# From Brake Lights to Beyond - Assessing Rear eHMI Designs through a Video-Based Survey

ANONYMOUS AUTHOR(S)

Rear-end collisions account for a large portion of road crashes and are closely related to drivers' car-following (CF) behaviors. Thus, providing additional information, especially the beyond-visual-range information, to support CF behaviors may reduce the rear-end collision risk. As a preliminary step, novel external human-machine interfaces (eHMIs) have been proposed to provide ego-drivers with the information of the indirect leading vehicle (DLV) ahead of the direct leading vehicle (ILV), We evaluated these eHMIs in a video-based survey study. The results from 165 valid responses showed that drivers with different characteristics had different preferences for the eHMIs with different contents (ILV speed, distance between ILV and DLV, brake of ILV, collision risk between ILV and DLV, and real-life video information) and communication methods (sign, text, animation and real-life video). The findings indicate the potential of eHMIs in supporting CF behaviors and highlight the importance of considering user heterogeneity when designing eHMIs.

CCS CONCEPTS •Human-centered computing~ Human computer interaction (HCI)~ Empirical studies in HCI

**Additional Keywords and Phrases:** eHMI design, Usability evaluation

## 1 INTRODUCTION

Rear-end collisions remain a major safety concern, accounting for approximately 28.9% of all road traffic crashes in the United States reported in 2023 [1], which can result in injuries, notably whiplash-associated disorders [2], and considerable property damage [3]. The rear-end crashes are closely related to the car-following (CF) behaviours of the drivers, which are traditionally treated as being strongly associated with drivers' responses to the motion of directly leading vehicles (DLV) [4]. However, the motion cues of the DLV can be trivial and may hardly be perceived effectively. Thus, as a mandatory vehicular device since the last century, the vehicles are equipped with brake lights and turn signals to inform the behaviour or intention of the ego-drivers [5]. However, these traditional signals offer only basic information about the DLV and may fall short in complex traffic situations.

Recent CF-related research and research on connected autonomous vehicles (CAVs) may provide some insights regarding further countermeasures to support safer CF behaviours of human drivers. The studies in the context of connected vehicles found that with the information of the road agents (e.g., vehicles ahead of the lead vehicle) beyond the visual range, the controllers can better balance the safety and efficiency of the traffic flow [6]. Further, a driving simulator study also found that providing the ego drivers with the information of the indirect leading vehicles (ILV, i.e., the vehicles ahead of the lead vehicle), the risk of rear-end crashes can be reduced, especially in emergent braking events [7]. However, the beyond-visual-range (BVR) information used in these previous studies was based on connected vehicle technologies; thus, the effectiveness of those solutions is restricted by the penetration rate of the vehicle-to-vehicle communication technologies, which, unfortunately, is still low.

Research on the external human-machine interface (eHMI) of autonomous vehicles (AVs) may provide some insights. In recent years, a number of studies have been conducted to facilitate communication between AVs and other road users [8]. Findings from this body of work have shown that eHMIs can facilitate better interaction between AV and road users. For example, a field study found that eHMIs showing deceleration or acceleration intention of the AV can support more efficient yielding behaviour of the human drivers in bottleneck scenarios [8]. However, the effectiveness of displaying BVR information on the rear of the vehicle to enhance CF safety has not yet been investigated. Specifically, to date, no research has been conducted to explore if the eHMIs can be used to provide additional BVR information (e.g., the states of the ILV in a CF event), in CF scenarios, in order to facilitate safer CF behaviours. Such CF-oriented eHMIs have been made possible with the rapid advancement of sensor technologies in vehicles[9], enabling them to detect and interpret the surrounding environment accurately.

Thus, we envision an alternative approach: what if BVR information detected by the ego-vehicle could be shared via an eHMI located on the back of the vehicle, so that the following vehicles (FVs) in the CF scenario can have access to the information of the traffic flow or ILV ahead (Figure 1)? Compared with the BVR information shared through V2V technology, eHMIs offer a more accessible and low-cost solution to convey the detected BVR information to following vehicles in CF events, especially in light of the increasing penetration of intelligent vehicles on the road.

As an innovative human-machine interface designed for drivers, it is important to evaluate drivers' perception of the eHMI, given that additional information may overload drivers in the already-complex scenarios [10]. Thus, as a preliminary study, we designed several eHMIs display concepts to convey BVR information in CF events, following basic design principles. These eHMIs have different contents (e.g., risk of rear-end collision vs brake behaviour of indirect leading vehicles), and communication methods (e.g., text vs animation). As a first step in the user-centric design process, to enhance the usability through iterative redesigns informed by user feedback [11] and to gain a holistic understanding of drivers' needs, a video-based survey study was conducted to obtain users' perceived usability of different eHMIs, from a large population with heterogeneous needs and characteristics.

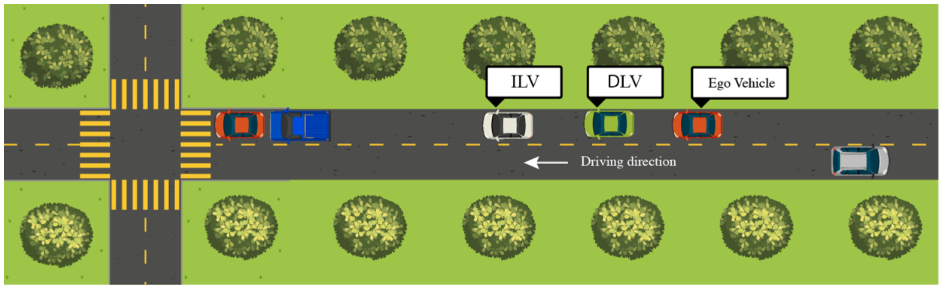



Figure 1: A typical car-following scenario with ILV, DLV and ego-vehicle, with the states of the ILV conveyed by the eHMI of the DLV.

## 2 EXTERNAL HUMAN-MACHINE INTERFACE DESIGN

Given that providing the information regarding the behavior of ILV on an in-vehicle display was found to benefit CF performance [7], we chose to focus on conveying the ILV information on eHMI in this preliminary study. Inspired by previous research, we selected five types of information regarding the ILV and the relationship between the DLV and ILV. They were visualized in 8 different designs as follows (see Table 1):

(a) The speed of the ILV. Similar to how a speedometer shows the speed of the ego-vehicle, the speed of the ILV is displayed in a numeric format (**Design No. 1**).

(b) The distance between the DLV and ILV [7]. Although numerical values can show the distance between the DLV and ILV, it may not be intuitive for drivers. To address this, an animation with two vehicle icons was used to represent the distance between the DLV and ILV visually (**Design No. 2**).

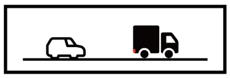
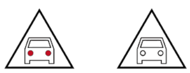
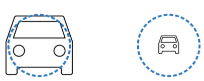
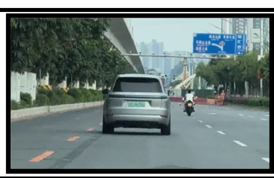
(c) The braking behaviour of the ILV, as inspired by [7]. The braking behaviour was represented using text (No. 3) and icons (No. 4) in two separate design concepts. In **Design No. 3**, textual information explicitly stated that the ILV is braking. In Design No. 4, two red circles indicate a braking action.

(d) The rear-end collision risk between the DLV and ILV, as materialized by the time headway (THW [12]). According to NASA Colour Guidelines [13], we selected red, yellow, and green to represent high (THW< 1 s), moderate (THW: 1 – 2 s), and low levels of risk (THW > 2 s) [14], respectively. Based on this scheme, we designed three eHMI concepts to convey crash risk information. **Design No. 5** featured flowing lights with a vertical gradient - from green at the top to red at the bottom - visually representing a transition from low to high risk. **Design No. 6** utilized a static symbol that changed colour to indicate the corresponding risk level. **Design No. 7** visualizes the crash risk using the size of a vehicle icon. A dashed-line circle marked the 2-second time headway threshold; if the vehicle icon extends beyond the circle, it indicates a high-risk situation.

(e) Real-time scenario from the perspective of DLV [7]. Such information was captured from the perspective of the DLV and is believed to provide the richest information, as drivers should be able to extract all kinds of information mentioned above from the video stream (**Design No. 8**).

In addition, to better capture the characteristics of the designs, we further classified these eHMI designs into distinct categories based on their communication methods (CM, text vs. video stream vs. animation), as presented in Table 1.

Table 1: Overview of eHMI designs in the survey

| No. | eHMI Design | Screenshot of the video in the survey | Categorization |
|---|---|---|---|
| 1 | 前方车速 24 km/h<br>Note: The text meaning the speed of IDV is 24 km/h. |  | CM: Text<br>Content: Speed of the ILV |
| 2 |  |  | CM: Animation<br>Content: Distance from the ILV to DLV |
| 3 | 前车刹车<br>Note: The text meaning the speed of IDV is 24 km/h. |  | CM: Text<br>Content: Braking behavior of the ILV |
| 4 |  |  | CM: Sign<br>CS: Implicit<br>Content: Braking behavior of the ILV |
| 5 |  |  | CM: Animation<br>Content: Rear-end collision risk between the ILV and DLV |
| 6 |  |  | CM: Sign<br>Content: Rear-end collision risk between the ILV and DLV |
| 7 |  |  | CM: Animation<br>Content: Rear-end collision risk between the ILV and DLV |
| 8 |  |  | CM: Video stream of the traffic ahead<br>Content: Real-life information |

## 3 MEYHOD

### 3.1 Survey Design

We developed a video-based survey hosted on Tencent Survey to evaluate our proposed eHMIs. A one-minute video depicting a CF scenario was recorded on a real urban road in Nansha District, Guangzhou, China. This video served as the background onto which we digitally overlaid the eHMIs designs on the rear of the DLV using Adobe After Effects. The information conveyed on the eHMI was consistent with the actual behavior of the ILV.

In the survey, we first collected participants' age, gender, affinity for technology interaction (ATI) [15], and driving experience (DE, as measured by the number of years they have regularly driven a vehicle). Next, we presented an image (Figure 1) to explain the CF scenario and how the eHMIs work. Then, for each eHMI design, keyframes of the eHMI were presented along with detailed text explanations. Finally, the same CF videos with different eHMIs were presented in random sequences. The participants watched the video and then answered the eHMI-related questions. The eHMI-related questions consisted of the Systems Usability Scale (SUS) [16]. Following [16], the perceived usability and learnability of the eHMIs were extracted from the SUS. The UEQ measures the emotional response and enjoyment as a result of using the eHMIs. To eliminate noisy answers, we set seven attentional check questions in the survey. Participants who failed to follow the instructions by selecting the specified answers were excluded from the analysis (e.g., "please choose strongly agree for this question").

### 3.2 Participants

We recruited 558 participants from the online social media WeChat and Little Red Book. The inclusion criteria are: (1) holding a valid Chinese driver's license; (2) being 18 years or older; (3) being a native/fluent Chinese speaker. We used the G*Power software to perform power analysis for linear mixed model, and the result indicated that a sample size of 146 participants would be necessary to reach a power of 0.9, an effect size of 0.15, and an error probability of 0.01. A total of 165 participants (112 males, 53 females) passed seven attention check questions and received a payment of 10 RMB. Their average age was 28.4 (standard deviation =5.8, range = [19, 47]).

### 3.3 Data Analysis

Using RStudio software, given the imbalanced number of combinations of eHMIs with different content and communication method, two types of linear mixed models were built, with either eHMI content or communication method as the independent variable and gender, age, DE, and ATI as covariates. The dependent variables included usability and learnability. In all models, a random intercept was set for each participant. A backward model selection process was conducted for the covariates. Pairwise comparisons were performed for significant main effects ($p < .05$), with Bonferroni corrections applied to control for multiple comparisons.

### 3.4 Results

Results of the models regarding usability are summarized in Table 2. The post-hoc analyses of the significant continuous variables are summarized in Table 3 and Table 4 and visualized in Figure 4. Perceived usability increased with greater driving experience, as indicated by Model 1 and Model 2 (estimate = 0.62, $t(161) = 2.57$, $p = .01$).

Table 2: Statistical results for usability

| DV | IVs | F-value | p-value |
|---|---|---|---|
| Model 1<br>Perceived usability ~ Communication Method | **Communication method** | **F (3, 1146) = 2.85** | **.03** |
| | **DE** | **F (1, 161) = 7.20** | **.008** |
| | **ATI** | **F (1, 174) = 97.12** | **< .001** |
| | Gender | F (1, 174) = 0.89 | .3 |
| | Communication method: Gender | F (3, 1146) = 0.19 | .7 |
| | **Communication method: ATI** | **F (3, 1146) = 2.68** | **.04** |
| Model 2<br>Perceived usability ~ Content of eHMI | **Content of eHMI** | **F (4, 1139) = 2.85** | **.02** |
| | **DE** | **F (1, 178) = 7.65** | **.006** |
| | **ATI** | **F (1, 178) = 94.00** | **< .001** |
| | Gender | F (1, 178) = 0.90 | .3 |
| | Content of eHMI: Gender | F (4, 1139) = 0.81 | .5 |
| | **Content of eHMI: ATI** | **F (4, 1139) = 2.49** | **.04** |
| | Content of eHMI: DE | F (4, 1139) = 0.31 | .9 |
| Model 3<br>Perceived Learnability ~ Communication Method | Communication Method | F (3, 1314) = 1.11 | .3 |
| | ATI | F (1, 172) = 1.01 | .3 |
| | Communication Method: ATI | F (3, 1314) = 3.24 | .5 |
| Model 4<br>Perceived learnability ~ Content of eHMI | **Content of eHMI** | **F (4, 1312) = 2.85** | **.02** |
| | ATI | F (1, 170) = 2.17 | .1 |
| | **Content of eHMI: ATI** | **F (4, 1312) = 2.66** | **.03** |

Table 3: Post hoc analysis of the interaction effect of communication method and ATI on perceived usability.

| DV | Perceived usability | | |
|---|---|---|---|
| | **Slope of ATI** | **95% CI** | **p value** |
| **Text** | **8.57** | **[6.13, 11.0]** | **<.0001** |
| **Animation** | **8.28** | **[6.06, 10.5]** | **<.0001** |
| **Sign** | **8.23** | **[5.79, 10.7]** | **<.0001** |
| **Real-life Video** | **12.19** | **[9.17, 15.2]** | **<.0001** |

Table 4: Post hoc analysis of the interaction effects of content of eHMI and ATI on perceived usability and perceived learnability.

| DV | **Perceived usability** | | | **Perceived learnability** | | |
|---|---|---|---|---|---|---|
| | **Slope of ATI** | **95% CI** | **p value** | **Slope of ATI** | **95% CI** | **p value** |
| **Speed of ILV** | **8.22** | **[5.20, 11.2]** | **<.0001** | 4.06 | [-1.72, 9.84] | .2 |
| **Distance between ILV and DLV** | **9.43** | **[6.40, 12.4]** | **<.0001** | 3.37 | [-2.41, 9.15] | .3 |
| **Brake behavior of ILV** | **8.72** | **[6.27, 11.2]** | **<.0001** | 2.06 | [-3.19, 7.32] | .4 |
| **Rear-end collision risk** | **7.78** | **[5.56, 10.0]** | **<.0001** | 1.20 | [-3.87, 6.26] | .6 |
| **Real-life information** | **12.19** | **[9.17, 15.2]** | **<.0001** | **7.24** | **[1.45, 13.02]** | **.01** |

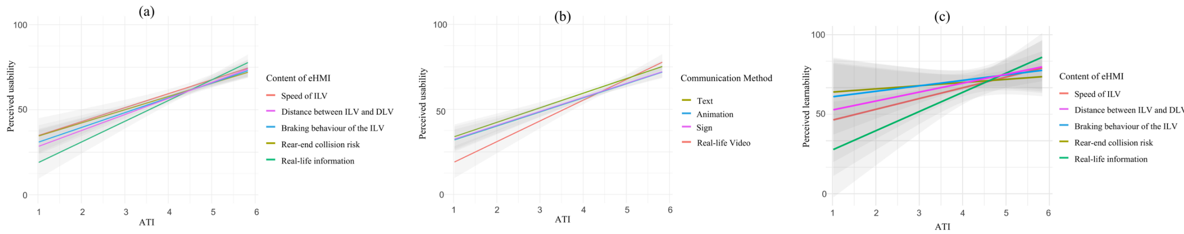



Figure 4: Significant interaction effects; (a) the effect of ATI on perceived usability with different contents; (b) the effect of ATI on perceived usability with different CMs; (c) the effect of ATI on perceived learnability with different contents.

## 4 DISCUSSION

In this study, we proposed eight windshield-displayed eHMI prototypes to display the BVR information in CF events. We investigated how the BVR information content and communication method affected participants' perceived usability of the eHMI. This study served as a preliminary exploration regarding how to support drivers with BVR information in CF events to improve traffic safety and efficiency.

First, we found that driving experience was positively associated with users' perceived usability of the eHMI. This effect may be attributed to experienced drivers' more active efforts to seek anticipatory information [17], which can be provided by the eHMIs. In contrast, novice drivers may be less aware of the importance of anticipatory information, and thus they have less expectation of BVR information. Future research may validate whether novice drivers who receive additional hazard perception training would prefer more BVR information.

At the same time, as expected, eHMI, as a novel interaction method, was perceived as more useful by drivers with a higher affinity for technology interaction (ATI). Such a phenomenon has also been observed when an e-learning platform is introduced to students [18], where those who had higher ATI also perceived the e-learning platform as more useful. At the same time, we found that the relationship between the ATI and the perceived usability can be moderated by the communication method and content of the eHMI. Specifically, the ATI had the strongest influence on users' perceived usability for the real-life video eHMI. As a result, the population with different characteristics holds different attitudes toward different eHMIs. Especially, the real-life information was least preferred among the users with lower ATI but most preferred among users with high ATI. It is likely that the real-life video in the eHMI is very different from the traditional taillights or symbolic displays that are widely adopted. Thus, the potential users' ATI would have a stronger influence on users' perception of the real-life video eHMI. These results underscore the importance of boosting potential users' ATI if new technologies are introduced.

However, the perceived learnability of the eHMI was not influenced by the communication method of the eHMI, and users' perceived learnability of the eHMI was only sensitive to the ATI when the content was real-life animation. It is likely that we provided a detailed introduction of the eHMIs before the survey, and the users had no difficulty understanding different communication methods, though drivers with higher ATI would still be familiar with new technologies and perceive the real-life animation as easier to learn compared to those with lower ATI. Similarly, as a result, the real-life information was rated as the least learnable among the users with lower ATI, but the most learnable among users with high ATI.

Finally, although this survey study suggests that eHMI designs should consider user heterogeneity and may consider an adaptive interface to improve user experience, it should be noted that, as a preliminary step to explore novel design ideas in the vehicle, the study focused only on subjective perceptions without measuring objective behavioural responses. Future research should test these eHMIs and validate our findings with diverse driver population in simulation or field experiments.

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