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Habits, attitudes, and expectations of regular users of partial driving automation systems

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ABSTRACT

Introduction: Little is known about regular users' perceptions of partial (Level 2) automation or how those perceptions affect behind-the-wheel behavior. *Method:* A mixed mode (phone and online) survey explored the habits, expectations, and attitudes among regular users of General Motors Super Cruise (n = 200), Nissan/Infiniti ProPILOT Assist (n = 202), and Tesla Autopilot (n = 202). *Results:* All three groups reported being more likely to engage in non-driving-related activities while using their systems than while driving unassisted. Super Cruise and Autopilot users especially were more likely to report engaging in activities that involved taking their hands off the wheel or their eyes off the road. Many Super Cruise and Autopilot users also said they could perform secondary (non-driving-related) tasks better and more often while using their systems, while fewer ProPILOT Assist users shared this opinion. Super Cruise users were most likely and ProPILOT Assist users least likely to think that secondary activities were safer to perform while using their systems. While some drivers said they found user safeguards (e.g., attention reminders, lockouts) annoying and tried to circumvent them, most people said they found them helpful and felt safer with them. Large percentages of users (53% Super Cruise, 42% Autopilot and 12% ProPILOT Assist) indicated they were comfortable treating their systems as self-driving. *Conclusions:* Some regular users have a poor understanding of their technology's limits. System design appears to contribute to user perceptions and behavior. However, owner populations also differ, which means habits, attitudes, and expectations may not generalize. Most people value user safeguards, but some implementations may not be effective for everyone. *Practical Applications:* Multifaceted, proactive user-centric safeguards are needed to shape proper behavior and understanding about drivers' roles and responsibilities while using partial driving automation.

1. Introduction

Partial driving automation, also known as Level 2 systems (SAE International, 2021), is a combination of driver assistance features that provide simultaneous longitudinal (speed and headway) and lateral (steering) support for extended periods. A common misconception is that government regulators have vetted the partial automation in vehicles on the market today, but that is not the case (Lin, Ma, & Zhang, 2018). Many of these systems are advertised as convenience features, and data are mixed about whether these systems have safety benefits (Goodall, 2021; HLDI, 2017, 2019, 2021, 2022; Leslie, Kiefer, Flannagan, Schoettle, & Owen, 2022).

None of these systems are capable of replacing the driver at any point. Often, they will behave in ways that require drivers to rapidly intervene (e.g., allow the vehicle to drift out of the lane, fail to detect an object ahead, or suddenly stop providing driving support; AAA, 2020; IIHS, 2018; Kim, Song, & Doerzaph, 2021). Due to the often functionally rigid nature of the system's support, drivers cannot safely engage in secondary (non-driving-related) activities while using the technology. However, research has shown that as drivers become familiar and experienced with the partial automation, they often use the technology to help them engage in such activities (Dunn, Dingus, Soccolich, & Horrey, 2021; Noble, Miles, Perez, Guo, & Flauer, 2021; Reagan et al., 2021).

Driver distraction is not unique to drivers who use partial automation; non-driving-related activities are prevalent without automation support (Nordhoff, Stapel, He, Gentner, & Happee, 2021). What is not well understood is how automation influences drivers' perceptions of non-driving-related activities and the likelihood that they will engage in them. The mental models that users have about their systems will

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influence how they use the technology and their willingness to engage in non-driving-related activities (see Lin et al., 2018). While the perceived safety benefits of a technology are not necessarily reflective of any actual crash reduction benefits, those expectations are strong indicators of user trust and acceptance (Nordhoff et al., 2021). However, trust and acceptance of a technology do not guarantee safe habits around its use. If drivers trust the automation too much, they may not intervene rapidly enough when the system inevitably encounters conditions it cannot handle, leading to uncomfortable or even dangerous situations (Lin et al., 2018; Schneider, Ahrens, & Pruksch, 2022; Victor et al., 2018).

Automakers use different design philosophies to shape the interactions and relationships that people have with their vehicles. For example, some automakers, such as General Motors (GM) and Ford, offer partial automation that is intentionally designed to allow drivers to take their hands off the wheel under certain conditions. It is unclear how this design influences user perceptions and behavior or how it compares with systems that require drivers to keep their hands on the wheel.

All production vehicles equipped with partial automation have mechanisms to help manage driver behavior and encourage proper system use. Some of these mechanisms activate when drivers do things they are not supposed to and therefore rely on the vehicle to monitor specific driver behaviors, such as steering torque, eye gaze, or head position. Studies have explored the perceptions owners have about the physical monitoring methods in their vehicles (e.g., steering wheel sensors and cameras; Consumer Reports, 2022) and the efficacy of such equipment for detecting certain behaviors (e.g., hands off the wheel and looking away from the road; AAA, 2022). However, driver monitoring is only as effective as the safeguard mechanisms it supports, and it is unclear how those mechanisms shape the expectations, attitudes, and habits of the people who use the automation.

Attention reminders are a safeguard mechanism that activates with the purpose of rapidly bringing drivers back in the loop when specific signs of inattention or distraction are detected (for a review of safeguard designs, see Mueller, Reagan, & Cicchino, 2021). The attention reminder process typically begins with alerts and, in some cases, will escalate to other vehicle kinematic responses (e.g., pulse braking or disengagement of ACC from its set speed and gradually bringing the vehicle to a stop). The timing, escalation sequence, and modes of communication vary among systems. Some automakers use other countermeasures when drivers do not respond to the attention reminders. These include system lockouts that prevent the driver from accessing the partial automation for a certain period of time. It remains uncertain how regular users experience and interpret these safeguards and how those perceptions affect the way they use automation systems.

Study objectives. Designs vary among automakers and vehicle models. There is also a wide range of factors that differentiate the customers of each automaker and vehicle model, such as age, gender, socioeconomic status, brand loyalty, technology savviness, personality, and risk perception. With this variability in mind, the goal of this study was to survey the perceptions and behavior of each customer group to understand how they use specific implementations of partial driving automation. Vehicle owners of interest were regular users of one of three systems: GM Super Cruise, Nissan/Infiniti ProPILOT Assist, and Tesla Autopilot. These systems were selected because they reflect the diversity of systems in vehicle market at the time of study.

These three manufacturers use sensors in the steering wheel to detect if hands are on the wheel (Cadillac, n.d.; Nissan, 2022; Tesla, n.d). In addition, Tesla (as of 2021 on certain models) and GM utilize camera-based monitoring to determine where the driver is looking. ProPILOT Assist (only version 1.0, which was what was available at the time of this study) and Autopilot require drivers to keep their hands on the wheel at all times, whereas Super Cruise permits drivers to have their hands off the wheel under certain conditions. These three systems differ in their attention reminder alert modalities, escalation sequences, countermeasures, and lane-centering designs in terms of how drivers interact with the steering control.

We explored attitudes and expectations that underlie tendencies to engage in certain non-driving-related activities to determine how the practical limitations of the system's support are understood and whether the system's support facilitates certain behaviors. We investigated experiences with and perceptions of attention reminder escalations and system lockouts to understand how the safeguard mechanisms are interpreted and what their impacts are on driver behavior and perceptions around system limits and driver responsibility. Lastly, we examined experiences with situations that require sudden driver intervention and how they are perceived as a way of pragmatically contextualizing driver understanding about how and where these systems should be used.

2. Method

2.1. Procedure

The survey was conducted in the United States using mixed-mode sampling by phone and online between January and November 2021. Average call duration was 14 min ($SD = 5$), and average time to complete online was 12 min ($SD = 7$). This study was determined to be exempt from review by an institutional review board (IRB).

2.2. Sample

The target population for this study consisted of owners of GM (specifically, Cadillac), Nissan/Infiniti, and Tesla vehicle models that are optionally equipped with partial driving automation (GM Super Cruise, Nissan/Infiniti ProPILOT Assist 1.0, and Tesla Autopilot). To be eligible to participate, individuals had to be at least 18 years of age, the primary drivers of the qualified vehicles in their households, drive at least a few times a month, have the partial driving automation system of interest equipped in their vehicles, and regularly use the technology. There were no state or geographical residence eligibility restrictions and all respondents resided in the United States at the time of study (see Table 2). The portion of the sample that was contacted by telephone came from Data Axle, which had access to publicly available driver and vehicle records. The remainder of the sample was contacted online, and those respondents came from Lucid Marketplace, an online community of panels and database sources that include likely owners of vehicles of interest.

A total of 8,464 individuals were contacted to participate ($n = 1{,}972$ by telephone and $n = 6{,}492$ online). Of that number, 2,068 refused to participate at the introduction or prior to eligibility determination, 5,754 were ineligible, and the responses of 38 did not pass quality control criteria. Specifically, of the individuals who were ineligible as a result of their self-reported responses to the screening questions, 122 were under 18 years of age, 4,878 did not own or refused to confirm ownership of a qualified vehicle, 55 were not the primary user of the qualified vehicle, 5 drove less than a few times per month, 416 did not have the partial driving automation in their vehicles, 256 reported "never" or "almost never" using the partial driving automation in their vehicles, and 22 were ineligible because the experimental group quotas had been filled. The final sample consisted of 200 GM ($n = 180$ participated by phone and $n = 20$ online), 202 Nissan/Infiniti ($n = 102$ by phone and $n = 100$ online), and 202 Tesla owners ($n = 67$ by phone and $n = 135$ by online, Table 1).

2.3. Survey instrument

System ownership. Self-reported vehicle ownership was first matched against an eligibility list of vehicles that had the systems of interest optionally equipped. Respondents who confirmed they owned an eligible vehicle were first provided a description of the partial driving automation's sustained longitudinal and lateral control functionality and asked whether they had such a system on their vehicle. If they said

Table 1
Respondent vehicle ownership by model year and model per manufacturer.

Manufacturer	Model year	Model	%
GM			(n = 200)
	2018 to 2020	Cadillac CT6	61
	2021	Cadillac Escalade	21
	2021	Cadillac CT4-V	5
	2021	Cadillac CT5-V	14
Nissan/Infiniti			(n = 202)
	2018 to 2021	Nissan Leaf	7
	2018 to 2021	Nissan Rogue	60
	2019 to 2021	Nissan Altima	22
	2019 to 2020	Infiniti QX50	11
Tesla			(n = 202)
	2015 to 2021	Model S	22
	2016 to 2021	Model X	51
	2017 to 2021	Model 3	24
	2020 to 2021	Model Y	3

Note. Percentages may not sum to 100 due to rounding.

Table 2
Sample demographics, vehicle ownership duration, driving exposure, and partial driving automation exposure.

	Super Cruise % (n = 200)	ProPILOT Assist % (n = 202)	Autopilot % (n = 202)
Gender			
Male	68	52	71
Female	32	48	29
Refused to answer	< 1	0	0
Age			
18 to 34	4	13	25
35 to 54	30	32	43
55 to 69	43	25	21
70 and older	18	26	10
Refused to answer	7	4	1
Region of residence [a]			
Northeast	5	16	12
Midwest	17	17	17
South	73	57	42
West	6	9	30
How long have you owned your vehicle?			
0 to 6 months	15	9	8
7 to 12 months	18	15	4
13 to 24 months	20	46	28
More than 25 months	48	30	59
How frequently do you drive your vehicle?			
Every day	40	52	61
A few days per week	53	36	32
Once a week	7	9	5
Less than once a week, but a few times a month	2	2	2
How often do you use [the system] when you drive?			
Sometimes when I drive	53	52	57
Almost every time I drive	43	29	37
Every time I drive	5	19	6

Note. Percentages may not sum to 100 due to rounding.
[a] Region of residence categories are comparable to those used by the National Center for Statistics and Analysis. (2022, August). Northeast: ME, VT, NH, MA, RI, CT, NY, PA, and NJ. Midwest: MI, OH, IN, IL, WI, MN, IA, MO, KS, NE, SD, and ND. South: WV, MD, DE, VA, KY, TN, NC, SC, GA, FL, AL, MS, AR, LA, OK, TX, and DC. West: AK, WA, OR, CA, NV, ID, UT, AZ, NM, CO, WY, MT, and HI.

yes, respondents were then asked about brand-specific details to confirm their vehicle was indeed equipped. Super Cruise owners were asked about the presence of the light bar in the steering wheel, and all three owner groups were asked about icons in the instrument panel that correspond with the partial automation's operational status, including the unique icon appearance and color coding associated with the systems' different states.

Non-driving-related activities. Respondents were then given a list of non-driving-related activities and, using five-point Likert scales, asked how often they typically perform any of those activities while driving with the system on and with the system off. Similar activity lists have been used in other studies, such as Nordhoff et al. (2021) and Teoh (2020). Respondents were also asked to indicate which things on the list they believed were safe to do with the system switched on, which they believed were safe to do with the system switched off, which they believed they could do better with the system switched on, and which they did more often with the system switched on.

Attention reminders. Respondents were asked if they had ever experienced attention reminder events, whether the attention reminders had happened while they were engaged in any of the secondary tasks described earlier in the survey, and whether the attention reminders affected how often they did those things. Afterwards, they were asked if they had done anything to make the attention reminders cease so that they could continue performing the secondary tasks (and, if so, what). A 5-point Likert scale measured how annoying they felt the attention reminders were. Using the same 5-point Likert scale, the whole sample was then asked how helpful the alerts were for getting drivers to pay attention and how safe they felt knowing that the system in their vehicle was designed to alert drivers who appeared to be inattentive.

System lockout. Only Super Cruise and Autopilot have a lockout countermeasure that goes into effect when a driver does not comply with attention reminders. The lockout feature makes the partial driving automation system unavailable for either a lengthy period or until the vehicle is powered off and restarted. Super Cruise and Autopilot users were asked if their system had ever shut off and not let them switch it back on while they were driving and, if it had, why it happened. Using a 5-point Likert scale, they were asked how annoying the lockout feature is. The system lockout feature was then explained to the whole sample and all respondents were asked, using the same 5-point Likert scale, how helpful they thought the countermeasure was in getting drivers to pay attention to driving and how safe they felt or would feel knowing that the system is designed to help prevent people from using it when they are not paying attention.

Unexpected vehicle behavior. Respondents were asked if their system had ever behaved in a way that was unexpected and required them to suddenly intervene by braking, steering, and/or accelerating. If so, they were asked whether they remember having had at least one hand on the wheel the last time it happened or whether they were engaged in any of the non-driving-related activities previously discussed.

Where to use the system. To gauge the propensity to misuse these systems as self-driving vehicles, respondents were asked if they ever felt comfortable letting the vehicle drive itself without their supervision and, if so, under what type of road conditions.

2.4. Analysis

Response data for non-driving-related activity habits and safety attitudes toward those activities were analyzed by pattern only to determine whether responses differed depending on whether Level 2 systems were switched on or off. Nevertheless, we report standard statistical tests in Tables 3–6 to help readers put the results into context of random variation. Tables 3 and 6 include the results of McNemar's tests and comparisons among system group pairs for those survey items were conducted using the R script developed by Zhao, Rahardja, Wang, and Shen (2014). Tables 4 and 5 contain the pairwise comparison results from Fisher's exact tests around the habits and attitudes toward non-driving-related activities as a function of system group. Statistical significance was determined using a critical p value of 0.05. Likert scale data were sometimes collapsed into general categories to facilitate interpretation. Refusal to answer or "I don't know" responses were

Table 3
Percent of drivers who reported engaging in certain behaviors or tasks at least sometimes while driving with the system switched on or off.

	GM Cadillac Super Cruise (n = 200)			Nissan/Infiniti ProPILOT Assist (n = 202)			Tesla Autopilot (n = 202)		
	On	Off	Relative percentage	On	Off	Relative percentage	On	Off	Relative percentage
Eating	65	30	2.2 * [a, c]	43	34	1.3 * [a]	46	31	1.5 * [c]
Drinking	86	80	1.1 *	66	57	1.1 *	64	52	1.2 *
Texting on a cellphone	49	14	3.7 * [a]	19	10	1.8 * [a, b]	44	18	2.5 * [b]
Using apps on a cellphone	21	5	4.0 * [a, c]	16	9	1.7 * [a, b]	39	13	3.1 * [b, c]
Watching videos on a cellphone or other device	5	4	1.4 [c]	9	4	1.9 * [b]	20	8	2.6 * [b, c]
Using a laptop or tablet computer	5	3	1.8 * [c]	8	4	1.6 * [b]	19	9	2.0 * [b, c]
Talking on a cellphone	48	14	3.7 * [a]	31	23	1.3 * [a, b]	55	29	1.9 * [b]
Having phone calls through the vehicle's Bluetooth	93	86	1.1 *	74	67	1.1 *	86	76	1.1 *
Talking to passengers	95	92	1.0	88	82	1.1 *	86	78	1.1 *
Sleeping	3	2	1.2	3	2	1.2	10	6	1.8
Brushing hair, putting on makeup, or other types of grooming	38	9	4.5 * [a,c]	11	6	1.9 * [a]	20	9	2.1 * [c]
Reading a book, magazine, or newspaper	3	3	1.0 [c]	6	4	1.4 [b]	18	5	3.5 * [b, c]
Keeping both hands off the wheel for shorter periods (a few seconds)	51	5	11.1 * [a,c]	19	9	1.9 * [a, b]	55	20	2.9 * [b, c]
Keeping both hands off the wheel for longer periods (more than a few seconds)	44	5	8.7 * [a,c]	15	8	1.7 * [a, b]	40	14	2.9 * [b, c]
Looking at scenery	61	22	2.8 * [a,c]	49	36	1.3 * [a, b]	63	37	1.7 * [b, c]
Looking away from the road for more than a few seconds	54	12	4.7 * [a,c]	22	10	2.1 * [a, b]	44	19	2.3 * [b, c]

* Statistical significance was determined through McNemar's tests of agreement between on/off per system (p <.05).
[a] Denotes statistically significant difference between Super Cruise and ProPILOT Assist (p <.05).
[b] Denotes statistically significant difference between ProPILOT Assist and Autopilot (p <.05).
[c] Denotes statistically significant difference between Super Cruise and Autopilot (p <.05).

Table 4
Percent of drivers who indicated that they can do certain things more often when using the partial driving automation in their vehicle.

	GM Cadillac Super Cruise (n = 200)	Nissan/Infiniti ProPILOT Assist (n = 202)	TeslaAutopilot (n = 202)
Eating	56 [a, c]	18 [a, b]	34[b, c]
Drinking	35 [a]	23 [a, b]	39[b]
Texting on a cellphone	45 [a, c]	15 [a, b]	34[b, c]
Using apps on a cellphone	8 [c]	9 [b]	23[b, c]
Watching videos on a cellphone or other device	3 [c]	5 [b]	20[b, c]
Using a laptop or tablet computer	6 [c]	5 [b]	18[b, c]
Talking on a cellphone	48 [a, c]	17 [a, b]	33[b, c]
Having phone calls through the vehicle's Bluetooth	42 [a]	30 [a, b]	45[b]
Talking to passengers	47 [a]	29 [a, b]	43[b]
Sleeping	2 [c]	3 [b]	10[b, c]
Brushing hair, putting on makeup, or other types of grooming	11[c]	5 [b]	18[b, c]
Reading a book, magazine, or newspaper	2 [c]	2 [b]	16[b, c]
Keeping both hands off the wheel for shorter periods (a few seconds)	47 [a]	15 [a, b]	41[b]
Keeping both hands off the wheel for longer periods (more than a few seconds)	35 [a]	6 [a, b]	36[b]
Looking at scenery	63 [a, c]	29 [a, b]	47[b, c]
Looking away from the road for more than a few seconds	58 [a, c]	19 [a, b]	39[b, c]

Note. Statistical significance was determined through Fisher's exact test.
[a] Denotes statistically significant pairwise test between Super Cruise and ProPILOT Assist (p <.05).
[b] Denotes statistically significant pairwise test between ProPILOT Assist and Autopilot (p <.05).
[c] Denotes statistically significant pairwise test between Super Cruise and Autopilot (p <.05).

Table 5
Percent of drivers who said that they can do certain things better when using the partial driving automation in their vehicle.

	GM Cadillac Super Cruise (n = 200)	Nissan/Infiniti ProPILOT Assist (n = 202)	Tesla Autopilot (n = 202)
Eating	69 [a, c]	29 [a, b]	44[b, c]
Drinking	36[c]	30[b]	51[b, c]
Texting	56 [a, c]	17 [a, b]	46[b, c]
Using apps on a cellphone	13[c]	15[b]	35[b, c]
Watching videos on a cellphone or other device	3 [c]	3 [b]	22[b, c]
Using a laptop or tablet computer	6 [c]	4 [b]	20[b, c]
Talking on a cellphone	57 [a, c]	18 [a, b]	44[b, c]
Having phone calls through the vehicle's Bluetooth	42[c]	39[b]	53[b, c]
Talking to passengers	54 [a]	43 [a, b]	58[b]
Sleeping	2 [c]	< 1 [b]	13[b, c]
Brushing hair, putting on makeup, or other types of grooming	16 [a]	4 [a, b]	21[b]
Reading a book, magazine, or newspaper	2 [c]	1 [b]	19[b, c]
Keeping both hands off the wheel for shorter periods (a few seconds)	49 [a]	18 [a, b]	46[b]
Keeping both hands off the wheel for longer periods (more than a few seconds)	31 [a]	7 [a, b]	37[b]
Looking at scenery	65 [a, c]	47 [a]	54[c]
Looking away from the road for more than a few seconds	57 [a]	26 [a, b]	49[b]

Note. Statistical significance was determined through Fisher's exact test.
[a] Denotes statistically significant pairwise test between Super Cruise and ProPILOT Assist (p <.05).
[b] Denotes statistically significant pairwise test between ProPILOT Assist and Autopilot (p <.05).
[c] Denotes statistically significant pairwise test between Super Cruise and Autopilot (p <.05).

Table 6
Percent of drivers who indicated certain activities are safe to do while driving with the system switched on or off.

	GM Cadillac Super Cruise (n = 200)			Nissan/Infiniti ProPILOT Assist (n = 202)			Tesla Autopilot (n = 202)		
	On	Off	Relative percentage	On	Off	Relative percentage	On	Off	Relative percentage
Eating	74	16	4.8 * [a, c]	42	25	1.6 * [a, b]	50	16	3.2 * [b, c]
Drinking	87	79	1.1 * [c]	53	50	1.1 [b]	62	38	1.7 * [b, c]
Texting on a cellphone	60	2	30.0 * [a, c]	14	2	7.0 * [a, b]	32	3	10.8 * [b, c]
Using apps on a cellphone	42	1	41.5 * [a, c]	12	< 1	12.0 * [a, b]	26	3	7.6 * [b, c]
Watching videos on a cellphone or other device	17	1	16.5 * [a]	5	2	2.2 * [a, b]	16	3	5.3 * [b]
Using a laptop or tablet computer	14	< 1	28.0 * [a]	5	2	2.0 [a, b]	13	2	6.8 * [b]
Talking on a cellphone	63	2	31.3 * [a, c]	19	4	4.8 * [a, b]	38	9	4.0 * [b, c]
Having phone calls through the vehicle's Bluetooth	90	85	1.1 *	64	54	1.2 *	70	57	1.2 *
Talking to passengers	91	88	1.0 [c]	65	61	1.1	69	58	1.2 * [c]
Sleeping	3	< 1	6.0	1	< 1	1.5	7	3	2.0
Brushing hair, putting on makeup, or other types of grooming	60	< 1	120.0 * [a, c]	13	2	6.5 * [a, b]	21	1	14.0 * [b, c]
Reading a book, magazine, or newspaper	14	< 1	27.0 * [a]	7	1	4.7 * [a]	12	2	6.3 *
Keeping both hands off the wheel for shorter periods (a few seconds)	74	2	37.0 * [a, c]	26	7	3.5 * [a, b]	47	11	4.3 * [b, c]
Keeping both hands off the wheel for longer periods (more than a few seconds)	52	1	51.5 * [a, c]	8	3	2.8 * [a, b]	29	2	11.8 * [b, c]
Looking at scenery	84	38	2.2 * [a, c]	51	31	1.6 *	51	27	1.9 * [a, c]
Looking away from the road for more than a few seconds	76	9	8.9 * [a, c]	27	5	5.0 * [a, b]	36	4	8.0 * [b, c]

* Statistical significance was determined through McNemar's tests of agreement between on/off per system (p <.05).
[a] Denotes statistically significant difference between Super Cruise and ProPILOT Assist (p <.05).
[b] Denotes statistically significant difference between ProPILOT Assist and Autopilot (p <.05).
[c] Denotes statistically significant difference between Super Cruise and Autopilot (p <.05).

excluded from the analysis. Relative percentages were calculated using unrounded numbers in Tables 3 and 6, but rounded percentages are reported in all tables.

3. Results

Distributions of age, gender, duration of vehicle ownership, driving exposure (in terms of number of days per week respondents typically drive), and partial driving automation exposure (in terms of the frequency of use whenever respondents drive) per system group are shown in Table 2. Super Cruise and Autopilot owners were predominantly male whereas ProPILOT Assist owners had more even gender representation. Super Cruise owners skewed older, whereas Autopilot owners tended to be younger. Autopilot owners had the longest vehicle ownership and Super Cruise owners the shortest. Although Autopilot owners reported driving their vehicles most frequently, all three groups reported similar system use frequency when they drove.

3.1. Non-driving-related activities

Performing secondary tasks was more common while using partial automation than while driving unassisted, though certain activities were more prevalent among some groups than others with and without system support (Table 3). When using the automation, certain activities, such as eating, using smartphone apps and grooming, were much more likely among Super Cruise users than the other two groups, compared with while driving unassisted. Super Cruise users were also more likely to report having their hands off the wheel and looking away from the road while using automation. In contrast, Autopilot users were more likely to watch videos, use a computer, and read while using automation than the other two groups. Both Super Cruise and Autopilot users were more likely to take their hands off the wheel, use peripheral devices, and look away from the road while using their systems than ProPILOT Assist users.

Many drivers said that they perform these activities more often (Table 4) and better (Table 5) with the support of the automation. Overall, the patterns were similar between the relative frequencies reported in Table 3 and the increased frequency in Table 4, with a few notable exceptions. Survey phrasing around frequency of activities affected groups differently. Specifically, respondents were asked about their activity frequency in two ways: *if* they did certain activities more often while using the technology and *how often* they did certain activities while using the technology. Autopilot users were especially likely to say that they engaged in certain risky behaviors more often while using the system when asked if they did the activities more often (see Table 4) than when asked how often they do those activities (see Table 3). We observed the opposite pattern for certain activities among Super Cruise users.

Compared with the other two groups, more ProPILOT Assist users did not report an increased frequency or improved ability for most activities while using the partial automation—in particular for activities that require the driver to take hands off the wheel and/or look away from the road. More Super Cruise users said that they could eat, talk or text on a phone, and look away from the road better and more often with the system's support than the other two groups. In contrast, more Autopilot users said that they could use smartphone apps, watch videos, use a computer, sleep, and read better and more often with the system's support than the other two groups. A similar percentage of Super Cruise and Autopilot users said they could have their hands off the wheel better and more often while using their systems.

The likelihood that an activity was perceived as safe was higher while using partial driving automation than while driving without assistance, and the pattern was most pronounced among Super Cruise users (Table 6). Compared with driving unassisted, Super Cruise users were more likely than the other two groups to characterize phone and other peripheral device use, watching videos, grooming, reading, and having hands off the wheel as safe to do while using the system. ProPILOT Assist users were the least likely to characterize non-driving-related activities as safe to do while using the system.

3.2. Attention reminders

The majority of Super Cruise (90%), ProPILOT Assist (62%), and Autopilot users (84%) said they had at some point received an alert or message to return eyes to the road or place hands back on the wheel. Drivers who reported receiving attention reminders were asked additional questions about them. Most of those drivers (82% for Super Cruise, 73% for ProPILOT Assist, and 82% for Autopilot users) said they had been engaged in at least one secondary task at the time of the alerts. When those who had been engaged in secondary tasks at the time of the

alerts were asked whether the attention reminders had changed how often they performed those activities while driving, 10% of Super Cruise, 10% of ProPILOT Assist, and 19% of Autopilot users said that they performed the activities more often, while 7% of Super Cruise, 34% of ProPILOT Assist, and 36% of Autopilot users said that they did those things less often as a result. A few of these drivers said that they had done something to make the system stop sending attention reminders so that they could continue doing those activities (2% of Super Cruise, 6% of ProPILOT Assist, and 6% of Autopilot users). Some drivers who had received attention reminders admitted that they got around the alerts by fooling the driver monitoring system; for example, by strapping a water bottle to the steering wheel to fool the torque sensor or temporarily touching the steering wheel to trigger the sensor.

Eighteen percent of Super Cruise, 18% of ProPILOT Assist, and 22% of Autopilot users who had experienced attention reminders said that they had been at least somewhat annoyed when the alerts happened (Table 7). However, when the whole sample was asked, 56% of Super Cruise, 57% of ProPILOT Assist, and 57% of Autopilot users said that they thought the attention reminders were extremely helpful for getting drivers to pay attention to driving. Likewise, 49% of Super Cruise, 49% of ProPILOT Assist, and 50% of Autopilot users said that they felt extremely safe knowing that their system is designed to alert drivers when it thinks they are not paying attention. Nearly identical patterns for attitudes around the helpfulness and safety of attention reminders persisted among those drivers who had experienced attention reminders.

3.3. System lockout

Only Super Cruise and Autopilot systems disable driver access to the partial driving automation when they do not comply with the attention reminders. Forty-four percent of Super Cruise and 39% of Autopilot users said that their systems had at some point switched off and would not reactivate while driving, and many of those Super Cruise (70%) and Autopilot users (62%) said they knew why. When asked through an open-ended question why the lockout events happened, some respondents gave more than one reason and others did not give a response at all. Distraction and inattention were commonly cited explanations (Super Cruise: $n = 33$, Autopilot: $n = 15$), for example, because of cellphone use ($n = 12$). Some Super Cruise users also cited conversing with a passenger or on the phone ($n = 5$), but none of the Autopilot users cited this.

Unlike the Autopilot system, Super Cruise permits hands-free driving under certain conditions, yet people in both groups (Super Cruise: $n = 25$, Autopilot: $n = 12$) described having their hands off the wheel as cause for the lockout. Nine more Autopilot users said that their hands had been on the wheel at the time but were not detected by the steering wheel sensors. Moreover, seven Super Cruise users mentioned eating as one of the activities that led to their lockout experience—most of them specifically described taking their hands off the wheel to eat—but none of the Autopilot users cited this reason. Illustrating the challenges of eating while driving, two Super Cruise users said that they had dropped their food (in one case a taco and in another case a hamburger) and had to let go of the wheel to retrieve their meals. Fifty-four percent of Super Cruise and Autopilot users who experienced lockouts said they were at least somewhat annoyed these lockout events happened.

While the goal was to investigate experiences with a system's deterrence countermeasure in response to a driver misusing the technology, a few respondents ($n = 20$) evidently interpreted it to pertain to any events in which the system deactivated, not necessarily in response to misuse. Seven drivers ($n = 1$ Super Cruise, $n = 6$ Autopilot) believed that system suspension or deactivation in response to driver input was a lockout event. For example, when a driver actively steers within the lane, Super Cruise's lane-centering support goes into temporary standby mode until the driver has stopped steering after which it automatically resumes, whereas Tesla's Autopilot lane-centering support switches off entirely. In addition, when the driver presses the accelerator pedal, system support can go into temporary standby mode or deactivate. Other reasons for lockout events unrelated to misuse included inclement weather ($n = 1$ Super Cruise, $n = 6$ Autopilot), ODD limitations ($n = 3$ Super Cruise users said the system did not work when passing through construction zones and intersections with ambiguous lane line delineation), sensor issues ($n = 1$ Super Cruise user mentioned sun glare affecting the driver monitoring camera), and system connectivity loss ($n = 1$ Super Cruise user, $n = 1$ Autopilot user).

The purpose of lockout features was then explained to the whole sample, and 45% of Super Cruise, 43% of ProPILOT Assist, and 43% of Autopilot users said that the feature is extremely helpful for getting drivers to pay attention (Table 8). Forty-three percent of Super Cruise, 39% of ProPILOT Assist, and 35% of Autopilot users said they felt extremely safe knowing that the partial driving automation is designed to prevent drivers from using it when the system detects that they are not paying attention. Among respondents who said they had experienced lockout events, a smaller percentage of each group said the countermeasure was extremely helpful (Super Cruise: 39%, Autopilot: 32%) or felt extremely safe with it (Super Cruise: 29% and Autopilot: 27%).

3.4. Driver intervention for unexpected system behavior

Almost half of Autopilot users (48%) but only about a quarter of Super Cruise users (25%) and ProPILOT Assist users (23%) said they had had experiences where their vehicles did something they had not expected that required driver intervention. These drivers were asked follow-up questions about their experiences. When asked to think about the last time this happened, over three-quarters of ProPILOT Assist users (77%) and Autopilot users (76%) but only 53% of Super Cruise users said they had had at least one hand on the wheel before realizing they had to intervene. Thirty-seven percent of Super Cruise, 17% of ProPILOT Assist, and 24% of Autopilot users who had experienced these unexpected events said they had been engaged in activities that involve at least one hand off the wheel (i.e., eating, drinking, texting, using smartphone apps or a computer, talking on a hand-held cellphone, grooming, and/or reading a book, magazine, or newspaper). Ten percent of Super Cruise, 9% of ProPILOT Assist, and 16% of Autopilot

Table 7
Perceived annoyance of attention reminders among those who have experienced them, and perceived helpfulness and safety value of attention reminders among the whole sample (in percent per automaker).

	Annoyance			Helpfulness			Safety of system safeguard		
	GM Cadillac Super Cruise ($n = 179$)	Nissan/Infiniti ProPILOT Assist ($n = 126$)	Tesla Autopilot ($n = 170$)	GM Cadillac Super Cruise ($n = 200$)	Nissan/Infiniti ProPILOT Assist ($n = 202$)	Tesla Autopilot ($n = 202$)	GM Cadillac Super Cruise ($n = 200$)	Nissan/Infiniti ProPILOT Assist ($n = 202$)	Tesla Autopilot ($n = 202$)
Not at all	51	63	49	< 1	3	< 1	1	1	< 1
Slightly	31	19	29	1	5	3	< 1	4	3
Somewhat	11	10	13	6	11	14	4	12	13
Moderately	6	6	7	37	23	25	46	34	34
Extremely	1	2	2	56	57	57	49	49	50

Note. Percentages may not sum to 100 due to rounding. Missing values not shown.

Table 8
Perceived annoyance of lockout events among those who have experienced them and perceived helpfulness and safety value of the system design to prevent misuse among the whole sample (percent per automaker).

	Annoyance		Helpfulness			Safety value of system safeguard		
	GM Cadillac Super Cruise (n = 87)	Tesla Autopilot (n = 78)	GM Cadillac Super Cruise (n = 200)	Nissan/Infiniti ProPILOT Assist (n = 202)	Tesla Autopilot (n = 202)	GM Cadillac Super Cruise (n = 200)	Nissan/Infiniti ProPILOT Assist (n = 202)	Tesla Autopilot (n = 202)
Not at all	17	19	4	8	3	3	8	2
Slightly	29	26	1	4	6	1	5	6
Somewhat	40	26	6	16	15	10	15	16
Moderately	9	22	46	27	31	44	30	40
Extremely	5	6	45	43	43	43	39	35

Note. Percentages may not sum to 100 due to rounding. Missing values not shown.

users said they had been doing things that involve looking away from the road (i.e., texting, using smartphone apps or computers, watching videos, sleeping, grooming, reading, looking at scenery, looking away from road). Lastly, 53% of those Super Cruise, 34% of ProPILOT Assist, and 30% of Autopilot users reported that they had been engaged in conversation (i.e., talking on a cellphone or through the vehicle's Bluetooth or conversing with passengers).

3.5. Where to use the system

Over half of Super Cruise users (53%), 42% of Autopilot users, and only 12% of ProPILOT Assist users said they were comfortable letting the partial driving automation drive the vehicle without having to watch what was happening on the road. Those who said they were comfortable doing this were asked to specify under what types of road conditions they felt comfortable letting the vehicle drive itself. Most of these drivers identified free-flowing traffic conditions on limited access highways or interstates with on or off ramps (Super Cruise: 95%, ProPILOT Assist: 79%, Autopilot: 75%). Some of them also included free-flowing traffic conditions on major roads or highways with traffic lights (Super Cruise: 13%, ProPILOT Assist: 33%, Autopilot: 51%), heavy stop-and-go traffic (Super Cruise: 10%, ProPILOT Assist: 46%, Autopilot: 32%) and low speed local roads (Super Cruise: 22%, ProPILOT Assist: 21%, Autopilot: 43%). Thirty-seven percent of Autopilot users, 25% of ProPILOT Assist users, and 10% of Super Cruise users also mentioned parking lots. (Many of these vehicles have partially automated parking assistance features). A few respondents (Super Cruise: 5%, ProPILOT Assist: 13%, Autopilot: 11%) also said they were comfortable letting the vehicle drive itself during inclement weather.

4. Discussion

The present study supports the finding of previous research that partial driving automation facilitates engagement in non-driving-related activities (e.g., Dunn et al., 2021; Noble et al., 2021; Reagan et al., 2021); however, the attitudes, expectations, and habits around individual activities and system design safeguards vary among drivers depending on the system they use. Each group was comprised of vehicle owners who have distinctive system-user characteristics, and this might help explain each group's propensity for certain non-driving-related activities over others. Moreover, Super Cruise, ProPILOT Assist, and Autopilot have unique design philosophies that likely influence user behavior as well. Although these survey data cannot disentangle driver and system design effects to explain the group differences observed, the findings nevertheless provide insight into the perceptions and behavior among regular users of several popular systems.

It seems logical that drivers would be more likely to engage in certain visual-manual activities when the system is explicitly designed to allow drivers to take their hands off the wheel. The hands-free design of Super Cruise may help explain why more Super Cruise users than ProPILOT Assist or Autopilot users said they were more likely to engage in certain visual-manual activities with the automation than without it. Also as expected with its hands-free design, more Super Cruise users reported not having their hands on the wheel the last time the vehicle did something that required driver intervention than did users of the other two systems. These drivers were also more likely to report that they had been doing an activity that required at least one hand off the wheel at the time of the intervention. This raises concerns about hands-free system users being less ready and able to steer when intervention is necessary than users of systems that require driver's hands to be on the wheel at all times.

Over-trusting either hands-free (Schneider et al., 2022) or hands-on-wheel partial automation (Victor et al., 2018) can lead drivers to not intervene even when they see a hazardous situation forming in front of them because they incorrectly believe the system can handle more than it was designed to do. One question this study could not answer was whether hands-free driving capability is more likely to give users the impression that the system is more functionally capable and safer than a hands-on-wheel system. Nonetheless, more than half of Super Cruise users in the current study said they were comfortable letting the system drive itself without having to watch what was happening on the road, compared with approximately 40% of Autopilot users and only 12% of ProPILOT Assist users. Super Cruise users were also far more likely than the other two groups to say that most non-driving-related activities were safe to do while using the system.

That said, even hands-on-wheel systems seem to differ with respect to how much they reinforce system limitations or convey the illusion of autonomous driving capability. Compared with ProPILOT Assist users, Autopilot users were more likely to report doing visual-manual activities that take their eyes off the road for extended periods while using the system. They were more likely to say is safe to do while supported by the system than while driving without automation. These findings are consistent with on-road observation studies (e.g., Banks, Eriksson, O'Donoghue, & Stanton, 2018; Morando, Gershon, Mehler, & Reimer, 2021; Reagan et al., 2021) and crash investigations (NTSB, 2017, 2019, 2020), as some people appear to use hands-on-wheel systems in a hands-free fashion. Although it is likely that the speed and manner with which these systems respond to inappropriate driver behavior contribute to the likelihood of treating a hands-on-wheel system as hands-free, it was beyond the scope of this study to determine how these three systems functionally differ in that respect.

A substantial proportion of ProPILOT Assist users reported never having received attention reminders, which raises the possibility that interactions with the system's lane-centering feature might also contribute to these group differences. ProPILOT Assist's lane-centering support remains active while the driver steers within the lane; this characteristic is a component of cooperative steering, or shared haptic control. This design philosophy encourages the driver to actively participate in the steering task (Marcano et al., 2021), helping to reinforce the driver's role in the relationship and improving the driver's sense of agency and willingness to intervene whenever necessary or desired (Wen, Kuroki, & Asama, 2019). In contrast, Autopilot's lane-centering support deactivates whenever the driver exceeds a (relatively small) threshold amount of steering torque. Super Cruise's lane-

centering support temporarily suspends and only automatically reactivates once the driver has stopped steering and the system has regained the necessary information to position itself within the lane. It is unclear to what extent these design differences influence driver behavior, but the temporary suspension or deactivation of system support might make drivers more reluctant to participate in the driving over time (Banks & Stanton, 2015).

While steering torque monitoring alone is a poor basis for managing driver behavior (Lin et al., 2018), the current study's findings indicate that camera-based driver monitoring on its own is not a silver bullet either. The longer a driver looks away from the road the greater their crash risk (Klauer, Dingus, Neale, Sudweeks, & Ramsey, 2006; Yang, Kuo, & Lenné, 2021). Even though Super Cruise uses camera-based monitoring to know where the driver is looking, many Super Cruise users reported being more likely to look away from the road for extended periods while using the system than the drivers in the other two groups. It is unclear why this is the case, but compared with Autopilot and ProPILOT Assist users, Super Cruise users were also more likely to say that looking away from the road is safe to do while using the system than during unassisted driving, and to say that they can do it better and more often with the automation's support. Clearly, the expectations and attitudes of many of these drivers do not reflect an accurate understanding of the system's limits.

Although attention reminders can be effective in deterring continuous non-driving-related activities (Gaspar, Schwarz, Kashef, Schmitt, & Shull, 2018), the current study found that they do not deter misuse among a minority of drivers. In fact, many Super Cruise and Autopilot users said that they had experienced system lockouts, often because of non-driving-related activities, which is troubling. A few drivers even said that they do these activities more after getting the attention reminders, and a handful of people even admitted to intentionally fooling the driver monitoring so that they could continue their activities, which underscores growing concerns about current implementations of driver monitoring (Vanderwerp, 2021). People can be trained to develop internal timers around secondary activities while driving (e.g., Pradhan et al., 2011), so perhaps these system users learned how long they can do certain activities before the attention reminder sequence escalates. This underscores the importance of other safeguards, such as cooperative steering and placing restrictions on automated functionality, to keep drivers in the loop and appropriately shape their expectations about the roles and responsibilities of the human and the machine (Mueller et al., 2021).

People who value the advantages of partial driving automation are more likely to want to use it (Nordhoff et al., 2021). Although some drivers in the current study who had experienced attention reminders and system lockouts found them to be annoying, most drivers said that both mechanisms were helpful and that they felt safer with them. This broad acceptance indicates potential for driver education and marketing to promote the safety benefits and adoption of these safeguard strategies among the general population. Hopefully their acceptance will lead to similar safeguards implemented in vehicles not equipped with partial driving automation to help combat driver distraction, which is a traffic safety issue regardless of vehicle technology (National Center for Statistics and Analysis, 2021).

4.1. Limitations and sample considerations

Each user group in the current study had idiosyncratic characteristics (e.g., age, vehicle ownership duration, driving exposure, and gender) that may have contributed to some of the differences observed in the data. Many of these differences were expected given the customer bases of these automakers and when their systems first became available. Until 2021, the only GM vehicle model equipped with Super Cruise was the Cadillac CT6, which was first released in the 2018 model year, discontinued in 2020, and was generally marketed towards middle-aged and older drivers. Tesla began offering Autopilot on 2014 vehicle models, and those vehicles have typically been marketed towards younger, tech-savvy people. Nissan/Infiniti's ProPILOT Assist was first available on the 2018 Rogue in the United States, and those vehicles have broader mainstream appeal. The differences observed among these groups serve as an important reminder that, while most research studies aim to have samples that represent the general driving population, the owner demographics and characteristics specific to certain models or even brands may not be representative of the broader driver population. This is reflected in the mixed mode survey method that was necessary to access the different owner groups. Specifically, being generally older drivers, most of the Cadillac owners participated by phone, whereas the majority of the (younger) Tesla owners participated online. Moreover, it is possible that the survey modes used could have affected responses (Zhang, Kuchinke, Woud, Velten, & Margraf, 2017).

As Lin et al. (2018) noted, the scarcity of vehicles equipped with partially automated systems in the registered vehicle fleet means that studies such as this one are presently capturing behavior and perceptions of early adopters. It is unclear how user attitudes and expectations will evolve as system designs change and the technology becomes more widespread. While the goal of this study was to explore the perceptions and behaviors of people who are familiar and experienced with a specific version of partial driving automation, it is likely that their attitudes and expectations are not representative of owners of the same vehicles who never or infrequently use or who at some point stopped using the technology (Koskinen, Lyyra, Mallat, & Tuunainen, 2019) or of future owners who are not early adopters.

Lastly, self-reported habits concerning non-driving-related activities may not be reflective of actual behavior, which means that the coarse frequency rates reported may over- or underestimate real-world behavior. The goal of this study was not to estimate prevalence of behaviors, but rather to capture the relative differences in user behavior and perceptions as a function of system ownership to help explain why people do what they do while using partial driving automation.

5. Conclusions

Although systems under the partial driving automation (Level 2) umbrella share functional similarities, they are not all the same, as evidenced by the mixed results regarding safety benefits (Goodall, 2021; HLDI, 2017, 2019, 2021, 2022). This study confirms that system designs and consumer populations vary among manufacturers, and these factors affect how people use the technology. Worryingly, some drivers appear to have a false sense of security about how they are meant to use the technology and what it is designed to do. Misunderstanding the user's roles and responsibilities corresponds with a higher degree of engagement in non-driving-related activities compared with driving without assistance. This confusion is likely influenced by system design, as some systems are more likely to give drivers the impression that they are more functionally capable than they are. It is possible that hands-free driving capability, sluggish attention reminder initiation and escalation, and noncooperative steering control facilitate these impressions, but it remains unclear to what extent. This study also captured user-specific differences, which further differentiate drivers based on the system they use. This would indicate that regular user behavior may not necessarily generalize to the broader driver population.

6. Practical applications

Automakers need to design their partial driving automation systems in ways that promote proper use from the outset. The helpfulness and safety value of these driver-oriented safeguards can be promoted through marketing, vehicle ratings programs, and education campaigns to help support their acceptance and use within and beyond the partial driving automation context.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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