From Brake Lights to Beyond – Exploring Information Needed for Car-Following Behavior

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ABSTRACT

The rear-end crash is highly related to the car-following (CF) behaviors. Increasing evidence suggests that, in addition to direct leading vehicle (DLV) information, considering beyond-visual-range (BVR) and implicit information when following the traffic flow can reduce collision risk. However, to date, little is known about drivers' needs for BVR and implicit information in CF events. Thus, to guide the innovation of external human-machine interface (eHMI) design, which aims to facilitate safer CF behaviors, we adopted a two-stage approach, including a focus group study (N=38) and a field study (N=30) to understand drivers' information needs and the decision-making process in CF events. Participants included drivers from various professions and with diverse driving experiences. Through thematic analysis, we found that drivers' CF behaviors depend on more than relative motions between the subject vehicle and the DLV, but also on the traffic conditions (congested or not), the behavior, mental state, and driving style of the leading driver, the traffic flow ahead, and even the behavior of the following vehicle. At the same time, drivers have high expectations of BVR information on eHMIs when following traffic. This study offers insights into CF behavior and eHMI design aimed at reducing rear-end collisions.

Keywords: human-machine interface, driver behavior, car-following, focus group

1 INTRODUCTION

The car-following (CF) behaviors are closely related to rear-end collisions, which accounted for over 28.85% of all crashes on the road (National Safety Council, 2023). Thus, endeavors have been made to guide and regulate CF behaviors and understand the factors that affect drivers' risky CF behaviors, such as tailgating (Kerwin & Bushman, 2020; Nicolls et al., 2022). In recent years, an increasing amount of research has found that following drivers would not only react to the direct leading vehicle (DLV) motion, but also actively seek the beyond-visual-range (BVR) information and implicit information to make earlier preparations for potential incidents in CF events (Muhrer & Vollrath, 2010; Nirmale et al., 2024). For example, He et al. (2021) found that when provided with BVR information about road obstacles, drivers were better at predicting traffic slowdowns before the DLV braked. Liu et al. (2025) found that drivers would consider the implicit states of the rear tailgating vehicles when following leading vehicles (LVs). Thus, explicitly informing drivers of the BVR information and the implicit information may support safer and more efficient driving behaviors.

However, under current road and vehicle conditions, communication between drivers primarily relies on limited explicit visual (such as headlights, brake lights, hazard lights, and turn signals) and auditory signals (such as horns), though implicit cues, including vehicle motion and driver gestures, can sometimes supplement (Moore et al., 2019). This type of vehicle-to-vehicle interaction is primarily based on the systems standardized over a century ago (e.g., brake lights were introduced in 1915, and turn signals were invented in 1909) (Moore & Rumar, 1999). These systems can only provide surrounding road users with explicit, operational-level information (i.e., immediate vehicle actions) within the range of visual perception.

In recent years, technological advancements have enabled the perception and transmission of BVR and implicit information in traffic. Firstly, intelligent connected vehicles have expanded the range of information that vehicles can acquire. By utilizing sensing hardware, vehicle-to-everything (V2X) communication, data from map providers, and roadside units, vehicles can now obtain speed and position information of multiple vehicles or obstacles ahead and broadcast this data, enabling the acquisition and transmission of beyond-line-of-sight information (Fayyad et al., 2020). At the same time, recent advancements in Driver Monitoring Systems (DMS) have made the assessment of drivers' states (e.g., fatigue and distration, Fu et al., 2024) or intention (e.g., lane-changing, Huang et al., 2024) possible. Such information, when integrated with vehicle communication systems, can be transferred to nearby road users (Koesdwiady et al., 2017), facilitating the communication of implicit information.

Unfortunately, to date, the use of BVR and implicit information in road systems is primarily focused on optimizing the perception, control, and coordination of intelligent connected vehicles (Bento et al., 2012; Karafyllis et al., 2025). There is no consensus on the needs of human road users for BVR and implicit information, although human road users will remain the dominant participants in traffic in the short term. Specifically, the BVR and implicit information can be conveyed through the human-machine interaction (HMI) systems, which can be categorized as in-vehicle HMI and external HMI (eHMI). The former relies on a standardized V2X communication protocol to function, while the latter can be based solely on the individual vehicle's perception capabilities (e.g., DMS or on-board LiDAR systems) and has greater potential to benefit traffic systems at this stage. For example, vehicles with eHMI can deliver their perceived information to nearby vehicles, thereby providing BVR and implicit information to surrounding road users without relying on V2X technologies. Thus, in this study, we primarily focus on drivers' needs for BVR and implicit information in CF events, specifically their expectations of obtaining them through the eHMI.

As a preliminary study, we adopted a two-step approach. First, in a focus group, we aimed to explore drivers' needs for BVR and implicit information in CF events, given that the focus group method can efficiently and relatively comprehensively capture users' needs. Specifically, we focused on drivers' expectations of BVR and implicit information in CF events and queried about their needs for eHMI to provide such information. Considering driving experience is associated with crash rates (da Silva et al., 2012; McCartt et al., 2003; Mullin et al., 2000) and drivers with different driving styles may exhibit different CF behaviors (Nees et al., 2021; Zorrofi et al., 2009), participants with diverse driving experiences and professions were recruited. Further, considering the prevalence of driving automation in recent years and the coexistence of autonomous vehicles (AVs) and human-driven vehicles (HDVs) on the road, we also sought the opinions of AV safety drivers. Then, in the second step, to elicit more valid opinions on the needs for BVR information in CF events, we designed two eHMI prototypes, based on the findings from the focus group, to convey basic BVR information to the following vehicles. Another batch of participants was invited to experience the eHMIs in the on-road field study, and we collected their feedback regarding the BVR information provided in the prototypes.

In summary, this study makes the following contributions. First, through thematic analysis of focus group discussions with drivers from diverse backgrounds, we identified a broader set of factors shaping CF decisions (beyond the kinematic states of the DLV), thereby expanding our understanding of drivers' information needs in CF events. Second, we provide empirical insights into eHMI designs to support drivers during CF events and evaluate two prototypes in an on-road field study, thereby informing future eHMI designs.

2 LITERATURE REVIEW

2.1 Factors affecting drivers' CF behavior

Drivers' characteristics, such as age, gender, and driving experience, were found to influence CF behaviors (Ishibashi et al., 2007). At the same time, even for the same driver, CF behaviors varied with driver states. Thus, various studies have examined factors affecting drivers' risky CF behaviors, such as tailgating (Kerwin & Bushman, 2020; Nicolls et al., 2022). For example, Zhang et al. (2016) found that higher fatigue levels, measured by the Karolinska Sleepiness Scale and the percentage of eye closures, led to shorter and more variable time headways, thereby increasing the risk of rear-end collisions. Another study suggested that the driver's attention to the average speed of nearby vehicles (not just DLV) is another influential factor in stabilizing traffic (Siwach et al., 2025).

In addition to driver-related factors, environmental factors such as road conditions, traffic density, and weather also played significant roles in shaping CF behaviors. Poor road conditions, high traffic density, and adverse weather could lead to more conservative driving behaviors, such as increased headways and reduced speeds (Han et al., 2022). Also, recent modeling studies that incorporate visibility effects have shown that limited visibility alters drivers' responses and can affect traffic stability, particularly in mixed-traffic environments (Redhu & Mehta, 2025). Furthermore, drivers considered not only the motion states of the DLV when following it but also the states of their taillight (Zhang et al., 2018). Finally, drivers may also take different CF strategies in different sections of the road. For example, Zhang et al. (2025) identified seven speed-control patterns when approaching and passing signal lights and found that signalized intersections can induce traffic oscillations compared with regular CF conditions.

In recent years, with the development of mixed traffic, AVs have also found to affect CF behaviors. For example, Rahmati et al. (2019) found that human drivers following AVs exhibited different driving patterns compared to those following HDVs. Specifically, the smoother, more predictable behaviors of AVs can lead to more stable traffic flow and reduce the formation of shockwaves in mixed traffic. Similarly, Ma et al. (2023) also suggested that increasing AV penetration reduces stop-and-go waves and improves traffic capacity in mixed traffic.

Based on these previous studies, it can be observed that CF behaviors are not only related to the relative position or speed of the LV but also to drivers' own states and information about other road agents and the environment. However, few studies have examined the influence of BVR information on drivers' CF behaviors, and, to the best of our knowledge, no studies have systematically examined drivers' needs for BVR and implicit information in CF events.

2.2 HMIs to optimize CF behaviors

Various studies have investigated how additional information can enhance CF behaviors. Among them, novel HMIs have been proposed to provide drivers with specific information, aiming to support safer CF behaviors. For example, in-cabin forward collision warning (FCW) systems that alert drivers to potential collision risks with the DLV have been widely studied, with their effectiveness validated in both driving simulator studies (Koustanaï et al., 2012) and on-road studies (Song et al., 2017). However, traditional FCW systems considered only the states of the DLV and could not provide BVR information. Thus, Gu et al. (2026) proposed four types of in-vehicle HMIs to inform drivers of the states of the indirect leading vehicle (ILV) during chain-braking events and found that such information could reduce the collision risk in CF events. Ren et al. (2025) further found that HMIs providing BVR information through connected vehicle technologies can reduce crash risk on foggy freeways. However, they tested only specific HMIs in a driving simulator study under a particular scenario. At the tactical level, He et al. (2021) provided drivers with upcoming traffic information in a bird-view display and found that such an HMI could improve drivers' hazard perception performance in CF events. However, although different HMIs were explored and some were found to be effective, no research has systematically evaluated drivers' needs for BVR or implicit information in CF events.

2.3 eHMIs development

Beyond HMI designs, which focus on optimizing CF behaviors, eHMIs have received extensive research attention in recent years, especially to facilitate interactions between AVs and human road users, with particular attention to AV-pedestrian interactions (Dey et al., 2024; Eisma et al., 2021; Song et al., 2023). However, there are still a few studies investigating how to use eHMI to improve interaction between AVs and HDVs. For example, in a bottleneck scenario, a 360° cyan light band representing the AV's intention to yield enhanced human drivers' trust and understanding of AVs when kinematic cues of AVs were ambiguous (Yang et al., 2025). Similarly, İppoliti et al. (2023) conducted a controlled field study using an LED matrix display to present the acceleration and deceleration intentions of AV and found that the eHMI could affect oncoming drivers' behaviors (passing the bottleneck or waiting for AV). In a merging scenario, Gwak et al. (2025) introduced a cyan-colored dashed-line LED band placed around the sides of the Level 4 truck, which blinked continuously over the merge zone from the start of the merge lane until the lane-change was complete. The eHMI was useful when surrounding drivers needed to accelerate or decelerate to avoid a collision. However, to date, very few studies have explored how to use eHMI to facilitate HDV-HDV interactions in CF events, and the drivers' needs for BVR and implicit information during such events have not been fully examined.

3 STUDY 1 – FOCUS GROUP

As mentioned, we aimed to understand drivers' needs for BVR information in CF events. Different from survey or simulation studies, the focus group discussion method was adopted as a first step because it can encourage participants to express their viewpoints through dialogue, explanation, or even disagreement with others (Kitzinger, 1995; Stewart & Shamdasani, 2014) and thus is more suitable for developing a new inventory or generating ideas (Gray-Vickrey, 1993; Morgan, 1996), without restricting participants' ideas to a specific and limited number of eHMIs. In this step, our goal was not to exhaustively identify all possible perspectives on the topic, but rather to generate novel ideas through group dialogue until thematic saturation is reached (Hennink et al., 2019).

3.1 Participants

Thirty-eight participants were recruited for the focus groups, who were required to speak Mandarin fluently, hold a valid driver's license, and have driven a car in the past six months. To ensure participant diversity, we included six groups of drivers from four distinct backgrounds: experienced non-commercial drivers (N=16 in two groups), novice non-commercial drivers (N=11 in two groups), safety drivers of autonomous taxis (N=5), and long-haul commercial truck drivers (N=6).

Specifically, the **non-commercial drivers** were drivers of passenger vehicles, including sedans, coupes, and hatchbacks. Among them, the experienced ones were required to have had their driver's license for over 3 years and driven at least 10,000 km/year in the past three years, while the novice ones were required to hold their driver's license within their obligatory 12-month escort period wherein they could drive on the highway only accompanied by a driver with more than 3 years of driving experience (Yeung & Wong, 2015). The **safety drivers of autonomous taxis** were backup drivers from autonomous taxi service companies who oversee the autonomous taxis and should take control of the taxis when needed. These drivers underwent extensive training, including several weeks of both classroom instruction and in-car practice, focusing on AV technologies and the safe monitoring of AVs on public roads. The **long-haul commercial truck drivers** all had their driver's licenses for over 10 years and drove long-haul trucks over 50,000 kilometers per year. Demographic information about participants from each group is presented in

Table 1. According to Hennink et al. (2019), one focus group per stratum was sufficient to identify key issues, with two focus groups yielding a more comprehensive understanding, and additional groups beyond this point yielded diminishing returns. Thus, in this study, one or two focus groups were recruited for each background.

Table 1. Demographic information

	FG 1: Experienced non-commercial drivers (N=8)	FG 2: Novice non-commercial drivers (N=5)	FG 3: Experienced non-commercial drivers (N=8)	FG 4: Novice non-commercial drivers (N=6)	FG 5: Safety drivers of autonomous taxis (safety driver) (N=5)	FG 6: Long-haul commercial truck drivers (truck driver) (N=6)
Age: average (SD, min, max)	24.4 (2.3, 22, 29)	20.8 (2.4, 18, 24)	29.1 (3.5, 26, 37)	21.1 (1.5, 19, 23)	27.6 (1.3, 26, 33)	40.8 (5.0, 37, 49)
Gender: male/female	8/0	5/0	1/7	0/6	5/0	6/0
Driving experience (year): average (SD, min, max)	4.8 (1.0, 3, 6)	0.47 (0.5, 0.08, 1)	5.2 (2.7, 3, 10)	0.6 (0.3, 0.25, 1)	7.4 (3.7, 5, 14)	20.83 (6.6, 12, 31)
Education background: JHS/Lower, HS/TS, AD, BD, PG/Above	N = 0/0/0/1/7	N = 0/0/0/3/2	N = 0/1/0/3/4	N = 0/0/0/5/1	N = 0/2/1/2/0	N = 3/2/1/0/0

Driving frequency (ranging from 1-5; 1: always, 5: never)	N = 4/4/0/0/0	N = 1/1/3/0/0	N = 6/2/0/0/0	N = 0/0/3/3/0	N = 5/0/0/0/0	N = 6/0/0/0/0
Mileage driven in the last year (km): <5,000, 5,000-20,000, 20,000-50,000, 50,000-100,000, >100,000	N = 0/4/3/1/0	N = 4/1/0/0/0	N = 0/5/3/0/0	N = 6/0/0/0/0	N = 0/2/3/0/0	N = 0/0/0/3/3

Note: FG stands for focus group; JHS/Lower stands for junior high school and below; HS/TS stands for senior high school/technical secondary school; AD stands for an associate degree; BD stands for bachelor's degree; PG/Above stands for postgraduate and above

3.2 Procedure and data collection

All focus groups were conducted using the same predetermined structure by the same two researchers. However, flexibility and adaptability were allowed to fit the group's needs (Allen, 2017). During the focus group, the moderator ensured that everyone was included in the discussion and encouraged quiet participants to fully participate as well (Silverman, 2020). Furthermore, discussions could be influenced by participants' social desirability biases; they may adjust their contributions to match those of others, which could affect the validity of the focus groups (Mortel, 2008). To overcome this bias, the moderator endeavored to create an open and permissive atmosphere by emphasizing that the moderator wanted to hear a range of different experiences and feelings (Morgan, 1993).

As shown in Figure 1, after obtaining informed consent, the focus groups began with an introduction to CF and eHMI definitions, followed by a video that showed a CF event and example eHMIs to facilitate better understanding. After the introduction, we asked about participants' previous impressive CF incidents and personal CF preferences to help refresh their memories. Then, two parts of questions were asked. The first part probed participants' crash or near-crash (CNC) experiences in CF events, seeking their thoughts and feelings about these experiences and suggestions for potential eHMI design to prevent such incidents. The second part focused on the efficiency of CF events and probed participants' experiences in improving CF efficiency, as well as their suggestions for eHMI design to improve traffic efficiency. Finally, a concluding question was asked to ensure participants had the opportunity to address any missing points or key aspects considered important during the discussion.

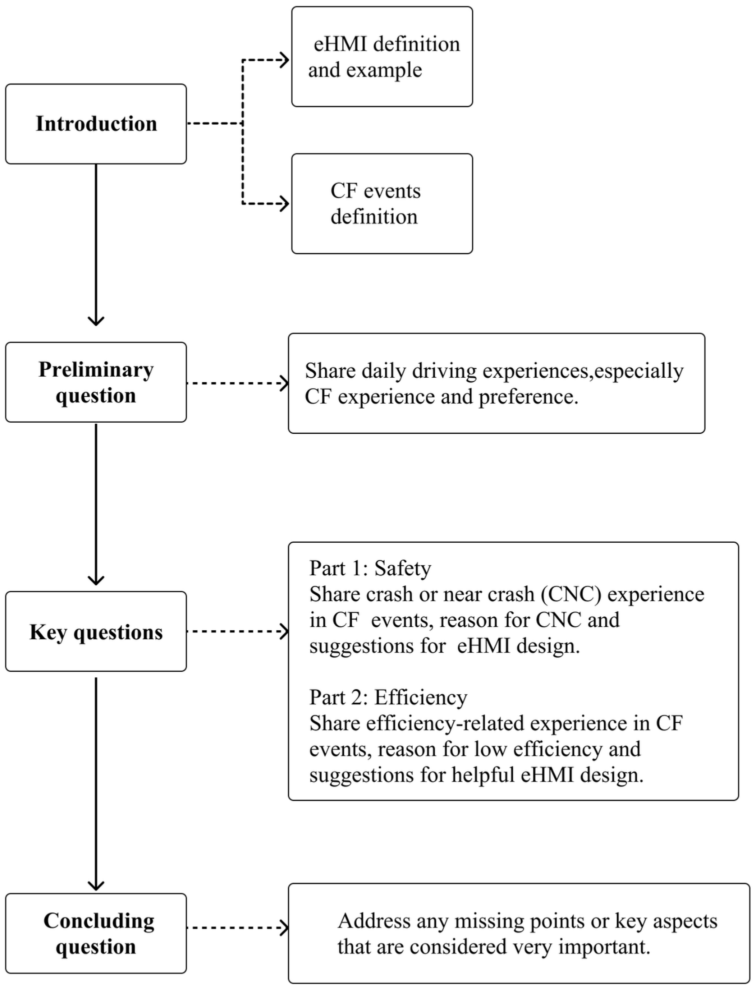


Figure 1. Flow diagram of focus group discussion.

All focus groups were recorded, and participants were assured that they would be anonymized throughout the study and that their data would be deleted after the study was closed. All discussions were conducted in Mandarin and lasted between 100 and 120 minutes. To accommodate participants' needs, discussions were conducted using hybrid approaches, with four sessions held in person and two held online. As an incentive, each participant was compensated with 200 RMB. This study was approved by the Human and Artefacts Research Ethics Committee at the Hong Kong University of Science and Technology (Guangzhou) (HREP-2024-0026).

3.3 Data analysis

The transcripts of the focus groups were analyzed by two researchers individually using a thematic analysis approach, which segments, categorizes, summarizes, and reconstructs data to capture important concepts within the dataset (Braun & Clarke, 2006). The purpose of this approach was to search for themes that occurred across the focus groups. Following the framework outlined by Boyatzis (1998), we first transcribed the focus group recordings and reviewed the accuracy of the transcripts. Then, two researchers independently coded emerging ideas and keywords frequently used by participants as indicators of important themes, using *Express Scribe* (NCH Software, 2019). Finally, we eliminated, combined, or subdivided the codes, and, at the same time, the inconsistencies were further discussed and adapted, with support from a third experienced researcher. The inter-rater reliability of coding across raters showed "near perfect agreement" (Cohen's Kappa = 0.86). The detailed codebook was listed in the Appendix.

In our analysis, we coded drivers' information needs and preferences for eHMIs in CF events in both HDVs and AVs, given the commercial operations of AVs in recent years. Specifically, considering that in CF events, drivers need to perceive the environment and make decisions of vehicle control maneuvers, we adopted the Stimulus-Cognition-Response (S-C-R) model as the framework (Wickens & Carswell, 2021), which explains how individuals process information (stimulus & cognition) and subsequently behave in response (response selection & execution) to external stimuli. By incorporating the S-C-R model, we aimed to understand drivers' information needs in CF events. Specifically, the narratives in the focus groups were organized as stimulus & cognition and response selection & execution.

3.4 Results

In this section, themes identified through the analysis of focus group transcripts were discussed, and sample quotes from participants' responses were provided. Quotes were attributed to an individual user by the username they were assigned, i.e., the group the participants belonged to (i.e., "Exp" for Experienced non-commercial drivers, "Nov" for Novice non-commercial drivers, "AVD" for Safety drivers of autonomous taxis, "TrD" for Long-haul commercial truck drivers) and the numbering of the participants. For example, Exp8 was the 8th participant in the "experienced non-commercial drivers" group. At the same time, Np showed the number of participants who mentioned a specific point, and Ns showed the number of mentions in the discussion. As shown in Table 2, there were three main themes, each further broken down into several subthemes. A detailed codebook presenting how codes were applied across each group and each theme was attached in the Appendix.

Table 2. Number of participants and number of codes in each subtheme.

Theme	Subtheme	Number of participants (Np)	Number of codes (Ns)
Information flow in CF events based on the S-C-R model	Perception & cognition	38	247
	Response selection and execution	36	160
eHMI expectation for CF events	Content	38	156
	Communication method	32	53
	Position	26	109
	Design principles	16	110
Expectations of leading autonomous vehicles	Perception of AVs	3	12
	Capability of AVs	5	22

3.5 Theme 1: Information flow in CF events based on the S-C-R model

Perception & Cognition are related to information acquisition in CF events, including the source of information to rely on and the estimation of self-capabilities. Good perception and cognition are the prerequisites for good CF actions.

- **Sources of Information**: Most novice drivers (Np=8) mentioned that the illumination of the brake lights on the front vehicle was directly mapped to braking action. Nov2 said: *"As soon as I see the taillights come on, I will step on the brake."* Compared to novice drivers, experienced drivers (Np=6) made decisions based on more diverse information beyond the brake lights of the DLV, for example, the onset of a red traffic light or unusual behavior from vehicles in other lanes. Exp3 said: *"While driving, I observe not only the car directly in front of me but also the vehicles in the adjacent lanes. If I notice unusual behavior from other cars, I may also begin to brake."* Instead, some experienced drivers even reported desensitization to brake lights (Np=8). They admitted that with the increase in their driving experience, they became desensitized to brake lights, and they admitted that this can be risky - when the LV brakes suddenly, they may not be able to react in time. For example, Exp1 said: *"For me, many times brake lights didn't raise my alertness."* Another reason for desensitization was that prolonged CF behavior may lead to driver daze. Exp13 said: *"Extended CF events, especially on the highway, often led to distraction."*

In addition, we observed many complaints (Np=8) about electric vehicles (EVs) due to the lack of visual cues of deceleration (i.e., braking lights) in some scenarios. Both novice and experienced drivers reported that regenerative braking in EVs was too abrupt and that the brake lights sometimes did not illuminate. This led to inadequate braking time and nearly rear-end collisions. They highlighted the importance of both motion cues (vehicle deceleration) and visual cues (braking light) in CF events. For example, Exp5 said: *"From my perspective, regenerative braking is similar to lightly stepping on the brakes, but the brake lights don't come on. I believe this is quite dangerous because people aren't aware that the car is slowing down!"*

- **Cognitive Capacities**: There were 89 coded statements on attention allocation during CF events, 90% of which were reported by novice drivers. They emphasized concerns about insufficient attention resources and difficulties managing overwhelming, simultaneous information in complex traffic conditions, leading to confusion, disarray, and stress. Nov5, who held only 2 months of driving experience, said: *"In CF events, my attention is primarily on the LV. On rainy days, I need to ignore the distraction of raindrops on the windshield while monitoring the speed of the car in front. If someone were to cut in during this time, I might not notice."* This result was consistent with previous research, which found that experienced drivers can be freed from basic vehicle operation tasks and have greater capacity to handle complex traffic scenarios (Patten et al., 2006; Silva et al., 2014).

Response Selection and Execution relate to drivers' actions in response to road events. Good performance in perception and cognition does not necessarily lead to good responses because of the possible disconnection between situation awareness and driving performance (Endsley & Garland, 2000). Thus, in this part, we discuss drivers' decisions and actions, ranging from whether to follow to the strategies they take when following LVs:

- **Factors Facilitating CF Decisions**: Experienced drivers may make CF decisions based on more factors. For example, 5 experienced non-commercial drivers, 2 safety drivers, and 4 truck drivers stated that they preferred to deliberately follow the LV in certain situations, such as poor road visibility, complex or unfamiliar traffic environments, and their own poor states (e.g., fatigue). In other words, following the LV can be used as a strategy to navigate the challenging traffic environment, which novice drivers have not mentioned. TrD3, an experienced driver, said: *"When my mental state is not good, I follow the leading car, because it can save my physical strength and energy."*
- **Factors Facilitating Overtaking Decisions**: When deciding whether to follow another vehicle, drivers exhibited different individual preferences. Some chose not to follow when possible, preferring a broader field of vision (Np=22, 9 experienced non-commercial drivers, 6 novice non-commercial drivers, 2 safety drivers, and 5 truck drivers; for example, Exp4: *"I don't like following others. I prefer to have a good view in front of me."* while others made decisions based on the speed of leading traffic flow (Np=10, 7 experienced non-commercial drivers, 1 novice driver, 2 safety drivers; for example, Exp7 said: *"If the current speed matches my expectation, I don't mind whether to follow the car or not."*).

Further, both novice (Np=4) and experienced drivers (3 experienced non-commercial drivers, 1 safety driver, and 3 truck drivers) reported that they tended to avoid following LVs exhibiting unusual behavior or hazard lights and sought opportunities to overtake them. For example, one truck driver (TrD6) mentioned that once observing the abnormal action of the LV, he would honk and flash high beams to remind the leading driver before overtaking it to avoid potential lateral collisions: *"If the LV is behaving erratically or shows signs of unfamiliarity with the road conditions, I would definitely overtake it. I think it would be dangerous because if the driver is unfamiliar with the road, they might suddenly make erratic movements or sudden turns, which are unpredictable."*

- **Headway Maintenance in CF Events:** As expected, keeping a safety margin from the LV was considered the most important safety tip during CF events (Np=35). Participants shared their previous CNC experiences, attributing incidents to insufficient CF distance. Exp4 said: *"Why do I pay attention to maintaining a safe distance? It's because I was almost involved in a rear-end crash before!"* In addition, obstacles ahead or unexpected vehicle behaviors were the reasons drivers care so much about CF distance (Np=17). For example, AVD2 from the safety driver group mentioned: *"It's very easy to encounter drivers who don't follow traffic rules. They will suddenly, uh, cut in front of your car, and sometimes if you're following too closely, you just can't brake in time."*

However, in congested traffic, nearly all experienced non-commercial drivers (Np=13) chose to follow the LV closely to prevent being cut in. On the other hand, novice non-commercial drivers (Np=7) were hesitant to follow closely due to a lack of confidence and concerns about rear-end collisions. Similarly, truck drivers (Np=5) avoided following closely, potentially due to the truck's long braking distance resulting from its large mass.

- **Selection of LVs in CF Events:** In addition to the following distances that can be captured by previous CF models, such as IDM (Treiber et al., 2000), drivers also mentioned many interesting strategies that have not been considered in CF models. For example, lots of participants mentioned not following heavy-duty vehicles (Np=6, including 2 novice drivers, 1 safety driver, and 3 truck drivers), actively following a vehicle when visibility was poor (Np=4, including 2 experienced non-commercial drivers, 1 safety driver, and 1 truck driver), and following experienced local driver if you can detect them (Np=1). For example, TrD4 said: *"Try to follow smaller cars because if you get rear-ended, you'll likely get less severely injured."*

- **Strategies to Avoid Being Rear-Ended in CF Events:** Some drivers considered the subject vehicle (SV) and the following vehicles' capabilities when executing braking maneuvers. Specifically, truck drivers (Np=3) estimated their vehicles' braking capability based on their experience and tried to brake gently to avoid being rear-ended. For example, TrD2 mentioned: *"In emergencies, when I must brake suddenly, I can't brake without considering the vehicles following me. That's not safe behavior."*

Thus, drivers developed some strategies to prevent others from tailgating. For example, all truck drivers (Np=6) mentioned that they did not like following other vehicles and being followed. They reported feeling irritated when they were being tailed for an extended period. Some drivers (Np=2) admitted to deliberately braking sharply as a warning to their followers to stop tailgating. For example, Exp1 said: *"If I find that a car is following me too closely, I choose to change lanes to let it pass. If it continues tailgating me, I step on the brake."*

- **Concerns Regarding Abrupt Acceleration of LVs:** Among all participants, only 4 drivers (Np=4) reported accelerating behavior while following another vehicle. This behavior mainly happened in congested traffic, where the following driver accelerated as soon as the LV started moving to avoid being cut off. Three participants reported that, in congested traffic, the leading EV, usually with superior acceleration, "always" accelerated abruptly, prompting the following vehicle to follow closely and, if the congestion was not cleared, could lead to harsh braking. For example, Exp5 said: *"The leading driver steps on the accelerator, and boom, he takes off, leaving quite a distance from me. I think that traffic may be released. Then I step on the accelerator. However, as soon as I start, the driver steps on the brake, and then I have to apply the emergency brake. I am quite upset with this, and it is common among EV drivers."*

3.6 Theme 2: eHMI Expectation for CF Events

Corresponding to the complex strategies drivers used to manage CF events, drivers also expressed expectations for novel eHMIs that may support CF behaviors. Their opinions can be organized into four categories, i.e., content, communication method, position, and design principles.

Content is about the type of information to be displayed on eHMIs. Four different categories of information are expected by drivers:

- **Beyond Visual Range Information**: Drivers expressed strong interest in information beyond the visual range in CF events, including obstacles in the lane (Np=13), traffic accidents ahead (Np=3), oncoming vehicles in wrong lanes (Np=1), congestion status (Np=3), lane-specific rules (Np=3), sudden appearance of animals (Np=3). Participants explained that the BVR information can allow them to make preemptive maneuvers, such as braking, changing lanes, or aborting a lane change in advance. It should be noted that the BVR information was not restricted to the current lane but extended to the entire stretch of road ahead. For example, TrD5 mentioned: *"If I can be warned of obstacles ahead in the target lane, I would abandon this maneuver."* Another participant, Exp6, said: *"Just tell me which lane is faster or less congested. Either by calculation, camera-based information, or other methods, it would help me make better decisions."*
- **Intentions of LVs**: The intentions and actions (Np=10) of LVs were also of interest to the following drivers. Four participants specifically noted that, in complex traffic with multiple lanes and junctions, turn signals cannot sufficiently convey LVs' intentions. For example, it was mentioned that if one knew the LV intended to make several lane changes to reach the far-right lane and exit the highway, he would slow down to give space. Exp2 said: *"Sometimes, the LV turns on its indicator on the expressway and changes from the leftmost lane to the rightmost lane. If I know the driver wants to exit the ramp, I will yield."*. At the same time, to help followers better prepare for the emergent braking of LVs, drivers also suggested that brake lights or other eHMIs should signal LV deceleration. For example, Exp1 suggested: "*The color of the taillight can change according to the braking force."* Another scenario where eHMI may be used is multiple vehicles travelling as a platoon during a group trip. Exp14 said: *"When a group of people travelled together in multiple cars, we usually followed each other. In such cases, an eHMI showing the LV's intentions, such as exiting to a service area, would be helpful."*
- **Driving Styles and Mental States of Leading Drivers**: Drivers were also interested in the driving style (e.g., aggressive or conservative, Np=8) and states (e.g., fatigue or distracted, Np=5) of leading drivers, based on which, following drivers may better assess the situation and decide whether to follow or overtake.

Specifically, novice drivers (Np=3) disliked following risky drivers and tended to maintain sufficient distance from them. In contrast, experienced drivers (Np=5) indicated that if they knew the leading driver was of a conservative driving style and drove slowly, they would proactively overtake them. Similarly, if it were known that the leading drivers had been driving for a long time and might be fatigued, participants would choose to overtake to avoid potential collisions. For example, TrD2 said: *"We can have a light outside to show the driver's status. If he is dozing off, it will tell drivers around that the car is dangerous."*

However, participants also admitted the difficulty of informing others of their driving style or state. Specifically, concerns about privacy (Np=6) and the likelihood of being overtaken frequently (Np=6) were raised when a conservative driving style is publicized. The participants (Np=3) also worried about the immediacy and authenticity of the information if the data did not accurately reflect leading drivers' styles and states, given the less-than-ideal performance of the driver monitoring system (DMS) at this stage (Guettas et al., 2020). Notably, Chinese traffic law requires novice drivers to display a learner's plate to signify their novice status, but most participants (Np=15) questioned its effectiveness and authenticity due to its widespread misuse.

- **Guiding Behaviors of Following Vehicles**: Some participants (Np=5) suggested that the eHMIs could also be used to guide the behavior of following vehicles, with concerns about tailgaters. For example, Nov2 said: *"Projecting a line from the rear of my car may guide the following vehicles to maintain a safe distance from me."*

Communication Method is about the coding and modality of information on eHMI.

- **Information Coding**: Icons and text were the two most frequently mentioned information codes expected by participants, yet conflicting opinions were expressed. Those (Np=14) favoring text emphasized the need for detailed information, as they believed text offered a more substantial amount of information. They suggested that textual information can provide a more comprehensive understanding of a situation, leading to more informed decisions. For example, TrD3 said: *"We can put a large screen at the rear of the car, on which various emergency information ahead is displayed in text."* Conversely, some (Np=7) raised concerns that textual information might be challenging to read or respond to quickly. Supporters of icons

(Np=19) emphasized their clarity and ease of recognition. They proposed designing rear warning lights based on traffic signal colors, which would provide them with enough information to make appropriate decisions. For example, Nov4 said: *"I feel that text is not as intuitive as a signal. For example, braking lights and turn signals are very clear—you can immediately tell if someone is turning left or right."*

- **Modality**: Interestingly, in addition to visual channels, a few drivers (Np=18) recommended using audio to share BVR information. Truck drivers expressed dissatisfaction with some current truck-embedded navigation systems that occasionally broadcast advertisements. They proposed replacing these ads with emergency broadcasts about road conditions ahead, believing this would lead to the least distraction. Another reason for support was that the audio is clear and easy to understand. Exp 9 said: *"Compared with the previously mentioned formats, I prefer audio, as it is easy to notice and understand. However, the audio should not resemble sounds currently used by mobile phones or vehicles."*

The Position of the eHMI has also been discussed by drivers. In general, participants shared similar views regarding the location of eHMI displays. They suggested that eHMIs should be at the rear of vehicles, such as by modifying the taillights (Np=19), adding an additional display screen on the rear window (Np=16), and integrating eHMIs into the rear design of the vehicle (Np=2). Other suggested locations include the shark fin antenna (Np=2) and projection on the road (Np=3). For example, AVD2 in the safety driver group said: *"Install something similar to a pilot light on top of the shark fin. It will be very visible at night, and it changes color between red and green depending on your speed."*

Design Principles are about the styles of eHMIs. There were a few conflicting preferences on the design principles of eHMIs. Participants (Np=18), including most novice non-commercial drivers (Np=10), strongly preferred simplified prompts, stating that overly complex information was challenging to process, and some experienced non-commercial drivers (Np=4) suggested that the eHMI should be concise even if it sacrificed some details. For example, Nov1 mentioned: *"Keep the information simple; just show the risk level of the road conditions ahead. If it's too complex, it will be difficult to use!"* In contrast, some truck drivers (Np=3) desired detailed information, such as road obstacles, agglomerated fog, and slow-moving vehicles ahead. For example, TrD6 mentioned: *"When I'm overtaking, if there are objects fallen on the* *road ahead, it's often too late by the time I see them. If the LV could inform me in advance about debris in the lane, I wouldn't attempt to change lanes and overtake."*

3.7 Theme 3: Expectations of Leading AVs

Perceptual Ability of AVs: Three experienced drivers mentioned the prevalence of vehicles equipped with driving automation on roads, and they suggested that making the road environment perceived by sensors such as LiDAR accessible to following drivers could enhance follower drivers' ability to assess road conditions ahead. For example, Exp7 mentioned: *"The digital environment of surrounding vehicles or lanes generated by AVs can be shown to other vehicles nearby. It looks real."*

Capability of AVs: A consensus was observed among safety drivers of autonomous taxis (Np=5), i.e., the capabilities of AVs were underestimated in congested traffic. During their work, they observed that following drivers frequently overtook AVs in congested traffic, assuming AVs were the cause of congestion. It was proposed that if the following drivers were more patient, AVs could navigate through congested areas more smoothly. For example, AVD5 mentioned: *"In most cases, we're not the cause of traffic congestion. This happens because the cars behind us don't want to wait for us, thinking we're too slow. They continually cut in front of us, leaving us stuck in the middle and creating the false impression that we're slowing down the traffic. I believe if everyone understands and cooperates with us, everyone could move more quickly and efficiently."*

4 STUDY 2 – FIELD STUDY

Based on findings from the focus group study, we developed two eHMIs to allow participants to better experience the CF events when the BVR information was available. Specifically, participants drove an SV, followed a DLV with eHMIs, and an ILV on a suburban road. Such an approach could provide participants with more contextual information about the role of BVR information in the CF events, thereby encouraging opinions with greater validity.

4.1 Participants

In total, 30 participants (15 male and 15 female) were recruited for the field study through social media. They were required to be experienced drivers (defined in the same way as those in the focus group, i.e., having held their driver's license for over 3 years and driven at least 10,000 km/year) for safety considerations in the on-road experiment. They had a mean age of 31.4 years, with a standard deviation (SD) of 4.8 (min: 23, max: 40) and a mean driving experience of 5.9 years (SD = 3.1, min: 3, max: 18). None of these 30 drivers attended the focus group.

4.2 Procedure and data collection

We aimed to collect broader views on the BVR information needed for CF events and elicit ideas on how to provide it. Thus, one of the eHMIs (see Figure 3a, brake-eHMI) on the DLV showed the brake behavior of the ILV, represented by the red color of the vehicle icon, which was a simple BVR information design mentioned in Section 3.6. Another eHMI (see Figure 3b, video-eHMI) presented a real-time scenario from the perspective of DLV, containing rich information as discussed in Section 3.6. These two eHMIs provided only basic BVR information without further processing (i.e., we did not calculate more complex metrics such as headway or time-to-collision, but instead presented the drivers with what can be perceived directly) to avoid constraining participants' opinions about the specific design of the eHMIs. By designing these two eHMIs, we allowed participants to experience typical CF events when BVR information was available, thereby eliciting their opinions on the potential eHMI application in CF scenarios.

The field study was conducted on a 2.6 km straight suburban road with a speed limit of 60 km/h (Figure 4). Three vehicles were involved: the ILV, the DLV, and the SV (Figure 5). An outdoor display (dimensions: 64 cm × 32 cm; brightness: 5000 nits) was installed on the rear of the DLV to serve as the eHMI, as also shown in Figure 3. Each participant experienced two drives with different eHMIs and one drive without an eHMI, with the order of the eHMI conditions counterbalanced using a Latin square design.

Prior to the drive, they were briefed on the meaning of the specific eHMI. During the drives, they followed the DLV, and the speed of the ILV varied between approximately 30 km/h and 60 km/h. Four driving regimes from Sharma et al. (2018) were adopted to reflect traffic speed fluctuations, i.e., acceleration, following, deceleration, and standstill. For safety considerations, in the standstill condition, the ILV decelerated to approximately 6 km/h rather than a full stop. After each drive with eHMI, participants completed the System Usability Scale (SUS) (Brooke, 1996). After the two drives, they were asked open questions regarding how they felt about having the BVR information in the CF scenario. The responses were recorded, transcribed, and analyzed following the same procedures as the focus group. This study was approved by the Human and Artefacts Research Ethics Committee at the Hong Kong University of Science and Technology (Guangzhou) (HKUST(GZ)-HSP-2024-0085).

(a)

(b)

Figure 3 The eHMIs used in the experiment (a) Brake-eHMI; (b) Video-eHMI.

Figure 4. Bird's eye view of the experimental field. The red line represented the route.

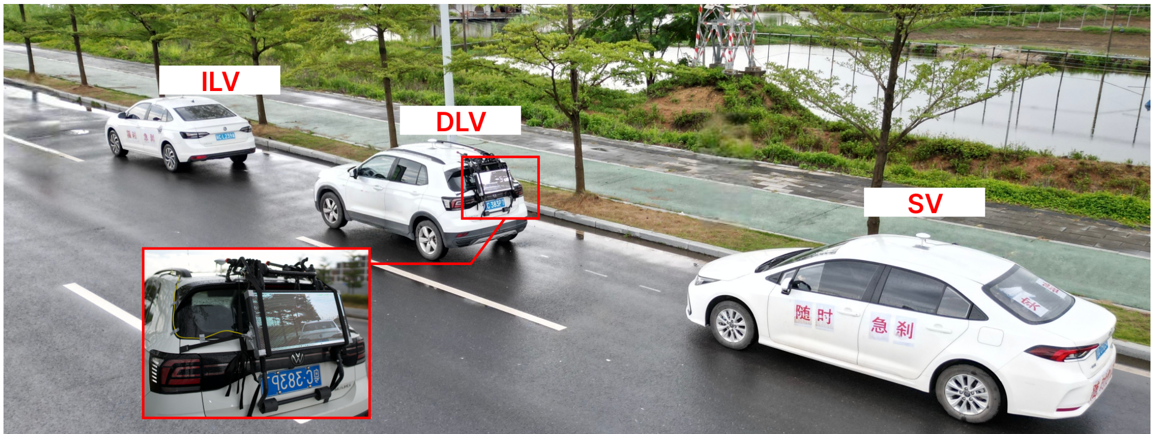


Figure 5. The CF event in the experiment and the installation of eHMI display.

4.3 Data analysis

The feedback from the field study followed the same analysis process as the focus group transcripts. Perceived usability and perceived learnability were derived from the SUS questionnaire using the standard procedure (Brooke, 1996). With the assumptions met, we conducted a paired t-test to compare usability and learnability between the two eHMI designs.

4.4 Results

The results of the field study transcripts were relevant to two of the main themes - Information flow in CF events based on the S-C-R model and eHMI design. In addition to the qualitative feedback, the quantitative analysis of SUS results was also reported.

Beyond visual range information

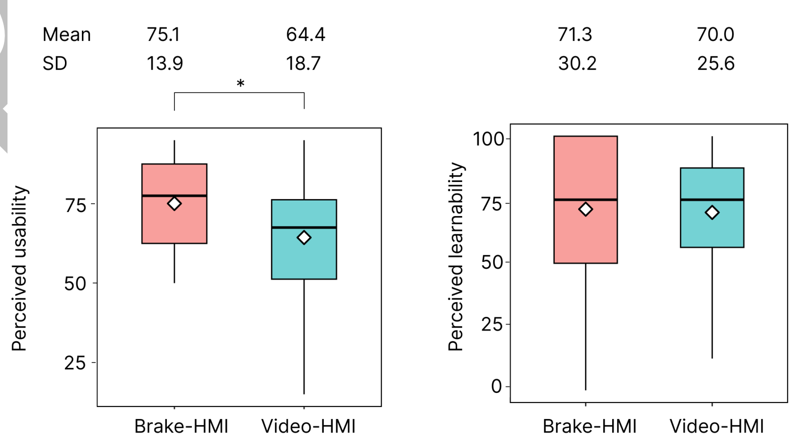
Nearly all participants (Np=28) agreed that both types of BVR information can help inform their cognition, decision, and behavior in their actual driving. Field Study (FS) participant 17 said: *"With this information, I could get additional information which makes me more comfortable to brake or accelerate when following the LV."* Ten participants stated that with the BVR information displayed, they felt confident about the potential unexpected circumstances. FS11 said: *"Knowing the indirectly LV did not step on the brake made me comfortable, especially when I was close to the LV."* However, three participants complained that the Video-eHMI provided too much information, leading to cognitive overload and leaving them "tired" after the experimental drive. FS28 said: *"I had to process too much information."*

Preference for the eHMI design

Seventeen participants from the field study preferred the brake-eHMI. Some (Np=14) stated that it is simple and straightforward. Some (Np=8) emphasized that the brake signal can help them prepare for the potential risks. For example, FS3 said: *"Previously, I responded only to the brake light of the DLV. With the help of the brake-eHMI, I was able to anticipate the braking behavior of the ILV, which allowed me to maintain a shorter following distance from the DLV."* In contrast, six participants preferred the video-eHMI. They highlighted that the video format can provide a lot of information, such as invisible bicyclists, the gap distance between the two LVs, and the turning intention of the ILV. For example, FS18 said: *"It gave me a comprehensive understanding of the situation ahead."* However, the Video-eHMI also suffered some opposition. The criticism mainly focused on the complexity of the information, which participants found distracting and challenging to process in real-time. FS21 said: *"The Video-eHMI looks good, but when I use it, I cannot get much information from it."* It should be noted that two participants opposed any eHMI format because they were concerned that the current installation might obstruct the rear view of the LV.

SUS questionnaire results

As shown in Figure 6a, the Brake-eHMI led to significantly higher perceived usability than Video-eHMI ($\Delta = 11.69$, $t(33) = 4.30$, $p = .0001$). In terms of perceived learnability, there was no significant difference between Brake-eHMI and Video-eHMI, as shown in Figure 6b.



(a) (b)

Figure 6. Boxplots of the perceived usability and perceived learnability of both eHMIs; Significant comparisons ($p < 0.05$) are marked with "*"; the boxplot represents the 1st quantile, median, and 3rd quantile; the white squares represent the mean of the group.

5 DISCUSSION

The findings of focus groups revealed insights into the CF behaviors under various circumstances, reflecting the complexities of human factors in traffic environments, and can provide general suggestions for eHMI design for following drivers.

5.1 How do Drivers Follow LVs in CF Events

Previous research usually assumed that drivers made acceleration/deceleration decisions based on the relative speed, distance, and desired distance between the SV and the LV, as well as the absolute speed of the SV (Chandler et al., 1958; Wang et al., 2018). However, our research revealed that CF is more than a set of responses to the DLV. Figure 7 illustrates the factors drivers consider in CF events.

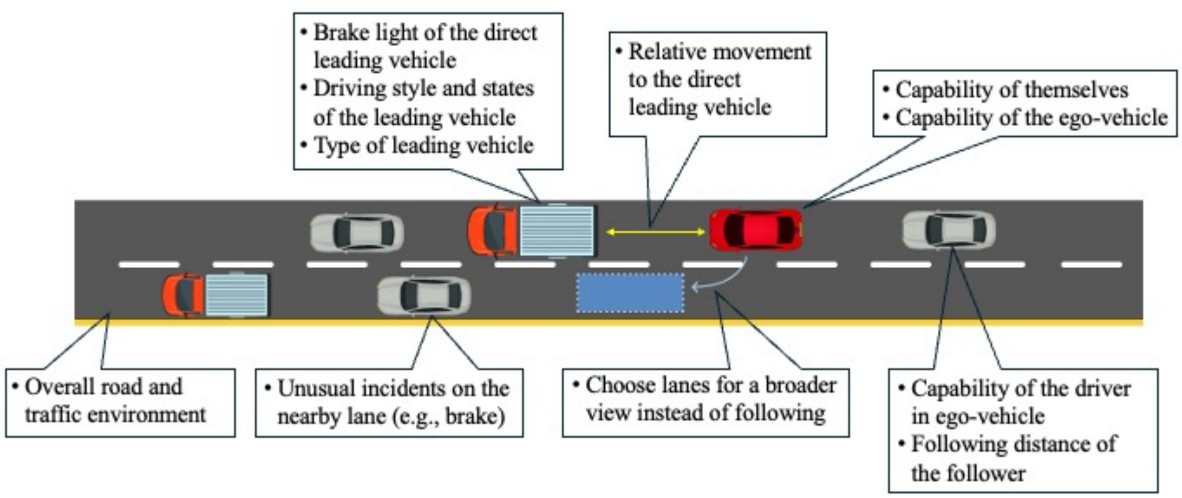


Figure 7. Illustration of the way drivers follow LVs in CF events. In the figure, the red vehicle is the SV.

First of all, the role of the brake lights has been frequently mentioned by drivers. The onset of the brake light is associated with deceleration, but no universally accepted standards exist across different countries. For example, in the U.S., the brake lights must be activated upon application of the service brakes (National Highway Traffic Safety Administration, 2004), while in China, the deceleration threshold is 0.7 m/s^2 (SAMR & SAC, 2019). Furthermore, different vehicle manufacturers and vehicle types (e.g., fueled vehicles versus EVs) may adopt different strategies (Palaniappan et al., 2021). For example, drivers have expressed concerns about the lack of brake lights on EVs in certain scenarios. In addition, desensitization to brake lights is a potential safety concern in traffic, highlighting the need to improve brake light design to maintain their effectiveness in alerting drivers.

Second, cognitive and attentional capacities play a role in CF events. Specifically, novice drivers reported having less spare attentional capacity during CF events than experienced drivers, indicating that the CF task is more than a simple stimulus-response task. The difference between novice and experienced drivers aligns with previous findings on tactical driving skills, which indicate that, compared to novice drivers, experienced drivers can automate some driving tasks and are more capable of hazard anticipation (He & Donmez, 2022; Young & Stanton, 2002). This difference in spare cognitive resources would also affect their strategies in maintaining CF distances to LVs, with experienced drivers preferring a close following distance to prevent being cut in, while novice drivers preferring a larger headway.

Further, driving is not only an operational task, but also a tactical task (Zhang et al., 2014), and drivers take into consideration more than the motion of the DLV when deciding the CF strategy. For example, drivers would actively seek a broader field of view, reduce uncertainty in challenging driving conditions (e.g., by following the LV closely in a foggy environment), and take into account the mental states and behaviors of other drivers in CF events. As mentioned earlier, experienced drivers would also adopt different defensive strategies, e.g., intentionally keeping shorter headways to LVs to prevent being cut off. These aspects should be considered when designing future human-like CF models or AV control algorithms.

Another major gap between the existing CF models and actual CF behavior lies in the sources of information. First, we noticed that when following LVs, experienced drivers consider not only the traffic ahead but also the states of the following vehicles to avoid being rear-ended. For example, truck drivers would take action to actively get away from the tailgaters. At the same time, most drivers mentioned the BVR information, indicating that the CF decision is based not only on the DLV but also on the traffic state and traffic flow further ahead. This is in line with previous research, which has found that BVR information transmitted via V2V communication can improve CF safety (Yan et al., 2023).

Finally, it should be noted that a discrepancy often exists between drivers' stated attitudes and their actual driving behavior. For example, almost all drivers admitted that a large enough headway was needed to ensure CF safety, but drivers still expressed their strategies to tailgate other vehicles, trying to prevent being cut in – a strategy that can potentially increase the efficiency of the SV. This finding is consistent with research on rear-end collisions, i.e., most drivers maintained a headway much smaller than the recommended 2 seconds (Huang et al., 2022). This safety-efficiency trade-off can be calibrated by several factors, for example, the risk threshold and confidence in driving capability (W. Zhang et al., 2006). Therefore, future research should investigate how drivers' subjective attitudes translate into actual driving performance.

5.2 eHMI Design for CF Events

Almost all participants preferred the CF-related eHMI to be on the rear of the vehicles, directly visible to followers. However, drivers expected more than brake information on the eHMIs, as shown in Figure 8. First of all, as has been mentioned, drivers expressed a strong interest in BVR information in order to take proactive actions for road events ahead, echoing the benefits of V2V information observed by Yan et al. (2023). At the same time, drivers also expected more information about the vehicle directly ahead, including their intentions, driving styles, and mental states of the direct leading driver, which is closely related to the V2V-based communication through HMIs. However, so far, most eHMI-related research focused on optimizing eHMIs for AV-pedestrian interactions (Dey et al., 2020; Lee et al., 2022; Wilbrink et al., 2021), but overlooked more common V2V communications. Especially with the prevalence of driving automation, vehicles can perceive more traffic information (Marti et al., 2019) and anticipate the surrounding traffic development (Milakis, 2019; Yu & Marinov, 2020). Thus, how to leverage the information perceived by driving automation warrants future research, which may improve the safety and stability of traffic flow (de Waard et al., 2004; Kallberg, 1993), before connected vehicles are deployed. Finally, although there were conflicting perspectives on the preferred communication methods and design principles for the eHMI, the field study suggested that simpler designs were more acceptable in terms of usability.

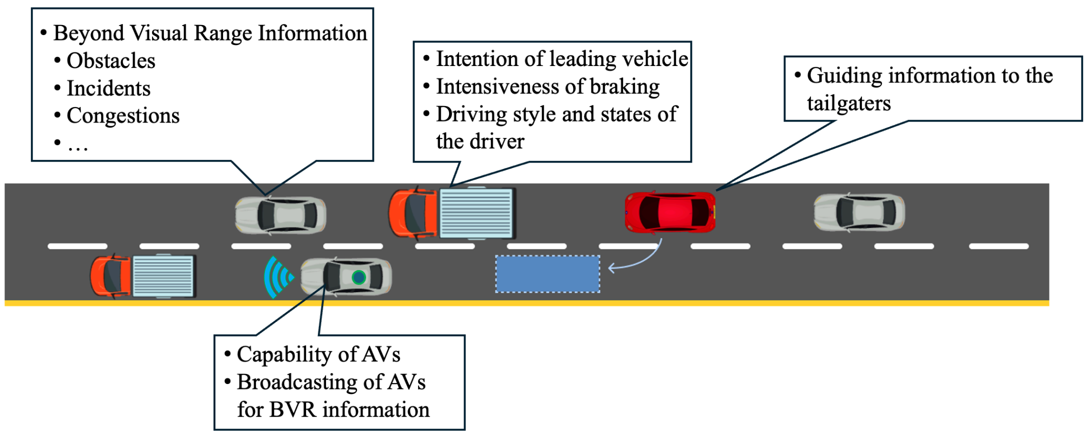


Figure 8. Information expected in eHMIs for V2V communications

Besides information about the DLV, drivers also supported the idea that the eHMI can help guide tailgaters' behavior, for example, by projecting the safe CF distance on the road. However, the effectiveness of this approach warrants further investigation, given that suggestions without enforcement typically have limited effects on regulating drivers' behavior (Zhong et al., 2010).

Furthermore, drivers held contradictory opinions about how the message should be conveyed on eHMIs. Some drivers preferred text messages while others preferred more concise icons. Given the vibration and motion states of vehicles and the short response times in emergency events on roads, it is necessary to balance conciseness and information richness and make trade-offs when designing icons for novice and experienced drivers. Thus, the eHMI design should be carefully validated, and standards should be proposed and followed for new eHMI systems.

Finally, the potential negative effects of the eHMIs should be considered. First, although both studies identified the need for eHMIs in CF events, the driving task is already mentally demanding (Salmon et al., 2005). Therefore, it is crucial to validate the effects of additional information in CF events on drivers' CF behaviors. Second, similar to what has been observed when the anti-lock braking system (ABS) was equipped in vehicles (Sagberg et al., 1997), drivers may take riskier CF behaviors when they have the BVR information, as they tend to stay at an acceptable risk level (Summala, 1988). Thus, future research should carefully evaluate the potential safety impacts of eHMIs in real-world settings.

5.3 Regulatory, Privacy, and Ethical Implications of eHMIs

Regulatory, privacy, and ethical concerns should be carefully considered, although technologies have made eHMIs for traffic flow and driver state (e.g., through DMS) possible, and drivers expect them to be available. Regulatory, privacy, and ethical concerns may limit the adoption of eHMI-based driver-state broadcasting if not well addressed (Wang et al., 2014). In future deployment, driver-state information should follow privacy principles such as data minimization and clear limits on externally shared information (OECD, 2013). From a privacy perspective, broadcasting detailed internal states (e.g., distraction or fatigue) may be sensitive and may cause unintended inferences. Thus, desensitized and less explicit messaging (e.g., "a fatigued driver ahead" instead of "the direct leading driver is fatigued") may be preferred. Ethically, designers or manufacturers must balance safety benefits and drivers' privacy. Thus, how to communicate driver-related information deserves further discussion, not just from a technical perspective, but from a social psychological perspective.

5.4 Drivers' Expectations of Autonomous Vehicles

Vehicle automation is expected to significantly enhance urban transportation, making roads safer (Fagnant & Kockelman, 2015), reducing travel costs (Bösch et al., 2018), and supporting a more sustainable transport system (Wadud et al., 2016). However, autonomous safety backup drivers in this study stated that the following drivers viewed AVs as traffic bottlenecks and frequently overtook AVs in congested areas.

Previous research also found that drivers may take different strategies when following AVs (Huang et al., 2022; Wen et al., 2023). Thus, when designing the eHMI for AVs, guiding the behaviors of surrounding vehicles can be an essential task.

From the surrounding drivers' perspective, some participants mentioned that to make use of the information perceived by the driving automation, especially the BVR information, eHMI should be used on AVs. However, the perceived validity of the information may be influenced by drivers' trust in AVs. Future research should investigate the impact of AV-based information on traffic safety and efficiency.

5.5 Limitations

First, participants of both studies are all from mainland China, which may limit the generalizability of the findings, given that different countries may have different driving cultures. Second, although the moderator made efforts to foster an open and nonjudgmental atmosphere to mitigate social desirability bias, it is acknowledged that certain risky CF behaviors, such as tailgating, traffic rule violations, and angry driving, may not have been fully disclosed or discussed. Future research should specifically address these problems in observational studies or naturalistic studies. Third, to avoid constraining participants' opinions to specific eHMI designs, we provided participants with only two eHMI designs with basic BVR information in the field study. To avoid misleading readers regarding the effects of the eHMI in CF events, we did not report driving performance data. Future studies should systematically vary the design of eHMIs based on our findings and identify suitable eHMI designs for CF events.

6 CONCLUSIONS

Through the focus group study, we systematically investigated how drivers use BVR and implicit information when following LVs in traffic. Though the focus group may not be able to collect quantitative data on users' behaviors, it covers broader topics than empirical studies and delves more deeply into what drivers expect. Following the focus group study, a field study was conducted to create a realistic driving experience and validate feedback on eHMIs for CF events. At this preliminary stage of the novel research direction, the two-stage method and diverse backgrounds of participants further enhanced the validity of drivers' opinions and provided insights for future empirical studies. Our major findings are listed below:

- CF involves not only operational driving tasks but also tactical decisions, which require cognitive resources.
- Drivers' CF behaviors depend not only on the relative motions between the SV and the DLV, but also on the traffic conditions (congested or not), the objective of the drivers (safety over efficiency or vice versa), the behavior, state, and driving style of leading driver, the traffic flow ahead, and even the behavior of the following vehicle.
- Drivers have high expectations of BVR information when following the leading traffic flow.
- The novel eHMIs are expected by drivers, but drivers have different needs for the conciseness of the information on eHMIs.
- The eHMIs are needed for AVs to improve interactions with HDVs, especially in congested areas.

Overall, this study can guide the design of eHMIs for information sharing between AVs and HDVs in CF events. The findings can also provide insights into optimizing the driver behavior modeling to facilitate more human-like CF algorithms for both traffic simulation and AV design.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available in the GitHub repository at: https://github.com/Feiqigu/Focus-group-transcripts-and-SUS-questionnaire-data. The data have been anonymized to protect participant privacy.

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APPENDIX

Codebook of the focus group and field study

Theme	Sub-theme				FG1 (n=8)	FG2 (n=5)	FG3 (n=8)	FG4 (n=6)	FG5 (n=5)	FG6 (n=6)	Total
					158	138	121	132	129	196	874
Information flow in CF events based on the S-C-R model	Perception & cognition	Sources of information	Behavior of other road users	Tailgated by following vehicle	0	0	0	0	0	1	1
				Sudden pedestrian intrusion	1	1	2	0	0	0	4
				Erratic behavior of the leading vehicle	1	1	1	1	0	3	7
				Acceleration of the leading vehicle	3	2	0	0	2	0	7
				Deceleration of leading vehicle	9	2	10	14	6	2	43
				Big vehicle ahead	1	4	0	10	0	1	16
			Field of view		0	0	0	0	0	3	3

			Weather conditions		0	2	0	2	0	1	5
			Fatigue		1	0	0	1	1	1	4
			Traffic environment	Traffic congestion	3	0	2	0	0	4	9
				Adverse road conditions	5	1	2	3	2	1	14
				Low road visibility	1	1	0	1	5	1	9
				Road obstructions	3	1	1	1	5	1	12
			Unfamiliarity with road		0	0	0	1	1	0	2
			Traffic light		1	0	0	0	0	0	1
			Road speed limit		1	0	0	0	1	0	2
			Speed of leading vehicle		8	0	2	3	3	3	19
		Cognitive capacities	Limited attention resource		2	20	2	12	0	0	36
			Long-term cognition		7	8	10	0	6	22	53
	Response selection and execution		Flashing headlights		0	0	1	0	0	2	3
			Avoid from being tailgated		2	0	0	0	0	11	13
			Horn honking		0	0	2	4	0	1	7
			Tailgating		3	1	1	0	0	5	10
			Accelerating		3	0	1	0	2	0	6

			Activating hazard flasher	0	0	1	0	1	3	5
			Maintaining distance	12	0	13	5	8	7	45
			Overtaking	4	8	2	3	4	9	30
			Braking	10	2	9	6	9	5	41
eHMI design	Communication method	Light		2	1	1	0	2	1	7
		Text		3	1	2	2	1	3	12
		Icon		4	2	7	4	3	3	23
		Audio		1	0	2	5	0	3	11
	Content	Driving instructions for following vehicle		0	0	0	0	0	5	5
		Traffic light		0	1	0	0	0	0	1
		Environmental perception of AVs		1	4	0	0	0	2	7
		Speed difference from the leading vehicle		3	0	7	9	0	1	20
		Distance from the leading vehicle		3	1	3	4	1	1	13
		Surrounding vehicle movements		11	4	0	0	2	1	18
		Leading driver	Driver state	4	6	1	2	0	0	13
			Driving style	6	2	1	0	3	0	12
			Driver's intended actions	3	2	0	2	9	0	16

		Forward road information	Intersection risk ahead	0	0	1	1	0	1	3
			Obstacles	0	0	2	0	0	2	4
			Oncoming vehicles ahead	0	0	0	0	0	1	1
			Lane information	0	2	0	0	2	0	4
			Curved road	1	0	0	0	1	0	2
			Lane narrowing	0	0	1	2	1	1	5
			Congestion	2	2	2	4	1	7	18
			Forward weather conditions	0	0	0	0	0	4	4
			Traffic accidents	0	1	2	1	4	7	15
	Design principles			14	34	19	7	7	29	110
	Position			18	21	8	22	8	32	109
Expectations of leading AVs	Perception of AVs			1	0	0	0	6	5	12
	Capability of AVs			0	0	0	0	22	0	22

Note: FG=focus group, n=number of times a code was applied within a focus group. Codes were analyzed and organized into categories to identify sub-themes.