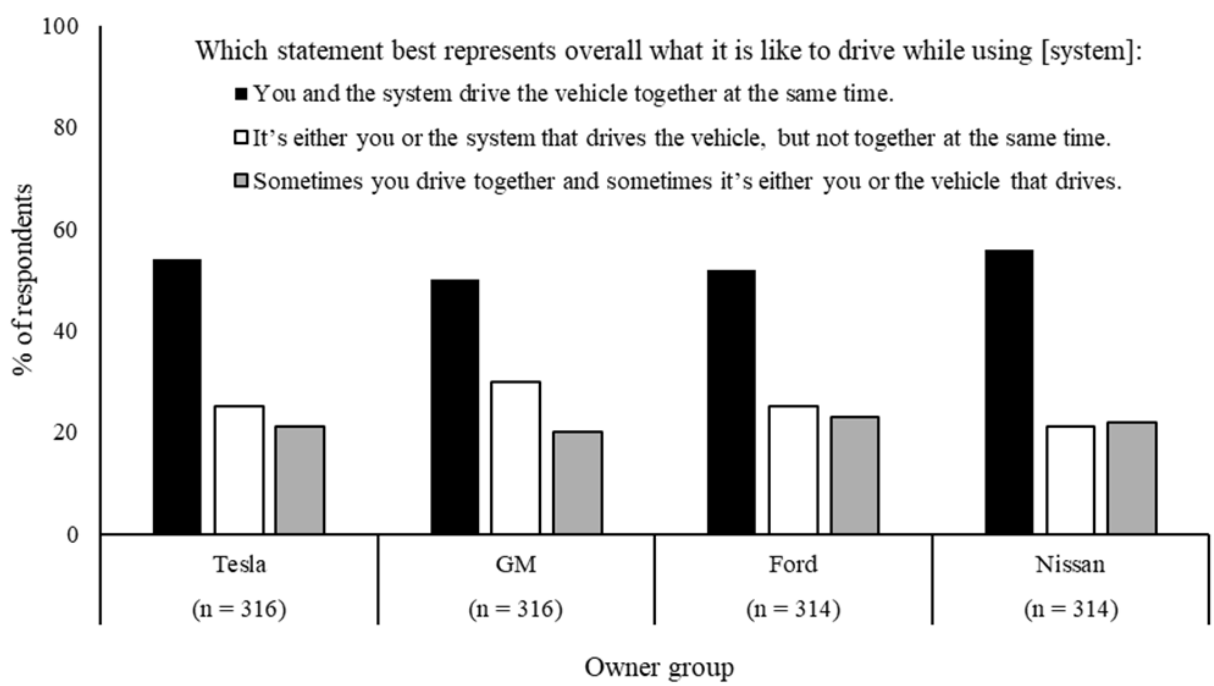


Figure 7

Distribution of respondents with impressions around what it is like to drive with their system as a function of vehicle owner group



Hands-free driving

A greater percent of Tesla (84%), GM (79%), and Ford owners (81%) said their systems let them drive hands-free for up to a few seconds than Nissan owners (65%); however, a smaller percent of people in each group thought their systems allowed them to drive hands-free for longer. Tesla (45%) and Ford owners (47%) were more likely than GM (34%) and Nissan owners (38%) to think that their systems let them drive hands-free for 30 seconds or longer. Unexpectedly, this meant that 59% of GM and 46% of Ford owners thought their systems were not designed for extended hands-free operation.

Many people, nevertheless, reported habitual hands-free use of their systems, as shown in Table 3. Despite both systems sharing similar geofencing restrictions for hands-free use, twice as many Ford owners than GM owners said they use their system hands-free all the time. About a quarter of the sample said they never use their system hands-free. Nissan owners were the most likely to say that their system can steer better with hands on the wheel, followed by GM and Ford owners, and least of all Tesla owners. Attitudes around hands-off system competency showed the opposite pattern, and about a quarter of drivers in each group said there was no difference between hands on and hands off the wheel.

Collapsing across automakers (not in table), the majority of those who said they drive hands-free most or all of the time were split between thinking that their systems drive better when their hands are on the wheel (44%) or off (40%) and a much smaller percentage thought there was no difference (16%). Those who said they sometimes drive hands-free were split about system performance being better hands on (30%), off (38%), or no difference (31%). A greater percentage of drivers who said they never drive hands-free said performance is better hands on (67%) than off (6%) or no difference (25%).

Table 3

Hands-free system use and impressions around its competency as a function of vehicle owner group

	Tesla (n = 316) %	GM (n = 316) %	Ford (n = 314) %	Nissan (n = 314) %
How often do you drive with both hands off the wheel when using [system]?				
All the time	7	8	18	4
Most of the time	23	22	15	29
Sometimes	51	44	44	33
Never	19	25	22	33
When is [system] better able to control the steering of the vehicle?				
When my hands are on the wheel	35	43	43	48
When my hands are off the wheel	39	34	30	25
No difference between when my hands are on and off the wheel	26	22	26	25

Note. Percent may not come to 100% because of rounding and "I don't know" and "refused to answer" responses are not included.

Situation-specific willingness to intervene

Steering. Table 4 shows the distribution of responses for the baseline, uncomfortable, and hazardous scenarios to questions about passing and steering. Respondents were asked after the uncomfortable and hazardous scenarios if they would pass the other vehicle while the system was in use. Most said that they would, and only a small minority said that they would press the brake pedal and remain behind the other vehicle. Note that with all four systems, pressing the accelerator allows the driver to temporarily override system support and it will automatically reactivate once the driver releases the pedal. Pressing the brake pedal fully deactivates the support from all four systems, which means the driver must manually reactivate each system to regain the driving support afterwards.

Drivers more often said they would steer to one side when imagining they were driving without the system than when the system was in use. The percentage of drivers who said they would steer to one side when the system was in use generally increased from the baseline to uncomfortable and hazardous scenarios (baseline: 11%–22% per owner group; uncomfortable: 27%–39% per owner group; hazardous: 33%–44% per owner group).

Table 4

Willingness to steer while partial automation is on and off in the baseline, uncomfortable, and hazardous scenarios as a function of vehicle owner group

	Tesla (*n* = 316) %			GM (*n* = 316) %			Ford (*n* = 314) %			Nissan (*n* = 314) %		
	B	U	H	B	U	H	B	U	H	B	U	H
Driving with the partial automation switched on												
Remembering that [system] is in use, what would you do in this situation?												
Response options for uncomfortable and hazardous scenarios only												
Press the brake pedal and remain behind the other vehicle	N/A	4	7	N/A	5	6	N/A	5	9	N/A	8	13
Let [system] pass the other vehicle and not press either the brake or accelerator pedal	N/A	62	62	N/A	59	56	N/A	64	59	N/A	51	46
Press the accelerator pedal and pass the other vehicle	N/A	34	30	N/A	36	38	N/A	31	33	N/A	41	41
Response options for baseline scenario and for uncomfortable and hazardous scenarios when asked what they would do if they let their system pass the other vehicle												
Not steer at all	19	20	17	23	21	19	18	20	18	21	16	12
Steer to keep centered in the lane	70	53	50	60	45	47	59	41	38	56	46	46
Steer to one side of the lane	11	27	33	16	33	33	22	39	44	22	37	41

Driving with the partial automation switched off												
Now imagine you were driving without [system]. What would you do in this situation?												
Remain behind the other vehicle	N/A	8	12	N/A	8	11	N/A	8	11	N/A	9	19
Pass the other vehicle and steer to keep centered in the lane	N/A	46	41	N/A	41	43	N/A	51	44	N/A	34	26
Pass the other vehicle and steer to keep to one side of the lane	N/A	46	48	N/A	50	45	N/A	40	43	N/A	56	54
Not steer at all	4	N/A	N/A	9	N/A	N/A	3	N/A	N/A	4	N/A	N/A
Steer to keep centered in the lane	80	N/A	N/A	71	N/A	N/A	68	N/A	N/A	67	N/A	N/A
Steer to one side of the lane	16	N/A	N/A	19	N/A	N/A	27	N/A	N/A	29	N/A	N/A

Note. B = baseline scenario; U = uncomfortable scenario; H = hazardous scenario; N/A = not applicable.

After controlling for what people said they would do without system assistance per scenario, logistic regression models revealed that drivers with cooperative systems were 36% (95% CI = 3%, 77%, $p = .03$) more likely than drivers with noncooperative ones to want to steer to one side in the baseline scenario, 26% (95% CI = 8%, 45%, $p = .004$) more likely in the uncomfortable scenario, and 29% (95% CI = 12%, 46%, $p < .001$) more likely in the hazardous scenario.

Hands. As seen in Table 5, most drivers said they would have two hands on the wheel in all scenarios, and the percentage with two hands on the wheel increased from the baseline to the uncomfortable and hazardous scenarios. After controlling for habitual hands-free system use (see Table 3), logistic regressions showed that drivers with cooperative systems were 40% (95% confidence interval

[CI] = −61%, −9%, p = .02) less likely than those with noncooperative systems to say that they would drive without any hands on the wheel in the uncomfortable scenario, and they were 48% (95% CI = −67%, −22%, p = .002) less likely to do so in the hazardous one. The difference was negligible and not statistically significant in the baseline scenario, as owners of cooperative systems were only 3% (95% CI = −34%, 41%, p = 0.87) less likely than owners of noncooperative systems to say they would drive hands-free.

Table 5

Willingness to have hands on wheel while partial automation is on in the baseline, uncomfortable, and hazardous scenarios as a function of vehicle owner group

	Tesla (n = 316) %			GM (n = 316) %			Ford (n = 314) %			Nissan (n = 314) %		
	B	U	H	B	U	H	B	U	H	B	U	H
How many hands would you have on the wheel in this situation?												
No hands	7	8	9	9	10	11	11	7	7	4	4	3
One hand	28	13	16	26	18	15	28	21	20	26	15	17
Two hands	65	79	75	65	72	74	61	71	73	70	82	80

Note. B = baseline scenario; U = uncomfortable scenario; H = hazardous scenario.

Comfort and confidence. Although reported comfort with the system doing the driving was high in all three scenarios, it declined somewhat from baseline to hazardous. As shown in Table 6, between 24% and 45% of owners believed they were better able to handle steering the vehicle than the system, depending on the owner group and scenarios. The percentage of owners who thought they were better able to steer increased from the baseline to uncomfortable to hazardous scenarios, although the differences among the scenarios for the Tesla owners were small.

Table 6

Attitudes around comfort with the system doing the steering and system versus driver competency in the baseline, uncomfortable, and hazardous scenarios as a function of vehicle owner group

	Tesla (*n* = 316) %			GM (*n* = 316) %			Ford (*n* = 314) %			Nissan (*n* = 314) %		
	B	U	H	B	U	H	B	U	H	B	U	H
How comfortable would you be with [system] steering in this situation?												
Extremely uncomfortable	0	0	2	1	2	3	0.6	0	4	0.6	1	4
Somewhat uncomfortable	0.3	2	4	3	5	6	3	6	7	3	5	6
Neither comfortable nor uncomfortable	2	3	5	5	5	6	6	6	7	8	11	11
Somewhat comfortable	50	50	46	54	58	55	47	50	46	53	57	51
Extremely comfortable	47	45	43	36	30	30	43	38	37	36	26	28
Who would be better able to steer the vehicle in this situation?												
Me as the driver	30	32	33	31	36	39	34	40	45	24	34	41
[System]	42	39	40	39	34	33	30	31	29	44	39	33
No difference between me and [system]	28	30	27	29	29	26	35	28	25	32	26	25

Note. B = baseline scenario; U = uncomfortable scenario; H = hazardous scenario.

Discussion

This study has shown that the expectations vehicle owners have about their partially automated systems do not always match what the manufacturers intended. Although experience with the technology can improve attention to the road while using it, mode awareness, and mental model accuracy (Forster et al., 2020; Mueller et al., 2020, 2022), we did not see evidence that it enhances recognition of cooperative design intentions. As the majority of our sample thought their lane centering was cooperative, cooperative steering may be an intuitive design philosophy for most drivers.

The fact that experienced system users have difficulty recognizing their systems' limitations (Mueller et al., 2024) may help to explain why expectations for cooperative steering dominated in this study. Even when used within the automaker's intended operational design domain, sometimes the driver has to correct system behavior. People might expect the lane centering to stay on whenever they steer because that is what many other driver assistance features do, such as automatic emergency braking (AEB) and lane departure prevention.

Regardless of expectations, system cooperability design appears to correspond with a driver's willingness to be involved while using it in specific driving situations. Drivers with noncooperative systems were more disinclined to have hands on the wheel than owners of cooperative systems in the uncomfortable and hazardous situations that called for driver readiness and to steer in all scenarios. This supports the idea that cooperation between driver and system can reinforce a driver's sense of responsibility for safe driving (Wen et al., 2019), proactive intervention (Marcano et al., 2021), and greater engagement in driving overall (Mueller et al., 2021). However, the cooperative influence seems to largely be implicit, given the difficulty our sample had with explicitly recognizing their system's design.

Proactive cooperative steering

A subset of our sample was unwilling to steer or have hands on the wheel in any scenario we presented. Those people may benefit from designs that explicitly require continuous driver participation. This is different from most systems available right now that simply tolerate the driver steering, but otherwise just require hands on wheel or intermittent wheel turning to satisfy their driver-in-loop requirements. The benefits of truly proactive cooperative lane centering might be obvious for people who expect it, and it might reset expectations for others to better align with the automaker's intent. However, it is not clear what characteristics best and universally elicit recognition of cooperative steering. One of the more significant barriers to its success is the fact that most systems are meant to be used on straight roads. It remains to be seen how drivers can be encouraged to continuously share the steering control when there are limited opportunities to do more than minor wheel adjustments for extended periods. Whatever the solution, it must be designed to anticipate mode confusion, because some drivers will resist and misunderstand designs that differ from their expectations (Lenneman et al., 2020).

With respect to acceptability, we saw that drivers were more likely to prefer how their system responds to the driver steering if they thought it was cooperative. People were also more likely to want to be involved in the driving if they thought they were better drivers than their systems. These findings contribute to the ongoing debate about whether system competency promotes or undermines driving engagement. One side posits that when systems perform reliably and competently most of the time, the driver can be lulled into thinking it is more autonomously capable than it really is and become complacent when intervention is required (Lin et al., 2018; Schneider et al., 2022; Victor et al., 2018). The other side argues that performance reliability heightens the chances of appropriate system interventions and makes the vehicle's behavior as predictable as possible to consumers (Consumer Reports, Inc., 2023; Euro NCAP, 2024). While these two positions seem at odds, it may be possible to satisfy both with shared control (de Winter et al., 2023).

If the driver is required to regularly participate to have continued access to the system, this could help to reinforce the notion that the technology is not self-driving. Likewise, physical driver participation should improve system performance to make it more consistent with normal human behavior in situations where it might struggle to perform optimally, thereby making the technology more intuitive and predictable (Banks et al., 2018; Larsson et al., 2014). Even though AEB and lane departure prevention act on the same types of highway crash scenarios as partial driving automation (Cicchino, 2024), if the driver is already in the loop, then their ongoing interaction with the automation may help to smoothen the crash avoidance intervention and reduce any uncomfortable or unexpected vehicle behavior.

Our findings also suggest that system cooperability is not the only design aspect that gets lost in translation for consumer understanding. Consistent with our earlier research (Mueller et al., 2024), many Tesla and Nissan owners thought their hands-on-required systems could be used hands-free for extended periods. We did not expect to see so many GM and Ford owners who thought the opposite about their systems, in part because there is a lot of advertising around the hands-free capability of Super Cruise and BlueCruise. It is possible that each system's driver-monitoring strategies and attention-reminder instructions are poorly understood, which might explain the confusion about what systems require or permit drivers to do with their hands. Despite these differences, a large percentage of all owner groups reported hands-free use of their systems at least some of the time.

Limitations

When it comes to understanding the influence of lane-centering characteristics, one element we were unable to address was steering torque resistance. Some systems that remain on are presently designed to generate so much torque resistance that people complain about the system actively resisting or "fighting" them, which is obviously noncooperative. Earlier research has shown that driver acceptance tends to be higher when the automation makes smooth gentle steering corrections (Kidd & Reagan, 2019; Reagan et al., 2020), but it is unknown how torque resistance corresponds with impressions of cooperation or willingness to be involved in the driving. Some automakers have approached this issue by implementing a ramping-down strategy for the torque resistance. When the driver first turns the wheel, the system responds with a high degree of torque resistance, which rapidly diminishes as the driver continues to turn the wheel. What this accomplishes is a smoother transition of priority between system-to-driver input and is especially helpful when going from hands-free to hands-on. However, it is not clear how to optimize torque response to promote impressions of cooperative design.

A key aspect of our analysis that is worth emphasizing here concerns the influences on behavior from system design and the characteristics of owners who choose to buy specific systems. Although this is a limitation common to research that targets unique owner populations (Mueller et al., 2024), we were able to control for habitual tendencies around system use (i.e., hands-free driving) and situation-specific intention without system support (i.e., willingness to steer) in our analysis to understand driver readiness intention in each scenario presented. It is encouraging that we were able to see differences in our respondents' intentions to steer and have hands off the wheel based on system ownership in these scenarios while accounting for these typical and scenario-specific facets of perceptions and behavior. Nevertheless, more attention in future studies must be paid to their influence on driver behavior to better understand population differences and why some people gravitate towards certain system designs over others.

Our sample was restricted to drivers who regularly use partial automation because we anticipated a lack of familiarity would undermine one's understanding of how these systems operate beyond lane-centering design. It remains to be seen whether there are differences in cooperability perceptions based on degree of experience with the technology or even with a particular system. Although beyond the scope of this study, the individual differences that attract consumers to specific vehicles likely contributed to the patterns we observed and are worth investigating to understand why some people do not want to participate in the driving. Lastly, while there are many differences between systems on the market, many of them share features that are relevant to the results of this study. More research is necessary to understand how well these findings generalize to other automakers and their respective owner populations.

Conclusions

Most drivers thought their lane-centering support was cooperative, which supports the potential for shared control to facilitate proper system use as it is a more intuitive design. Moreover, a driver's willingness to be involved in the driving depends not only on the driving situation but also on the cooperability of the system. Owners of cooperative lane-centering systems were more willing than owners of noncooperative systems to be involved in scenarios that called for readiness to intervene. Complicating the matter, though, is that many people did not recognize the hands-on-requirements versus hands-free capability of their systems. Our findings suggest that lane-centering functionality should be cooperative as part of a multifaceted approach to partial automation design that safeguards driving engagement.

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