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The impact of visual user interfaces on drivers' understanding of driving control mode and hands-on steering wheel requirement in Level 2 automated vehicles

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ABSTRACT

As vehicles transition between driving automation levels, drivers need to be continually aware of the automation mode and the resulting driver responsibilities. This study investigates the impact of visual user interfaces (UIs) on drivers' mode awareness in SAE Level 2 automated vehicles. It focuses on their understanding of speed and distance control, steering control, and the hands-on steering wheel requirement presented through UIs. Forty-five UIs were generated, presenting the activation of Lane Keeping Assist (LKA) and Adaptive Cruise Control (ACC) and the hands-on steering wheel requirement. Through an online questionnaire with 1080 respondents with experience of SAE Level 2, the study evaluated how these visual UIs influenced users' understanding of control responsibilities, information usability, and trust in automated vehicles. The results show a limited role of UI in shaping users' understanding of control. ACC UIs and LKA UIs had no significant effects, and apparently, the understanding of speed and distance control and steering control was independent of the ACC UI and LKA UI. A large variance in responses regarding the understanding of steering control and speed and distance control indicates confusion caused by mode ambiguity, suggesting that drivers do not well understand how the speed and distance control and steering control task is shared between the driver and the automation. However, the hands-on steering wheel UIs significantly improved the understanding of the hands-on steering wheel requirement. The hands-on steering wheel UI combining the hands on the wheel icon and the text "Keep hands on steering wheel" yielded 94.4% correct understanding and outperformed the UI with hands but without text (87.8% correct) or no UI (82.5% correct). In addition, the variation of visual UI did not affect trust. This study contributes to the understanding and design of visual UIs for effective communication of driver responsibilities in automated vehicles.

1. Introduction

Automated vehicles have the potential to improve road safety by supporting drivers in various situations (Litman, 2017). Current and future vehicles will offer multiple levels of driving automation ranging from manual driving (SAE Level 0) to full driving

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automation on all roads (SAE Level 5). Many current vehicles offer Level 1 driving automation with adaptive cruise control (ACC) controlling speed and following distance. An increasing number of vehicles also provide partial driving automation (SAE Level 2), where ACC is complemented with lane-keeping assistance (LKA), which supports steering control. However, in SAE Levels 1 and 2, the vehicle cannot safely handle all situations, and drivers need to monitor the driving task and intervene when needed actively (SAEInternational, 2021). In conditional driving automation (SAE Level 3), the car can perform the driving task in specific conditions, while drivers need to remain prepared to take over the control when prompted by the vehicles. In manual (SAE Level 0) or full (SAE Level 5) driving automation, there is no misunderstanding of who – the driver or the car – is responsible for performing speed and distance control and steering control and monitoring the driving environment (Janssen et al., 2019). However, in the intermediate levels of automation, there is potential confusion on who handles and is ultimately responsible for which part of the driving task (Martens & van den Beukel, 2013). On-road studies with SAE Level 2 automated vehicles have revealed mode awareness issues, with drivers not being aware of driving assistance functions while operating (Banks et al., 2018; Endsley, 2017; Wilson et al., 2020). Wilson et al. (2020) identified situations where the drivers incorrectly thought that the vehicle was in SAE Level 2 when, in fact, it was not, and the drivers were responsible for the primary driving task. Similarly, Banks et al. (2018) found that drivers failed to engage SAE Level 2 properly and, in other situations, did not understand that SAE Level 2 was disengaged.

Mode awareness refers to the knowledge about the current mode of automation, its performance level and drivers' tasks and responsibilities (Sarter & Woods, 1995). Deficient mode awareness is typically caused by mode confusion. Mode confusion occurs when drivers misinterpret the driving mode or the behaviour of the automation (Bredereke & Lankenau, 2005). This can induce misunderstanding of the automation state (Carsten & Martens, 2019) and affect trust in the automation (de Vries et al., 2003; Muir & Moray, 1996). When drivers are unsure about the vehicle's mode of operation, they may feel uncomfortable or inadvertently take driving control, leading to potentially unsafe situations (Kurpiers et al., 2020). Hence, appropriate mode awareness is necessary for the safe and trustworthy operation of automated vehicles. Perceived control influences drivers' perception of the mode and their responsibility for the driving task (Flemisch et al., 2012; Novakazi et al., 2021). To ensure a satisfactory interaction between the driver and the vehicle, drivers' perceived control should match the state of the driving automation. This study measures perceived control as an understanding of control mode. In this study, the 'control mode' means who (the driver or the car) controls the driving control, which also indicates the perception of activation of the driving automation.

Several studies have pointed to the importance of user interfaces (UIs) as a means to support drivers in developing an appropriate understanding of automation and mitigating mode confusion. For example, Carsten and Martens (2019) have argued that when drivers are decoupled from active control, the design of the UI becomes even more critical. Seppelt and Victor (2016) disputed the need to design user interfaces to support drivers having an appropriate mental model in changing control from a higher to a lower level of automation. Lee et al. (2014) suggested that mitigating mode confusion means providing drivers with a transparent display of the automation state and correct and concise information via different in-vehicle UIs. However, although the argument is that UIs can enhance mode awareness (Carsten & Martens, 2019; Lee et al., 2022), confusion can occur if drivers fail to perceive or comprehend the automation mode (Monsaingeon et al., 2021). Furthermore, understanding these systems can affect trust. Lee and See (2004) argued that an understanding of system capability calibrates trust. Trust calibration is the dynamic change of trust to an appropriate level that matches system capability. A poor understanding of automation may lead to human misuse and disuse (Parasuraman & Riley, 1997). Misuse refers to overreliance on automation, which can result in failures of monitoring or decision biases, while disuse is the neglect or underutilisation of automation. According to the trust in automation model by Hoff and Bashir (2015), UI design features, such as appearance, ease of use, communication style, and transparency, can help build and maintain trust in automation. Therefore, this study investigates the influence of visual UIs on trust as well as drivers' understanding of control.

Visual UIs in commercial automated vehicles may contribute to mode confusion as their information may contain unambiguous messages pertaining to the driving automation state and responsibilities of drivers. Perrier et al. (2021) have shown that LKA icons produced ambivalent meanings for drivers. LKA activation symbols typically exist in two versions with a steering wheel image, either with or without the driver's hands placed on the steering, as shown in Fig. 1. The steering wheel icon used in LKA may lead drivers to conflate vehicle steering control with their understanding of the hands-on steering wheel requirement. For example, if no hands are in the symbol (Fig. 1 right), drivers may falsely assume they do not need to place their hands on the steering wheel.

In SAE Level 2, drivers still need to keep their hands on the steering wheel most of the time. However, currently, the information for the hands-on steering wheel requirement is not always present in commercial vehicles' visual UIs. Instead, pop-up messages and auditory warnings are provided if drivers do not provide sufficient torque to the steering wheel, as shown in Fig. 2. In the absence of continuous hands-on steering wheel requirement information, drivers may wrongly assume that there is no need to place one or two hands on the steering wheel. Therefore, it is necessary to investigate how drivers understand driving control mode and the hands-on steering wheel requirement through visual UIs and suggest design guidelines that clearly convey the meaning of driving control and requirements.

Fig. 1. LKA symbols with hands (left) and without hands (right).

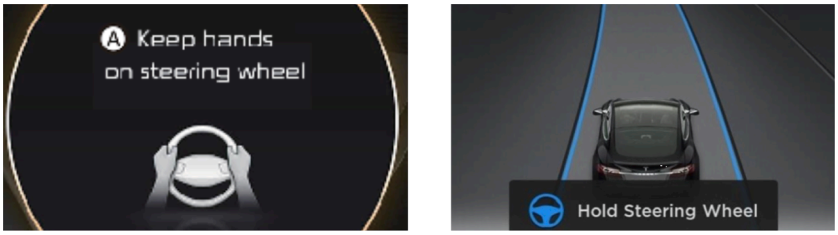


Fig. 2. Pop-up warning message when drivers do not place their hands on the steering wheel, Kia EV6 (left), Tesla (right). A beep audible warning accompanies the visual UI.

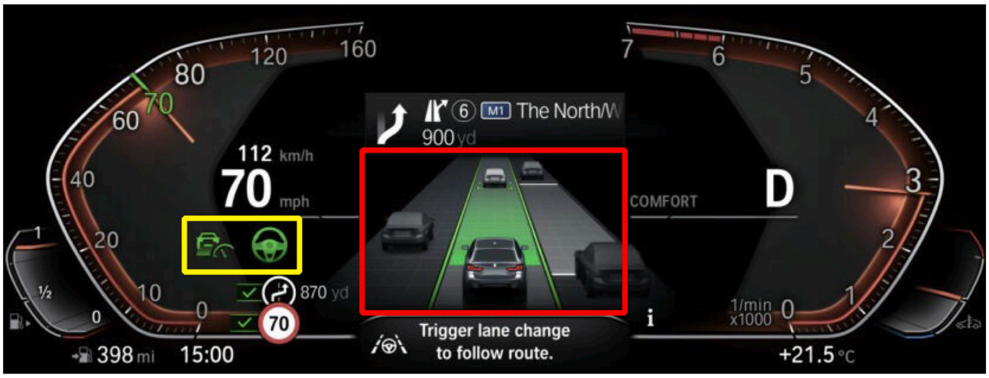


Fig. 3. Example of a visual interface in a cluster (BMW5). The yellow box indicates symbols, and the red box indicates the visual interface presented in the middle.

This study, using an online questionnaire, investigates how the design of visual UIs can support drivers' understanding of the active driving control mode and the hands-on-steering wheel requirement in SAE Level 2. Drivers are provided information regarding the activation of ACC and LKA through visual UIs presented in the middle of the cluster (Fig. 3 red box) and symbols (Fig. 3 yellow box). While an investigation into symbols of LKA and ACC has already been carried out by Perrier et al. (2021), there is a lack of studies investigating the visual interface presented in the middle of the cluster. In addition, compared to the symbols with universal guidelines for the driving automation feature activation, such as ISO 7000–2580 (ACC) or ISO 7000–3128 (LKA), there is no design guideline for the visual interface presented in the middle of the cluster. Therefore, car manufacturers developed a range of visual interfaces, and little is known about how the visual interfaces influence drivers' understanding of driving control mode. In this study, we focus on visual user interfaces presented in the middle of the cluster (red box in Fig. 3), showing activation of ACC and LKA and providing information regarding the hands-on steering wheel requirement. The two main research questions are:

1. What are the drivers' understanding of the information presented on visual UIs regarding speed and distance control and steering control, and the hands-on steering wheel requirement in SAE Level 2?
2. To what extent are information usability and drivers' trust in automation affected by the information presented on the visual UIs in SAE Level 2?

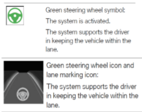
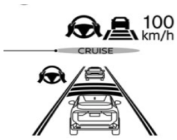
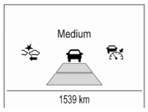
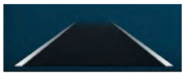
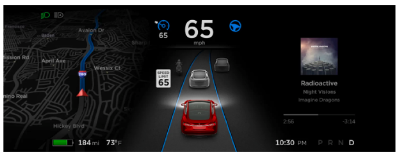
The structure of the following sections is as follows. Section 2 presents the methodology for generating visual user interfaces based on an analysis of visual interfaces available in commercially SAE Level 2 automated vehicles and for designing an online questionnaire to test these visual interfaces. Section 3 presents the results of the online questionnaire, and Section 4 discusses the results and provides recommendations for visual interface design.

2. Method

2.1. Review of visual interfaces

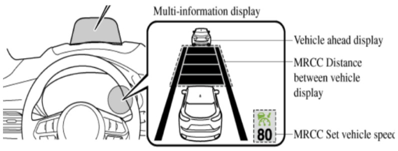
We selected twenty-three visual user interfaces (UIs) presenting SAE Level 2, as shown in Table 1, from twenty well-known car brands (best-selling vehicles of 2021). The visual UIs were available either in commercial or concept cars. They were accessible on the company's official site, YouTube, owner's manual or consumer reviews websites. We analysed the selected visual UIs regarding their presentation of speed and distance control (ACC) and steering control (LKA) activation mode. The ACC visuals varied in terms of the presentation of the gap between the ego vehicle and the vehicle in front. The visuals presenting of LKA mainly differed in terms of their presentation of the detection of the lanes. The activation of the functions typically used green, blue, white, or combined green and

Table 1
Visual UIs of SAE Level 2.

Number	Visual interface (instrument panel)	Number	Visual interface (instrument panel)
1		13	
2	 	14	
3		15	
4		16	 
5	 	17	
6		18	
7		19	
8		20	

(continued on next page)

Table 1 (*continued*)

Number	Visual interface (instrument panel)	Number	Visual interface (instrument panel)
9		21	
10		22	
11		23	
12			

* Sources are presented in the Appendix 1.

white colours.

2.2. Design of visual interfaces

We categorised three interface elements (ACC UI, LKA UI, and Hands-on steering wheel UI) to create 45 combinations for an online questionnaire, aiming to investigate the effects of various display differences in ACC and LKA interfaces from commercial vehicles, as well as the effects of displaying the currently unrepresented Hands-on steering wheel UI.

2.2.1. ACC and LKA UI

The interfaces of vehicles in commercial use in Table 1 have many commonalities. For this study, we created eight generic visual interfaces (see Table 2 and Table 3), capturing key variations from Table 1 and omitting brand-specific details to avoid influencing since these were considered irrelevant to our research. We generated three ACC UIs. ACC UI_1 shows the gap between the ego vehicle

Table 2
Visual UIs displaying ACC activation and corresponding actual vehicle interfaces from Table 1.

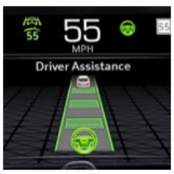
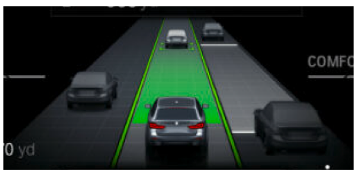
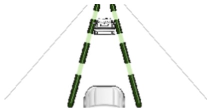
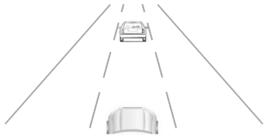
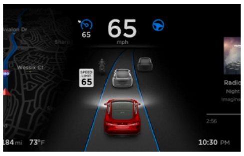
ACC	ACC UI_1	ACC UI_2	ACC UI_3
Generated image			
Example			

Table 3
Visual UIs displaying LKA activation and corresponding actual vehicle interfaces from Table 1.

LKA	LKA UI_1	LKA UI_2	LKA UI_3	LKA UI_4	LKA UI_5
Generated image					
Example					

and the vehicle in the front by individual blocks. ACC UI_2 shows the gap by a carpet. ACC UI_3 does not show the gap but only the front car. Five LKA UIs were generated. LKA UI_1 presents the centre lane and the next lanes. LKA UI_2 displays the extended detection area by showing the next lanes. LKA UI_3 highlights the central lane without other lanes. LKA UI_4 displays the centre lane and adds the steering wheel. LKA UI_5 only presents the steering wheel. In addition, we decided to use green colour to show the activation of the steering control because green is associated with the correct operation or current use of the systems (Campbell et al., 2018; ISO, 2010).

2.2.2. *Hands-on steering wheel UI*

We generated three UIs that varied in terms of their presentation of the information on drivers' placement of their hands on the steering wheel (Table 4). Hands-on steering wheel UI_1 presents a steering wheel icon with a text message. Hands-on steering wheel UI_2 only presents an icon, and Hands-on steering wheel UI_3 does not present any information pertaining to the steering wheel.

2.2.3. *Aesthetics*

To control the impact of the layout and aesthetics, the ratio of the background display was 1:3, and the background colour was black. All visual UIs included the activation of the automation functions and speed information. In addition, the same ACC and LKA icons were used in all images (Fig. 4) in line with Perrier et al. (2021). Two symbols were evaluated as the most notable interpretations of each function. The ACC icon includes information regarding the maximum speed, controlling the gap to the front vehicle, and speed control. The LKA icon shows the steering wheel without hands and lane.

Table 4
Hands-on steering wheel UI variation.

	Hands-on steering wheel UI_1	Hands-on steering wheel UI_2	Hands-on steering wheel UI_3
Generated image			No visual UI

Fig. 4. ACC and LKA icons in all UIs (Perrier et al., 2021).

Fig. 5. Example of two visual combined UIs. Left: ACC UI_1, LKA UI_2, and Hands-on steering wheel UI_1, Right: ACC UI_5, LKA UI_3, and Hands-on steering wheel UI_2.

In total, 45 visual UIs were created, resulting from the combination of three ACC UIs, five LKA UIs, and three Hands-on steering requirement UIs. Two examples of combined visual UIs are presented in Fig. 5. All visual UIs are presented in Appendix 2.

2.3. Online questionnaire

An online questionnaire evaluated the visual UIs presented in Section 2.2 to evaluate these UIs in terms of drivers' understanding, information usability, and trust.

The online questionnaire was created on Qualtrics and distributed through the crowd-sourcing survey platform Prolific (https://www.prolific.com). To ensure that the distribution of respondents across the UIs was balanced in terms of age and gender, we divided respondents into six groups differing in gender (male and female) and age (age 19–29, 30–39, and 40–49) using an embedded respondent's profile setting in Prolific. Respondents received financial compensation for their participation in the study with approximately €3 per respondent. The study was approved by the Human Research Ethics Committee of the TU Delft (ID: 3019), following GDPR.

Prior to participating in the study, respondents were asked to provide their written consent. They received the following information on the functionality of SAE Level 2 and further instructions on the questionnaire.

> *Have you ever heard of automated cars?*
> *Automated cars are being developed at a fast pace. While fully automated cars are still a few years away, SAE Level 2 automated cars are already commercially available. SAE Level 2 automated cars take over part of the driving task for you and are already widespread on the market. This can manifest itself in the car taking care of acceleration, braking, and assisting in steering.*
> *This means: 1. The car controls 'speed and distance' 2. The car assists in 'steering'*
> *You, as a driver, still have to supervise the performance of the car. So, you still have to keep your hands on the steering wheel.*
> *With this brief survey, we investigate how you interact with user interfaces in vehicles. We would appreciate it highly if you could take some minutes to share your experience. This survey will take you approximately 5 min. This study is organised by researchers at the Delft University of Technology in the Netherlands.*

Screening questionnaires were distributed to ensure that respondents had a driver's license, experience with SAE Level 2 (both LKA and ACC), and used desktop devices, laptops and tablets. Next, respondents were asked to provide information about their gender, age, and country of residence.

The study was conducted in a between-subject design. Within the same age and gender group, respondents were randomly assigned to one of 45 visual UIs. Each visual UI was evaluated by twelve questions measuring drivers' understanding of user interfaces in terms of speed and distance control and steering control, placement of hands, information usability, and trust (Appendix 3).

2.3.1. Understanding of control

With the first and second questions, respondents were asked to indicate their understanding of whether the car or driver is performing speed and distance control (Question #1) and steering control (Question #2) on a categorical scale. The response options were: 'The car is fully performing this driving task', 'The car is partly performing this driving task', 'Both car and driver are jointly performing this driving task', 'I (as a driver) am partly performing this driving task', 'I (as a driver) am fully performing this driving task'. In addition, they were asked to indicate whether it is required to keep their hands on the steering wheel most of the time (Question #3), measured in the following options: 'Yes', 'No', and 'I don't know'.

2.3.2. Information usability

Next, respondents were asked to indicate their agreement for questions measuring the usability of information on a 5-point Likert scale (Strongly disagree (1), Disagree (2), Neither agree nor disagree (3), Agree (4), Strongly agree (5)). The questions about clarity (Question #4) and ease of understanding (Question #5) of information were from the information quality section of the Post-Study System Usability Questionnaire (PSSUQ) (Lewis, 1992). In addition, questions about to what extent the understanding of information on speed and distance control (Question #6), steering control (Question #7), and hands-on steering wheel requirement (Question #8) were presented.

2.3.3. Trust

Finally, four trust-related questions (reliable (Question #9), trust (Question #10), dependency (Question #11), suspicion (Question #12)) were assessed using a 5-point Likert scale (Strongly disagree (1), Disagree (2), Neither agree nor disagree (3), Agree (4), Strongly agree (5)) questionnaire modified by (Jian et al., 2000). The scores for the *Suspicion* were reversed in the calculation.

2.4. Data analysis

Before the statistical analysis, we employed a Jackknife analysis (Miller, 1974) to remove outlier respondents and removed fifty-five respondents with $\alpha > 0.01$. The data was analysed to evaluate the effects of information about speed and distance control, steering control, and the hands-on steering wheel requirement. For every visual UI, a categorial variable with the different UIs representing nominal categories was created. Each visual UI included three UI factors: LKA UI, ACC UI, and Hands-on steering wheel UI.

Descriptive statistics were used to understand the distribution of respondents' choices for UI factors. Furthermore, to analyse the effects of UI factors on the *Understanding of control*, a Nominal logistic analysis and multiple correspondence analysis were performed.

The analysis examines the impact of the presentation of the information about speed and distance control (ACC UI) and steering control (LKA UI) as well as the placement of hands on the steering wheel (Hands-on steering wheel UI) during partially automated driving on the understanding of speed and distance control, steering control, and hands-on steering wheel requirement. In addition, a three-factor between-subjects ANOVA was applied to analyse the effects of UI factors on *Information usability* and *Trust*. The effects were statistically significant if $\alpha < 0.05$, and post-hoc analysis was conducted with a Tukey-Kramer HSD test with adjusted α; LKA UI: $\alpha = 0.002$, ACC UI and Hands-on steering wheel UI: $\alpha = 0.008$. The analysis was done in JMP Pro 17.0.

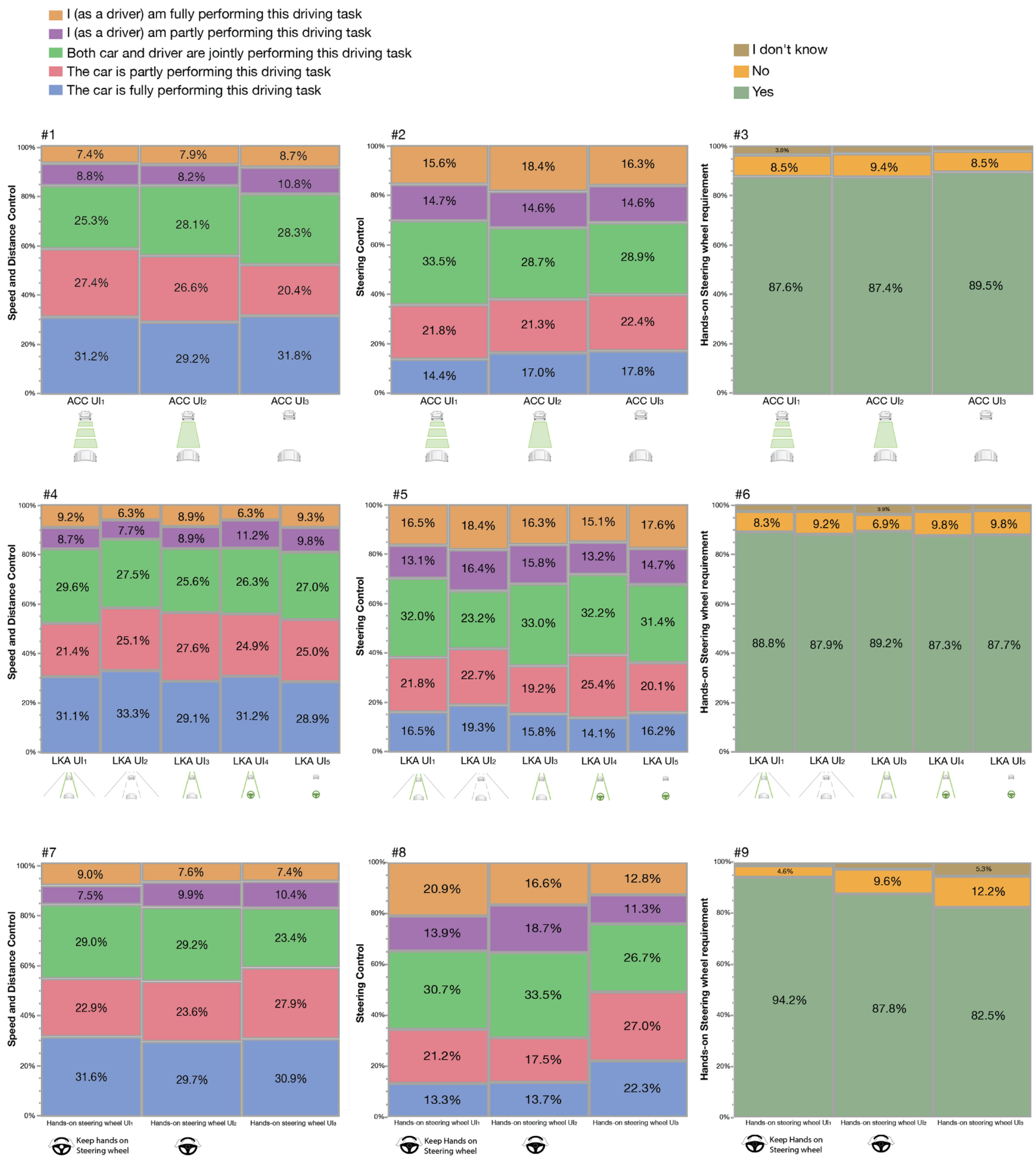


Fig. 6. Respondent's choice of speed and distance control (left), steering control (mid), and hands-on steering wheel requirement (right) for ACC UI (top), LKA UI (mid), and Hands-on steering wheel UI (bottom). * *Note: The vertical order of each bar in the graph corresponds to the vertical order of the legend descriptions.*

3. Results

3.1. Data validation

1125 respondents completed the questionnaire between April and May 2023. A data filtering process was carried out to exclude respondents whose survey completion time was the shortest from each UI condition. The resulting sample size was 96 % (1080 respondents) of 1125 respondents. Within the resulting sample, the median time to complete the survey was 04:20 min, and the fastest time to complete the questionnaire was 01:30 min. The general characteristics of the 1080 retained respondents were as follows. 50 % of respondents were female and 50 % were male. The age distribution ranged from 18 to 49, with 33 % between 19 and 29, 33 % between 30 and 39, and 33 % between 40 and 49. 6 % were from Germany, 24 % were from the United States, and 70 % were from the United Kingdom. All respondents owned a car and had experience with driving with LKA and ACC.

3.2. Understanding of control

ACC UI, LKA UI, and Hands-on steering wheel UI were expected to influence the understanding of speed and distance control, steering control, and hands-on steering wheel requirement, respectively. However, the results indicated that only the Hands-on steering wheel UI had any significant effect on the understanding of control.

This is illustrated graphically in Fig. 6, whereas statistics are in Table 5. The left column of Fig. 6 shows the respondent's choice of *speed and distance control*; the middle column shows *steering control* and the right column shows the *hands-on steering wheel requirement*. The left and middle columns show major dispersion between respondents in the choice of control, with no discernible differences in control comprehension based on ACC UI and LKA UI. Over 8 % incorrectly stated the driver to be in full control of speed and distance, and over 18 % incorrectly stated the driver to be in full control of steering. Conversely, over 30 % state the car is in full control of speed and distance, and around 16 % state the car is in full control of steering.

Respondent's choice of *Hands-on steering wheel requirement* showed a difference in response by Hands-on steering wheel UI, whereas even without hands-on steering wheel information (*Hands-on steering wheel* UI_3 in Fig. 6 right-bottom), 82.5 % correctly stated that hands should be on the wheel. This improved to 87.8 % with the icon without text (*Hands-on steering wheel* UI_2 in Fig. 6 right-bottom) and to 94.2 % with the icon with text (*Hands-on steering wheel* UI_1 in Fig. 6 right-bottom). The Hands-on steering wheel UI also affected the respondents' choice of *Steering control*, where the *Hands-on steering wheel* UI_1 with an icon and text increased the number of responses of the driver being in full control of steering (Fig. 6 mid-bottom).

The following statistical analysis supports these findings.

Nominal logistics analysis was conducted with UI factors (LKA UI, ACC UI, and Hands-on steering wheel UI) as independent variables and respondents' choice of control as a response variable. A generalized Linear Model Fit revealed a statistically significant effect suggesting the model's usefulness in differentiating between respondents' choice of *Steering control* ($\chi^2(176, N = 1025) = 208.20$, $p < 0.01$, $R^2(U) = 0.065$, $AICc = 3450.37$, $BIC = 4261.01$) and *Hands-on steering wheel requirement* ($\chi^2(88, N = 1025) = 127.70$, $p < 0.01$, $R^2(U) = 0.145$, $AICc = 951.73$, $BIC = 1378.11$). However, no statistically significant evidence was found supporting the model's usefulness in differentiating between respondents' choice *of distance control* ($\chi^2(176, N = 1025) = 170.66$, $p = 0.60$, $R^2(U) = 0.056$,

Table 5
Effect likelihood ratio tests of the respondents' choice of control.

	UI factors	L-R χ^2	df	*p*-value	*Pseudo-R-squared*	*Cramér's V*
Speed and distance control	LKA UI	7.11	16	0.58	0.005	0.118
	ACC UI	3.92	8	0.45	0.003	0.087
	Hands-on steering wheel UI	3.24	8	0.59	0.002	0.079
	LKA UI * ACC UI	17.23	32	0.35	0.011	0.183
	LKA UI * Hands-on steering wheel UI	22.53	32	0.06	0.015	0.210
	ACC UI * Hands-on steering wheel UI	12.03	16	0.09	0.008	0.153
	LKA UI * ACC UI * Hands-on steering wheel UI	33.66	64	0.36	0.022	0.256
Steering control	LKA UI	16.97	16	0.39	0.005	0.129
	ACC UI	8.435	8	0.39	0.003	0.091
	Hands-on steering wheel UI	32.32	8	< 0.001	0.010	0.178
	LKA UI * ACC UI	37.59	32	0.23	0.012	0.192
	LKA UI * Hands-on steering wheel UI	30.57	32	0.54	0.009	0.173
	ACC UI * Hands-on steering wheel UI	19.17	16	0.26	0.006	0.137
	LKA UI * ACC UI * Hands-on steering wheel UI	90.26	64	0.20	0.028	0.297
Hands-on steering wheel requirement	LKA UI	2.54	8	0.97	0.003	0.050
	ACC UI	0.00	4	1.00	0.000	0.000
	Hands-on steering wheel UI	16.64	4	< 0.001	0.019	0.127
	LKA UI * ACC UI	7.41	16	0.96	0.008	0.085
	LKA UI * Hands-on steering wheel UI	6.09	16	0.99	0.007	0.077
	ACC UI * Hands-on steering wheel UI	1.96	8	0.98	0.002	0.044
	LKA UI * ACC UI * Hands-on steering wheel UI	38.58	32	0.20	0.044	0.194

* Note: Cramér's V ≤ 0.2 means the results are weak, 0.2 < Cramér's V ≤ 0.6 means the results are moderate and 0.6 < Cramér's V means the results are strong.

Table 6
Contingency analysis of the respondent's choice.

	UI factors	*n*	*df*	*−Loglikelihood*	R square (*U*)	χ^2 (likelihood ratio)	*p-value*	*Percentage of the model fit*	*Cramér's V*
Distance control	LKA UI	1025	16	3.644	0.0024	7.288	0.97	4.3 %	0.084
	ACC UI	1025	8	3.499	0.0023	6.997	0.54	4.1 %	0.083
	Hands-on steering wheel UI	1025	8	3.834	0.0024	7.268	0.51	4.5 %	0.084
Steering control	LKA UI	1025	16	5.338	0.0033	10.677	0.83	5.1 %	0.102
	ACC UI	1025	8	1.978	0.0012	3.956	0.86	1.9 %	0.062
	Hands-on steering wheel UI	1025	8	16.485	0.0102	32.97	< 0.001	15.8 %	0.179
Hands-on steering wheel requirement	LKA UI	1025	8	1.136	0.0026	2.272	0.97	1.8 %	0.047
	ACC UI	1025	4	1.119	0.0025	2.237	0.69	1.8 %	0.047
	Hands-on steering wheel UI	1025	4	12.628	0.0286	25.256	< 0.001	19.8 %	0.157

* Note: Percentage of the model fit is loglikelihood/full mode loglikelihood.

AICc = 3310.83, *BIC* = 4121.147). The results of the effect likelihood ratio test, *Pseudo R-squared* and *Cramér's V* are presented in Table 5. The McFadden Pseudo R-squared statistic (McFadden & Zarembka, 1974) was used to assess the model's fit, and *Cramér's V* was employed as a measure of effect size. The effect likelihood ratio tests also indicated that Hands-on steering wheel UI had a statistically significant effect on respondents' choice of *Steering control* and *Hands-on steering wheel requirement*.

Furthermore, the original contingency table (Reynolds, 1977) was split up into three types of control, as presented in Table 6. A comparison of the fit of the sub-table to the whole model table is shown as a percentage of the model fit, indicating the contribution of each UI factor to the entire model. The analysis results demonstrate that the Hands-on steering wheel UI accounts for 15.8 % and 19.8 % of the *Steering control* and *Hands-on steering wheel requirement* logistic regression model, respectively.

The biplot of multiple correspondence analysis is presented in Fig. 7. The results show that the Hands-on steering wheel UI influences responses and diverges based on the varying levels of performance of the answer. The first two dimensions of the analysis accounted for 72.1 % of the total inertia (dimension 1: 54.9 %; dimension 2: 17.2 %). The first dimension, which explains the majority of the variability (54.9 %), primarily reflects differences in responses related to the Hands-on steering wheel UI. This suggests that respondents' answers varied significantly depending on the presence or absence of the Hands-on steering wheel UI. For instance, respondents tended to indicate that they would place their hands on the steering wheel or perceive the driver as fully performing steering control when *Hands-on steering wheel* UI_1 and *Hands-on steering wheel* UI_2 were provided. Conversely, when hands-on steering wheel information was absent (*Hands-on steering wheel* UI_3), respondents tended to report not placing their hands on the steering wheel or perceiving the vehicle as fully performing steering control. The second dimension, accounting for a smaller portion of the variability (17.2 %), represents differences in responses between systems that were partially performing and those that were fully performing. This indicates that respondents' answers also differed based on the level of performance of the systems being evaluated.

3.3. Information usability

Respondents indicated that Hands-on steering wheel information presented using text and an icon provides higher information quality and makes it easier to understand the hands-on requirement, as shown in Fig. 8. Fig. 8 displays the mean scores of the two attributes (*Information quality* and *Understanding of hands-on requirement)* categorised by Hands-on steering wheel UI.

The mean score of two questions about clarity (Question #4) and ease of understanding (Question #5) of information were used in the analysis as *Information quality*. Cronbach's analysis showed a high reliability between each respondent's score of four items (Cronbach's alpha = 0.90). The results showed the effect of UI factors on respondents' answers to *Information quality* ($F(44, 980) = 1.64, p = 0.01, \eta^2 = 0.068$) and *Understanding of hands-on requirement* ($F(4, 980) = 7.43, p < 0.001, \eta^2 = 0.261$). There was no significant effect of UI on the answers to *Understanding when the car controls speed and distance* ($F(44, 980) = 0.90$, $p = 0.66$, $\eta^2 = 0.050$) and *Understanding when the car controls steering* ($F(44, 980) = 0.97$, $p = 0.52$, $\eta^2 = 0.039$). Table 7 presents the effect tests on the respondents' answers. The results revealed that Hands-on steering wheel UI affected the respondents' answers to *Information quality* and *Understanding of hands-on requirements*.

Post-hoc analysis revealed that the scores were significantly higher when information was presented using both text and an icon (*Hands-on steering wheel* UI_1), compared to when there was no hands-on steering wheel information (*Hands-on steering wheel* UI_3) or when there was the information presented only in the text (*Hands-on steering wheel* UI_2), as shown in Fig. 8.

3.4. Trust

The respondent's trust was not affected by UI factors but by the interaction between all UI factors. The mean score of four trust-related items was used to analyse Trust. Cronbach's analysis showed the high reliability between each respondent's score of four items (Cronbach's alpha = 0.80). The results showed there was an impact of UI factors on respondents' answers to *Trust* ($F(44, 976) = 1.68, p = 0.004, \eta^2 = 0.063$). Table 8 shows the effect of the test on the respondent's choice. The respondents' answers were not affected by a single UI factor but by the three-factor interaction among ACC UI, LKA UI, and Hands-on steering wheel UI.

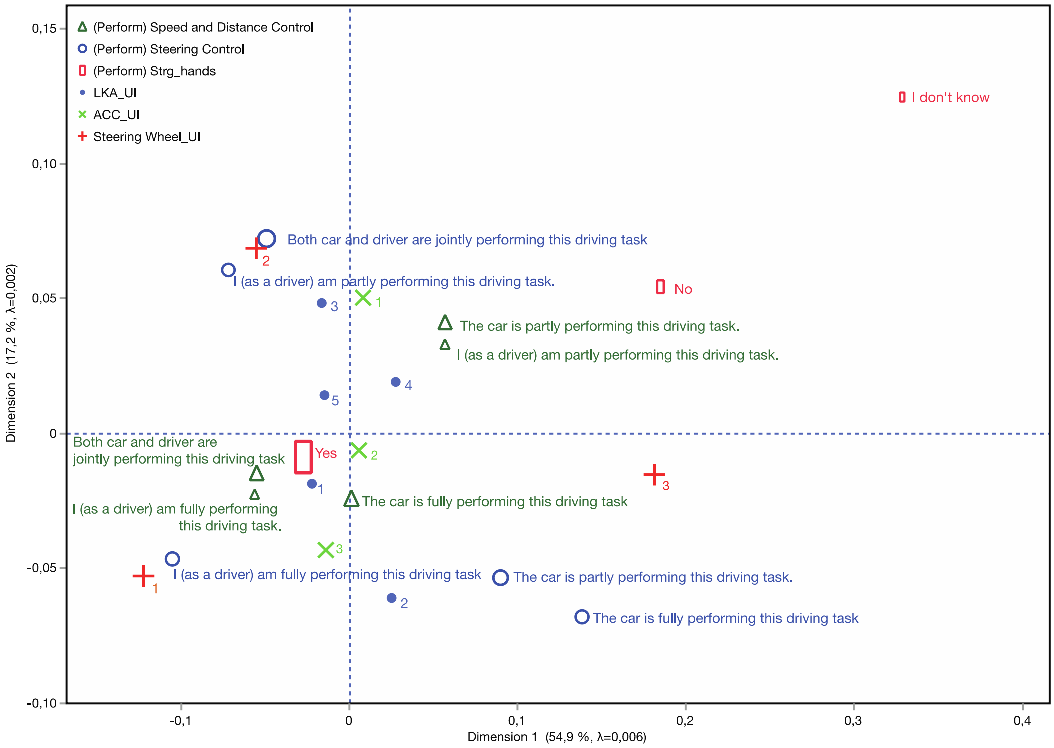


Fig. 7. Biplot of multiple correspondence analysis.

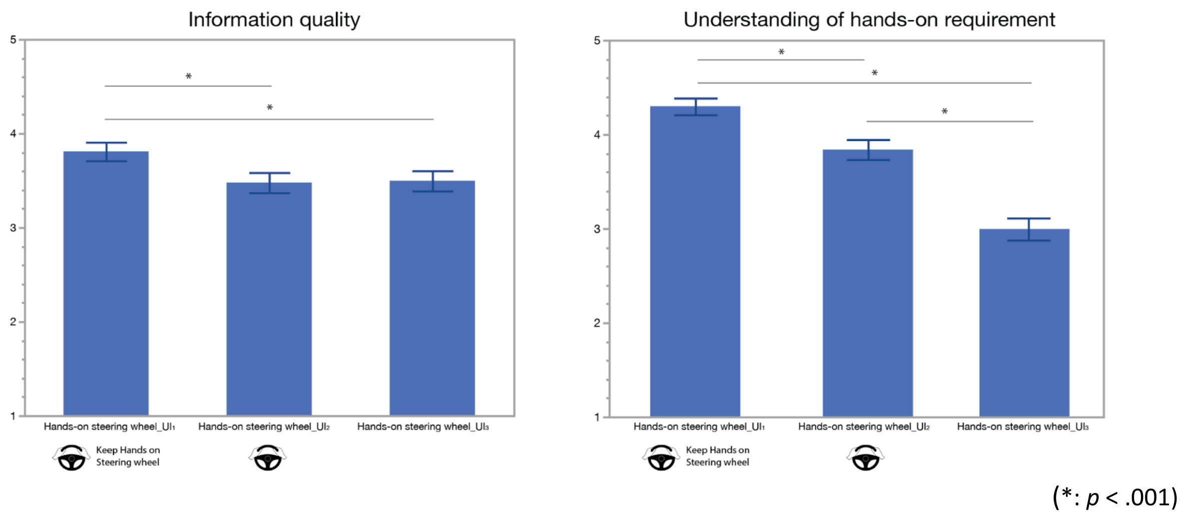


Fig. 8. The mean score of Information quality (left) and Understanding of hands-on requirement (right) categorised by Hands-on steering wheel UI.

Fig. 9 illustrates the average trust scores of Hands-on Steering Wheel UI and the interaction between LKA UI and ACC UI. Each line in the graph represents the trust score when combined with the LKA UI for each ACC UI. The average trust score for each Hands-on steering wheel UI is indicated in the middle of the graph. When the *Hands-on steering wheel UI$_1$* is combined with ACC UI$_3$ and LKA UI$_4$, the trust score significantly drops compared to the average trust score of ACC UI$_3$ and LKA UI$_4$ alone. Despite the overlap of the steering wheel icon, there appears to be a decrease in trust when presenting different information through similar iconical information.

Table 7
Effect tests on the respondent's choice of Information usability.

	UI factors	df	F Ratio	p-value	η^2
Information quality	LKA UI	4	1.22	0.30	0.005
	ACC UI	2	0.65	0.52	0.001
	Hands-on steering wheel UI	2	10.62	0<.001	0.021
	LKA UI * ACC UI	8	0.62	0.66	0.005
	LKA UI * Hands-on steering wheel UI	8	1.97	0.05	0.016
	ACC UI * Hands-on steering wheel UI	4	2.06	0.08	0.008
	LKA UI * ACC UI * Hands-on steering wheel UI	16	1.01	0.44	0.016
Understanding when car controls speed and distance	LKA UI	4	0.33	0.86	0.001
	ACC UI	2	0.06	0.94	0.000
	Hands-on steering wheel UI	2	0.72	0.49	0.001
	LKA UI * ACC UI	8	0.26	0.98	0.002
	LKA UI * Hands-on steering wheel UI	8	1.68	0.10	0.013
	ACC UI * Hands-on steering wheel UI	4	1.93	0.10	0.008
	LKA UI * ACC UI * Hands-on steering wheel UI	16	0.85	0.63	0.013
Understanding when car controls steering	LKA UI	4	0.12	0.97	0.000
	ACC UI	2	0.90	0.41	0.002
	Hands-on steering wheel UI	2	2.89	0.06	0.006
	LKA UI * ACC UI	8	0.75	0.65	0.006
	LKA UI * Hands-on steering wheel UI	8	1.34	0.22	0.010
	ACC UI * Hands-on steering wheel UI	4	1.89	0.11	0.007
	LKA UI * ACC UI * Hands-on steering wheel UI	16	0.70	0.80	0.011
Understanding of hands-on requirement	LKA UI	4	0.48	0.75	0.001
	ACC UI	2	2.09	0.12	0.003
	Hands-on steering wheel UI	2	137.57	0<.001	0.211
	LKA UI * ACC UI	8	1.28	0.25	0.008
	LKA UI * Hands-on steering wheel UI	8	1.49	0.16	0.009
	ACC UI * Hands-on steering wheel UI	4	2.28	0.06	0.007
	LKA UI * ACC UI * Hands-on steering wheel UI	16	1.10	0.35	0.013

Table 8
Effect test on the respondent's choice of Trust.

	Sources	df	F Ratio	p-value	η^2
Trust	LKA UI	4	2.12	0.08	0.008
	ACC UI	2	2.62	0.07	0.005
	Hands-on steering wheel UI	2	1.33	0.27	0.003
	LKA UI * ACC UI	8	1.44	0.18	0.011
	LKA UI * Hands-on steering wheel UI	8	1.16	0.32	0.009
	ACC UI * Hands-on steering wheel UI	4	0.92	0.45	0.004
	LKA UI * ACC UI * Hands-on steering wheel UI	16	2.09	0.01	0.033

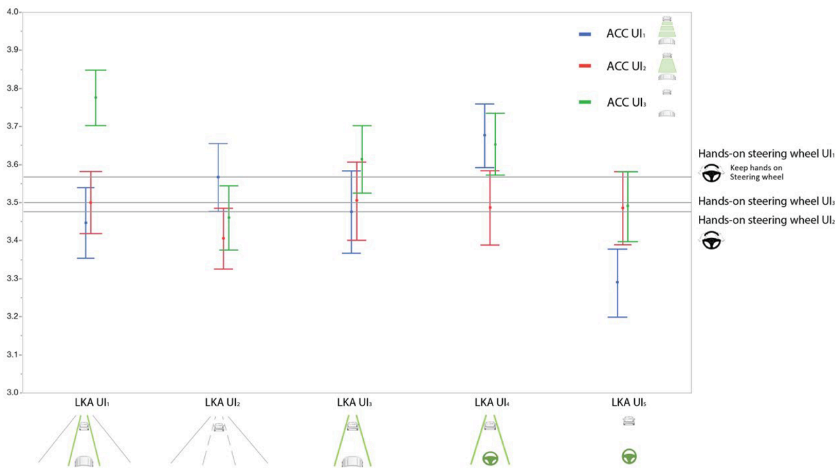


Fig. 9. Trust score of interaction between LKA UI, ACC UI and Hands-on steering wheel UI (Range of trust rating is 5 Likert scale (1 to 5)). **Note: Each Hands-on steering wheel UI score is the average trust score.*

4. Discussion

4.1. The impact of visual UI

The results highlight the beneficial and limited role of visual user interfaces (UIs). Hands-on steering wheel UI impacts respondents' understanding of two understandings of control: hands-on steering wheel requirement and steering control. The presence of hands-on steering wheel information effectively communicates to drivers the requirement of keeping their hands on the steering wheel. At the same time, variations of the ACC UI and LKA UI did not affect the understanding of the control mode.

In the study, *Hands-on steering wheel UI_1* provides hands-on requirement information by combining the hands on the wheel icon and the text "Keep hands on steering wheel". Regarding the understanding of the requirement of hands-on steering, the best results were obtained with *Hands-on steering wheel UI_1*, which is significantly more effective as compared to only *Hands-on steering wheel UI_2*, which does not provide text and no UI of hands-on requirement (*Hands-on steering wheel UI_3*). The same result can be seen in the response as to whether hands-on requirement information helps understand the hands-on steering requirement. Hands-on steering wheel UI influenced the understanding of information clarity and ease of understanding. When text accompanied the icon (*Hands-on steering wheel UI_1*), respondents indicated that it was more straightforward and easier to understand than when only icons were provided or no textual information was present.

The responses regarding the understanding of steering control categorised according to the Hands-on steering wheel UI demonstrated a tendency to perceive lower driver steering control when there were no displayed requirements for hands-on steering. Interestingly, the understanding of steering controls appeared to be more influenced by the depiction of the Hands-on steering wheel UI than the LKA UI. It can be interpreted that the *Hands-on steering wheel UI_1* tends to increase the perceived driver role in steering. This encourages active steering control, thereby stimulating driver engagement. Here, it shall be realised that most LKA systems also encourage active steering by assisting only when needed, while others, like Tesla Autopilot, do not require active steering. Thus, most LKA creates shared control with a dominant role of the human driver.

While the Hands-on Steering Wheel UI factor has demonstrated a significant impact, the LKA UI and ACC UI factors have shown no effect on understanding their corresponding automation mode. The five LKA UI variations did not influence the understanding of steering control, and the three ACC UI variations did not affect the understanding of speed control. Regardless of the UI, including LKA and ACC UI as well as the icon of LKA and ACC (Fig. 4), the large variance in responses regarding the understanding of steering control and speed and distance control (Fig. 6 left and middle column) indicates confusion caused by mode ambiguity, suggesting that drivers do not well understand how the speed and distance control and steering control task is shared between driver and automation. This ambiguity can be reduced through user interfaces, but it fundamentally stems from system design and the driver's perception of it. Driving automation features may lead to differences in how each driver perceives the division of control between the driver and the car, and even further, there are differences in interpretation. A system design that diverges from the driver's understanding or is unclear points to a more fundamental issue, such as a lack of comprehension that affects how drivers interpret and respond to the information provided by the user interfaces.

Furthermore, the study found no significant impact of UI factors on respondents' choices regarding trust except for the three-way interaction effect. Drivers may understand the function of driving automation mainly through icons consistently provided in all UIs. Since drivers already have SAE Level 2 experience and understand the fundamental purpose of vehicle automation, variations in the visual UI design may not significantly impact their trust. In addition, trust in automated vehicles is typically influenced by a combination of factors, including system performance, reliability, user experience, and safety records. While important for recognition and usability, icon design may be a secondary or less critical factor in determining trust compared to these primary factors.

4.2. Design Implications

Current SAE Level 2 automated vehicles present information regarding the hands-on steering requirement through pop-up messages rather than fixed images. This study emphasises the necessity of implementing a dedicated continuous Hands-on Steering Wheel UI. When the hands-on steering wheel information was not provided, approximately 20 % of respondents either misunderstood the need to keep their hands on the steering wheel or became confused about this requirement. When the hands-on steering wheel requirement was clearly displayed with an icon and text, respondents better understood these requirements, with 94 % correct responses. This also affected respondents' understanding of steering control, with more respondents indicating to be in control. This happens due to LKA icons in current market vehicles. LKA activation is shown with the steering wheel icon – sometimes with a hand or sometimes without hands on the steering wheel, as shown in Fig. 1. This has also been spotted for an LKA icon, depicting hands on the steering wheel (Perrier et al., 2021). This is not seen as a UI design error but rather as a reflection of understanding the driver's perceived steering control in association with whether they keep their hands on the steering wheel.

With the advent of SAE Level 3, the concept of control handover between the vehicle and the driver will likely add another layer of complexity. Especially in SAE Level 3 automated vehicles, not only does the source of main control (the driver or the car) shift, but the responsibility of control (the driver or the car) also changes, so drivers should understand the driving mode and their own role. For example, a SAE Level 3 automated vehicle on-road driving study (Kim et al., under review) showed that even when drivers were aware of the hands-on steering wheel requirement, some drivers naturally removed their hands from the steering wheel after transitioning from SAE Level 3 to Level 2. Integrating multiple driving automation levels within a vehicle highlights the importance of designing a driver-vehicle interaction (Kurpiers et al., 2020; Sarter & Woods, 1995). The introduction of higher driving automation has already sparked important discussions and considerations regarding issues of perceived control and responsibility (Novakazi et al., 2021). The lack of the current understanding poses a safety risk, as an understanding of control can be attributed to various factors, including insufficient cues to indicate mode changes or a lack of current automation status information. Consequently, the design and implementation of effective UIs become increasingly important in ensuring safe, efficient, and user-friendly interactions with complex systems. For driver safety, the results of this study suggested that it is advisable to indicate the hands-on steering wheel requirement clearly. Notably, given the potential for ambiguity in conveying this information through icons alone, the results underscore the importance of incorporating accompanying text for effective communication. At the same time, in-vehicle visual information can also be visually demanding, potentially distracting from the task of driving (Nordhoff & Hagenzieker, 2024) or drivers sometimes just put their hands on the steering wheel to appease the system (Nordhoff et al., 2023). Therefore, the hands-on steering wheel requirement has to be critically investigated in future research.

4.3. Limitations and future research

This survey used static images to evaluate drivers' understanding of driving automation status in SAE Level 2 driving scenarios. While static images offer controlled and consistent stimuli for evaluation, they lack the dynamic nature of real-world driving environments. Automation status is not conveyed through isolated snapshots in actual driving situations but evolves continuously as the vehicle interacts with its surroundings. Drivers' understanding of the automation status may differ when confronted with the dynamic and evolving nature of a live driving scenario. While this study contributes insights into drivers' understanding of user interfaces, further study is needed to show UI effectiveness in real-time dynamic interactions. In addition, simplified images were used to control the factors that have visual effects, but the visual UIs of real vehicles include more information. Since we referenced the ACC and LKA icons from a previous study, not all possible combinations of different icons were examined. Given that the steering wheel image in the LKA icon can lead to confusion, further research is warranted to investigate the design of the LKA icon and the Hands-on steering wheel requirement icon, with a focus on differentiating between these two meanings.

5. Conclusion

This study investigates the impact of visual user interfaces (UI) on driver mode awareness in SAE Level 2 automated vehicles through an online questionnaire. The findings highlight both the limitations and effects of the UI in shaping users' understanding of control. Specifically, differences between the Adaptive Cruise Control (ACC) UI and the Lane Keeping Assist (LKA) UI did not significantly affect users' perceptions of speed/distance control and steering control. Additionally, the wide variation in responses related to understanding speed/distance control and steering control indicates confusion stemming from mode ambiguity. This suggests that mode ambiguity may be rooted in system design limitations rather than UI presentation alone. However, the Hands-on steering wheel UI significantly improved drivers' understanding of the hands-on steering wheel requirement. The combination of a hand icon on the steering wheel and the text "Keep hands on steering wheel" enhanced understanding of the hands-on requirement compared to conditions where no text or no information was provided. Variations in the visual UI did not influence trust in the system. This study emphasises the need for UIs that clearly communicate steering wheel requirements to drivers. Furthermore, it highlights the inherent limitations of interface design in fully mitigating mode confusion, especially in complex systems where drivers are required to manage multiple driving automation modes within a vehicle. This study contributes to the understanding and designing of visual UIs for effective communication of driving modes in automated vehicles.

CRediT authorship contribution statement

Soyeon Kim: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Formal analysis, Data curation, Conceptualization. **Sina Nordhoff:** Writing – review & editing, Methodology, Conceptualization. **René van Egmond:** Writing – review & editing, Visualization, Supervision, Methodology, Formal analysis. **Riender Happee:** Writing – review & editing, Supervision, Methodology.

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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Appendix 1: Visual UI references

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2. BMW 3 2021 owner's manual: https://www.bmwusa.com/owners-manuals.html

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5. Ford Explorer 2021 owner's manual: https://www.ford.com/support/vehicle/explorer/2021/owner-manuals/
6. GMC Sierra 2022 owner's manual: https://www.gmc.com/support/vehicle/manuals-guides
7. Honda HR-V 2020 owner's manual: https://www.honda.co.uk/cars/owners/manuals-and-guides/honda-hrv-owners-manuals.html
8. Honda Legend 2022 official YouTube: https://www.youtube.com/watch?v
9. Hyundai Ioniq5 2023 owner's manual: https://www.hyundai.com/kr/ko/digital-customer-support/helpdesk/download-center
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14 Nissan Ariya 2021 owner's manual: https://www.nissanusa.com/owners/ownership/manuals-guides.html
15. Nissan Ariya concept 2022 official site: https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwirv-nn_NWCAxV-hv0HHdTSCBsQFnoECBsQAQ&url=https%3A%2F%2Fwww.nissan-global.com%2FEN%2FINNOVATION%2FDESIGN%2FDESIGNWORKS%2FARIYACONCEPT%2F&usg=AOvVaw2NX3K8uoU4sTKy61t9UCH5&opi=89978449
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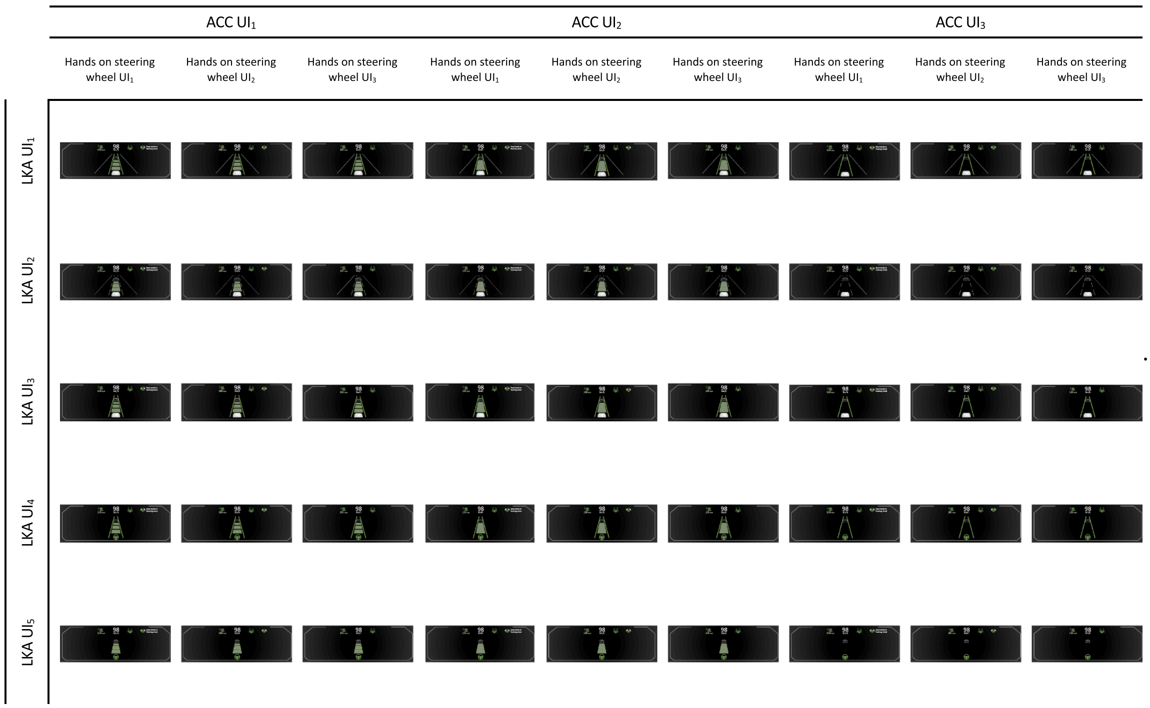
23. Volvo XC 40 2021 owner's manual: https://www.volvocars.com/uk/support/car/xc40/22w46

Appendix 2: 45 images



Appendix 3: Questionnaire

(Question 1–2) Who is performing each part of the driving task? By driving task, we mean speed and distance control, and steering.

	The car is fully performing this driving task	The car is partly performing this driving task.	Both car and driver are jointly performing this driving task	I (as a driver) am partly performing this driving task.	I (as a driver) am fully performing this driving task
Speed and Distance Control (Acceleration and Braking)	◦	◦	◦	◦	◦
Steering Control	◦	◦	◦	◦	◦

(Question 3) Do you think that it is required to keep your hands on the steering wheel most of the time?

◦ Yes

◦ No

◦ I don't know

(Question 4–8) Please rate the quality of the information provided on the image.

	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
The information on the image is clear	◦	◦	◦	◦	◦
The information on the image is easy to understand	◦	◦	◦	◦	◦
The information on the image helps me to understand when the car controls speed	◦	◦	◦	◦	◦
The information on the image helps me to understand when the car controls steering	◦	◦	◦	◦	◦
The information on the image helps me to understand when I have to keep my hands on the steering wheel	◦	◦	◦	◦	◦

	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
The automated car is reliable	◦	◦	◦	◦	◦
I can trust the automated car	◦	◦	◦	◦	◦
The automated car is dependable	◦	◦	◦	◦	◦
I am suspicious of the automated car's intent and action	◦	◦	◦	◦	◦

Data availability

Data will be made available on request.

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