Express What I Think: The Impact of External Human-Machine Interfaces on the Performance of Lane Change Maneuvers

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Lane change is a complex behaviour involving subtle interactions among road users. Providing external human-machine interfaces (eHMIs) may improve the safety of lane-changing events. However, previous studies on eHMI mostly focused on the interaction between autonomous vehicles and pedestrians. As a first attempt, we investigated the yielding behaviour of drivers in lane-changing scenarios when different kinds of eHMIs regarding the intentions of the cutting-in vehicles (i.e., command, polite and explanatory) are provided. In a driving simulation experiment with 32 participants, we found that all three eHMIs increased yielding rates and minimum time to collision (minTTC) compared to the baseline condition without eHMI, with the polite eHMI yielding the best results. Regarding subjective evaluation, polite eHMIs were also perceived as having the highest usability. This study underscores the effectiveness of explicitly expressing lane-changing intentions through eHMIs and demonstrates that the eHMI design can influence driver behaviour, usability perception, and traffic safety.

CCS Concepts: • **Human-centered computing → Empirical studies in interaction design**; **Interface design prototyping**.

Additional Key Words and Phrases: External Human-Machine Interfaces, eHMIs, Lane-changing Events, V2V Communication, Driver Behavior

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1 Introduction

Lane change is a common maneuver during driving, and it is one of the leading factors of on-road crashes [34, 36, 40]. Particularly in high-density traffic, inappropriate cut-ins can lead to emergency braking of rear vehicles being cut in [40], thereby increasing the risk of rear-end or side collisions [12, 34]. At the same time, the low yielding rate of the rear vehicles, as a result of inappropriate lane change timing, can also negatively affect the efficiency of the traffic [42], especially near the entrance of the ramp. The lane-changing scenario is a typical gaming process. Therefore, increasing the transparency of the players, i.e., the cutting-in vehicles and the being cutting-in vehicles (BCV), may increase the success rate, safety and efficiency of the lane-changing process.

Explicitly expressing intention during driving has been widely investigated in the domain of autonomous driving, mostly relying on external human-machine interfaces (eHMIs) [4, 36]. For example, to facilitate safer and more efficient interaction between autonomous vehicles (AVs) and pedestrians, previous studies have proposed eHMIs to communicate AV intentions and, therefore, reduce misunderstandings and uncertainties [14, 20]. In AV-pedestrian interactions, previous research has shown that both tone and informational content presented by eHMIs can facilitate pedestrians' interpretations of the AV and subsequent street-crossing decisions [9, 23, 25, 27]. Positive expressions or clearly stated intentions conveyed by eHMIs typically increase pedestrian trust and compliance, leading to safer crossing decisions [1, 5, 11, 25]. Conversely, ambiguous or overly assertive messages can cause uncertainty or discomfort, potentially compromising interaction safety [2, 37, 41].

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However, though many studies have explored if marking the AVs with eHMI would affect users' rating of and responses to the AVs [15, 17], very few studies have investigated how the eHMIs can facilitate vehicle-vehicle interactions in more dynamic environments, such as lane-changing scenarios, where the explicit expression of intentions may play a more vital role. One study has tried to improve the legibility of AVs' lane-changing intentions for vehicle-to-vehicle communication by optimizing the AV movement during lane-changing; however, the AV movement is still implicit, and its effectiveness depends on other drivers' interpretation [24]. Another study has highlighted the importance of timing and clarity of eHMI communication in dynamic scenarios such as automated truck merging, emphasizing how explicit signals can benefit driver reactions and safety outcomes in highway merging scenarios [18]. However, interacting with trucks is different from interacting with other sedans, as the trucks may impose higher pressure on other road users.

More importantly, there are two major gaps in previous research. First, these previous studies did not consider the tones of the eHMI in vehicle-to-vehicle interaction scenarios, which, as has been found in previous AV-pedestrian interaction studies, may shape human road users' behaviours [10]. Second, previous studies mostly focused on AV-human interactions. However, human drivers may use different strategies to interact with AVs than with human-driven vehicles [21]. Therefore, our current study aims to explore whether explicit expression of driver intention on eHMIs of human-driven vehicles, especially the eHMIs with different tones, can facilitate safer and more efficient lane-changing interactions among human-driven vehicles.

Through a driving simulator experiment, we examined how different eHMIs tones (i.e., polite, commanding and explanatory) can affect rear vehicle drivers' yielding behavior and safety metrics during lane-changing scenarios. Given that we aim to observe participants' behaviours in a more natural scenario, the participants were not informed of eHMIs before the experiment. Thus, to ensure better interpretability of the eHMIs [10], we adopted three different text-based eHMIs, varying in tones. We propose two research questions:

1) **RQ1:** whether the presence of any eHMIs on a human-driven cutting-in vehicle influences the yielding rate of the following vehicles in a lane-changing scenario.

2) **RQ2:** whether different tones of eHMI on a human-driven cutting-in vehicle lead to different yielding rates of the human-driven following vehicles.

In response to RQ1, we hypothesize that the presence of an eHMI would influence the yielding behaviour of the following vehicles (H1), as previous research in AV-human driver interactions has shown that external communication signals from AVs can improve human drivers' understanding of the AV's intention and increase their willingness to yield [10, 19]. In response to RQ2, we hypothesize that different tones would lead to different responses (**H2**), as previous research has demonstrated that clear and direct instructions in a commanding style can enhance response speed in emergency situations [30, 33], polite requests are generally more acceptable and can increase compliance rates [7], and even simple explanations can significantly enhance others' willingness to cooperate in social contexts [8].

2 Method

2.1 Participants and Apparatus

Prior to the experiment, all participants completed a recruitment questionnaire regarding their demographic information, including gender, age, and driving experience. To ensure they are frequent drivers, all participants were required to have held a driver's license for at least 2 years and drove at least 5,000 km and at least 3 times per week in the past year. A total of 32 participants (16 male and 16 female) with valid driving license participated in this study. The participants' ages ranged from 20 to 35 years, with a mean age of 28 and a standard deviation (SD) of 3.66 years, and the years of driving experience ranged from 2 to 9 years (mean: 4.75, SD: 2.19). The study was approved by the Human and Artefacts Research Ethics Committee at the Hong Kong University of Science and Technology (protocol number: HKUST(GZ)-HSP-2024-0107).

The experiment was conducted on a stationary driving simulator by Info Tech (Figure 1). The simulator has three 43-inch displays located in front and to the sides, with a horizontal viewing angle of 150° and a vertical viewing angle of 47°. The driving scenarios were built in SiLAB software by WIVW GmbH, which records the vehicle-related and driving-related data at 60 Hz.

Fig. 1. The driving simulator.

2.2 Scenario Design and Driving Tasks

In the experiment, drivers were required to drive on an 8-kilometer-long, three-lane highway with three on-ramps and a speed limit of 80 km/h, as shown in Figure 2. To replicate typical highway traffic with a middle level of congestion, the highway was designed to have 20 vehicles per kilometre, an average bumper-to-bumper distance of 20 meters between all vehicles, and an average flowing speed of 60 km/h (i.e., the direct leading vehicle and the vehicle in adjacent lanes both travelled around 60 km/h). The middle level of congestion was selected as lane-changing in such scenarios can be more challenging due to smaller gaps between vehicles.

In the driving task, participants were instructed to stay in the middle lane of the three-lane highway when possible, follow the lead vehicle and drive safely. When the distance between the ego vehicle and the entry ramp was 200 meters, a cutting-in vehicle 50 meters behind was triggered to further accelerate (starting from 60 km/h) at 6 m/s^2 until reaching a position 15 meters ahead of the ego vehicle (which took around 4 seconds) before initiating its lane change maneuver. As shown in Figure 3, the cutting-in vehicle would make two consecutive lane changes from the leftmost lane to the far-right lane and then exit via the on-ramp. The scenario included four lane-changing events, during which participants needed to react appropriately, either to yield to the lane-changing vehicle or to pass it before they finished the lane-changing task, depending on the driver's willingness.

(a) (b)

Fig. 2. Driving scenarios: (a) Normal driving scenario; (b) Lane–changing scenario.

2.3 eHMI Designs

In this study, we designed three distinct types of eHMIs: command eHMI, polite eHMI and explanatory eHMI. Specifically, the command eHMI stated, "Changing lanes, slow down immediately," the polite eHMI stated, "Changing lanes, please yield to me," and the explanatory eHMI stated, "About to exit ramp, preparing for lane change." As mentioned previously, the command eHMI was based on the fact that clear and direct instructions can speed up responses in emergencies [30, 33]; the polite eHMI was based on

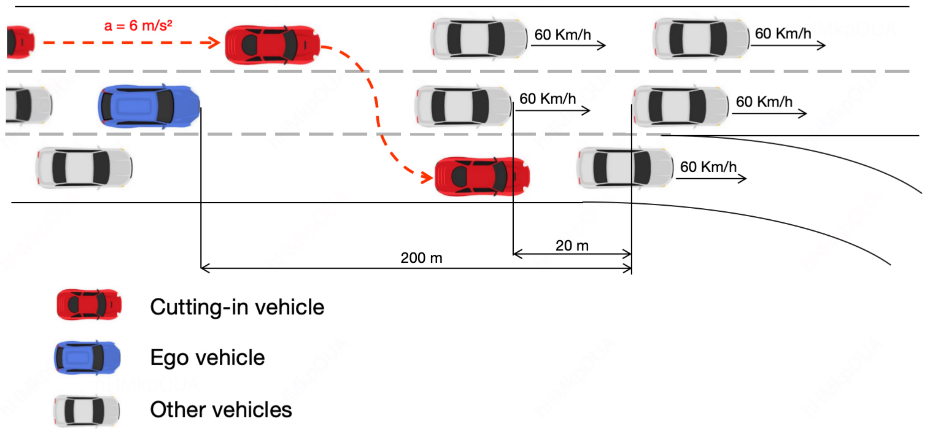

Fig. 3. The bird view of the lane-changing scenario.

the Politeness Theory that polite requests may increase compliance rates [7]. Finally, the explanatory eHMI was based on the fact that explanations can enhance others' willingness to cooperate in social contexts [8], which is the case in lane-changing scenario.

All eHMIs were shown in red text on both the rear window and the sides of the cutting-in vehicle. The colour matched the eHMI design in a large portion of research [13] to improve the salience of the eHMI (as the participant was not told of the eHMI in advance). However, the placement was somewhat different from what has been widely adopted in AV-pedestrian interaction [13]. Such a placement better satisfied the needs in the lane-changing scenario by ensuring the eHMIs were clearly visible to surrounding drivers, including drivers of the ego vehicle (i.e., our participants). Additionally, a baseline group without eHMI was included. The eHMIs showed up after the cutting-in vehicle started to accelerate and remained visible throughout the entire two-lane-change maneuver, until the vehicle exited via the ramp. The designs of the three eHMIs and the baseline are illustrated in Figure 4.

2.4 Experiment Design

This experiment adopted a within-subject experiment design with the eHMI type as the experimental variable. The order of the eHMI conditions (one baseline and three eHMIs) was balanced using a Latin square design, and there were four lane-changing events in each drive; therefore, there were four different drives with distinct eHMI orders. The order of the four drives was further counterbalanced using the Latin square design, with eight participants for each order (four males and four females). Thus, the data from a total of 512 lane-changing events were collected (32 participants $*$ 4 drives $*$ 4 lane-changing events in each drive).

(a) (b) (c) (d)

Fig. 4. eHMI designs: (a) No eHMI; (b) Command eHMI: "Changing lanes, slow down immediately"; (c) Polite eHMI: "Changing lanes, please yield to me"; (d) Explanatory eHMI: "About to exit ramp, preparing for lane change".

2.5 Procedures

Upon arrival, participants signed an informed consent form. They then received training on the operation of the simulator, followed by a demo drive to familiarize themselves with the setup. They were told to drive along the highway as they normally would in daily life, while keeping in the middle lane of the three-lane highway when possible, following the lead vehicle and driving safely. However, the eHMI was not mentioned in the training. This was an intentional design choice to avoid priming effects [31, 32, 35] and allow participants to interpret the eHMIs based on their own perceptions and driving experience, thereby enhancing the ecological validity of the study.

Following the demo drive, participants did four formal experimental drives, each was around 10 minutes long and contained four lane-changing events. After completing all experimental drives, participants completed a questionnaire evaluating the usability of the eHMIs and the baseline interaction (i.e., with brake lights and turn signals only) using the System Usability Scale (SUS) [6]. Finally, before the experiment concluded, participants were asked an open-ended question to gather feedback on the content and design of the eHMIs.

2.6 Dependent Variables and Statistical Analysis

In this study, both objective and subjective measures were used to assess the effectiveness of different eHMIs. The impact of the eHMIs on traffic efficiency was evaluated using the yield rate in the lane-changing events, which was defined as the number of instances in which the driver of the ego vehicle yielded to the cutting-in vehicle. The safety impact of the eHMI was evaluated using the time-to-collision (TTC), which was calculated as the time remaining until a potential collision between the ego vehicle and the cutting-in vehicle, assuming constant speeds and trajectories. In the analysis, we focused on the minimum TTC (minTTC) during the cutting-in event, which represents the moment with the highest collision risk in an event [22]. The perceived usability of different eHMI types was measured using the standard System Usability Scale (SUS), with a score ranging from 0 (low) to 100 (high) [6].

All statistical analyses were conducted in SAS on demand. A Poisson regression model was utilized to examine the effects of eHMI on the yielding rate. For minTTC and the SUS scores, a Linear Mixed Model (LMM) was employed. Given that gender may also have an impact on users' perception of the eHMIs [39], in all models, the eHMI type (four conditions) and participant gender (male and female), as well as their two-way interaction, were included as independent variables. The repeated measures were accounted for through generalized estimation equations (GEE) [26]. If statistically significant effects were identified ($p < .05$), Wald tests were performed for post-hoc pairwise comparisons of yielding ratio and Tukey's HSD test was applied for post-hoc pairwise comparisons of minTTC and SUS score.

3 Results

3.1 Yield Rate and TTC

As shown in Figure 5 and Figure 6, the eHMI type significantly affected the yield rate ($\chi^2(3) = 45.65$, $p < .001$) and the minTTC ($F(3, 93) = 50.5$, $p < .001$) in the lane-changing event. However, gender did not have a significant effect on yield rates ($p = .2$) nor on minTTC ($p = .2$). The post-hoc comparisons for significant effects of Yield Rates and minTTC are presented in Table 1.

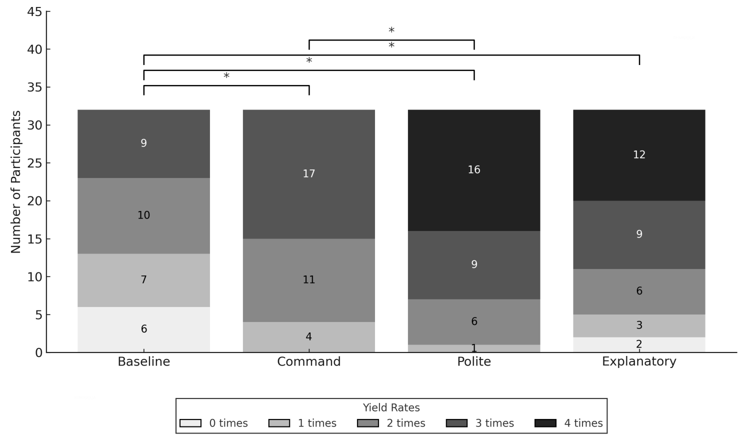

Fig. 5. Yield Rates across different eHMI conditions, the darker the colour, the higher the number of yields in the experiment. There is a maximum of 32 trials under each eHMI condition. In this figure and the following figures, significant (p < .05) pair comparisons are marked with *.

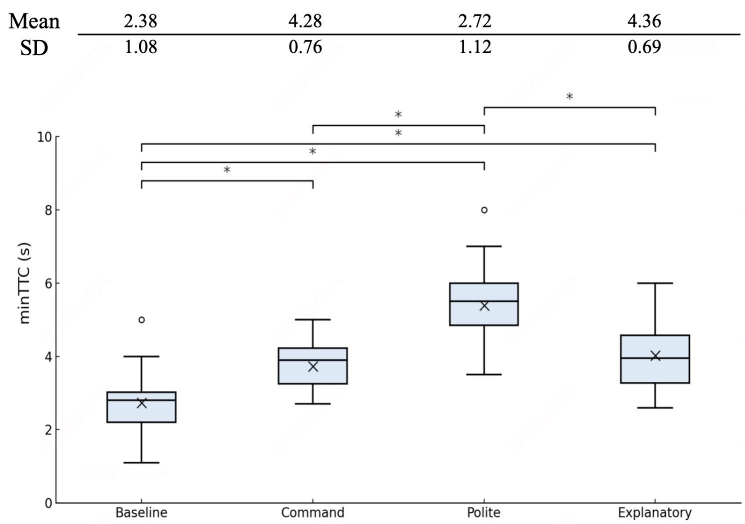

Fig. 6. minTTC across different eHMI conditions. In this figure and the following figures, the boxplot represents the minimum, 1st quartile, median, 3rd quartile, and maximum, and the symbol x is the mean of the group. M and SD stand for mean and standard deviation, respectively.

Table 1. Pairwise comparisons across eHMI conditions on Yield Rates and minTTC.

Condition Comparison	**Yield Rates**			**minTTC**		
	Δ (95% CI)	Wald Stat	*p*-value	Δ (95% CI)	Wald Stat	*p*-value
Baseline vs Command	−0.355 (−0.703, −0.007)	3.996	.046	−1.003 (−1.426, −0.580)	32.573	< .001
Baseline vs Polite	−0.655 (−0.984, −0.327)	15.268	< .001	−2.806 (−3.229, −2.384)	170.621	< .001
Baseline vs Explanatory	−0.511 (−0.848, −0.173)	8.807	.003	−1.294 (−1.716, −0.871)	33.744	< .001
Polite vs Command	0.301 (0.006, 0.595)	3.996	.046	1.803 (1.379, 2.226)	49.491	< .001
Polite vs Explanatory	0.145 (−0.138, 0.427)	1.008	.315	1.512 (0.943, 2.091)	26.313	< .001
Command vs Explanatory	−0.156 (−0.461, 0.148)	1.009	.315	−0.291 (−0.693, 0.115)	2.062	.358

3.2 Subjective Metrics

As shown in Figure 7, significant differences were observed in participants' perceived usability of the eHMI types ($F(3, 124)=36.47$, $p < .001$). No other significant effects were observed ($p > .05$). The post-hoc comparisons for significant effects are presented in Table 2.

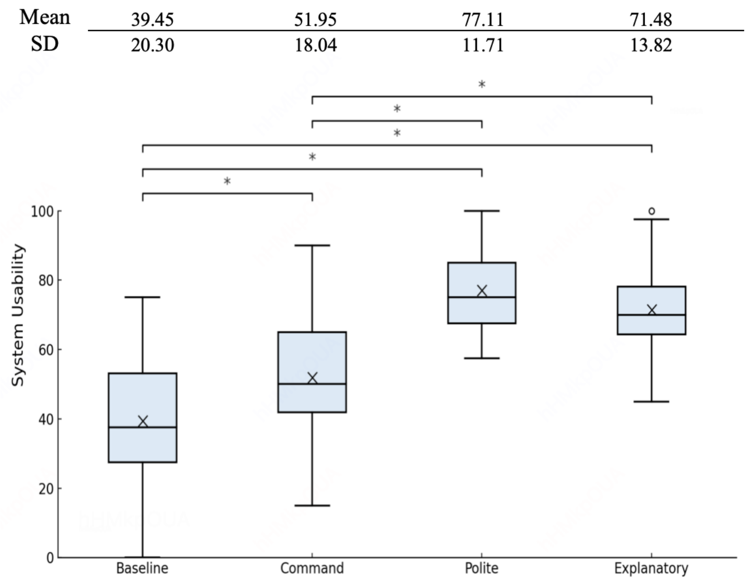

Fig. 7. SUS scores across different eHMI conditions.

Table 2. Pairwise comparisons across eHMI conditions on SUS.

Condition Comparison	**Δ (95% CI)**	***p*-value**
Baseline vs Command	−12.51 (−23.13, −1.87)	.014
Baseline vs Polite	−37.66 (−48.29, −27.03)	< .001
Baseline vs Explanatory	−32.03 (−42.66, −21.41)	< .001
Polite vs Command	25.16 (14.53, 35.79)	< .001
Polite vs Explanatory	5.63 (−5.01, 16.25)	.515
Command vs Explanatory	−19.53 (−30.16, −8.90)	< .001

4 Discussion

In this study, we designed three eHMIs to facilitate safer and more efficient lane-changing interactions in a driving simulator environment. Participants with balanced genders experienced lane-changing scenarios where different eHMI types were displayed on cutting-in vehicles.

The results demonstrated clear benefits of using eHMIs: vehicles equipped with eHMIs significantly increased both yielding rates and minTTC compared to baseline vehicles without eHMIs. In response to RQ1 and in line with H1, these results indicate that explicitly conveying lane-changing intentions can substantially enhance interaction safety and efficiency between drivers, similar to what has been found in previous AV-human driver interaction studies that used the eHMI to convey the intention of AVs [19, 28]. It should also be noted that, different from previous pedestrian-AV interaction studies that also considered the component of the eHMIs [10], our study provides novel evidence extending these benefits into a more dynamic vehicle-to-vehicle interaction scenario consisting of only human-driven vehicles. Though drivers may not be able to distinguish human-driven vehicles and AVs by observing the behaviours [38], participants in previous AV-equipped eHMI studies were clearly informed of the AVs. Thus, our findings indicate that eHMIs may also be considered for human-driven vehicles in addition to turning signal alone (in the baseline condition), as the turning signal may not be enough to express drivers' emotions or intentions.

In response to RQ2 and in line with H2, our results also revealed nuanced differences between the types of eHMIs tested. The polite eHMI was most effective, resulting in the highest yielding rates and the greatest minTTC compared to both command and explanatory eHMIs. This finding aligns well with the Politeness Theory [7, 29], emphasizing that drivers respond more positively to cooperative, respectful messaging. Interestingly, although the command eHMI and explanatory eHMI did not significantly differ in safety-related metrics, participants perceived the explanatory eHMI as more usable. This discrepancy likely arises because the explanatory message provided contextual information, making the lane change appear justified and reasonable [19]. In contrast, the command message, while clear and direct, potentially conveyed an authoritarian or aggressive tone, triggering psychological resistance or reduced acceptance among drivers [29]. These subtle yet important insights underscore the critical role of message framing in shaping driver perceptions and cooperation and may be extended to other scenarios involving AVs and human road users. Consequently, designers of vehicle interfaces should carefully consider not just the clarity of the intention expressed but also the social and connotations conveyed by different wording choices.

While these results provide valuable insights, certain limitations should be acknowledged. Firstly, the study was conducted in a driving simulator, which offered controlled and reproducible scenarios but removed the complexity and variability in real-world traffic scenarios. Consequently, certain behavioural nuances and comprehensive driving metrics might not be fully captured. Future studies should consider validating our findings in on-road experiments. Secondly, participants were not explicitly informed whether the surrounding vehicles were AVs or human-driven vehicles. Thus, it is unclear whether participants assumed the cutting-in vehicles were AVs or human-driven vehicles, which may limit the interpretability of the findings. Future studies should clearly inform participants about the vehicle types beforehand or even explore how the vehicle type can influence users' perception of the eHMIs. Thirdly, although the SUS scores in this study reflected participants' subjective impressions of eHMI clarity and effectiveness, its original design for active system users may limit its suitability for evaluating the reception of external information on vehicles. Future research should explore alternative subjective measures that are more suitable for evaluating the effectiveness of external message communication. Moreover, though we considered the gender effects in the models, we did not observe differences between males and females regarding behavioural metrics and preferences and the current analysis did not explicitly account for other individual differences, such as driving styles (i.e., aggressive or conservative tendencies) and personability. Given that heterogeneous groups may have different levels of susceptibility to the framing of the information [3], their influence on driver responses and acceptance of different eHMIs should be considered. Furthermore, the participant sample was composed predominantly of young drivers with less than 10 years of driving experience. This demographic narrowness limits the generalizability of our findings, particularly to older or more experienced populations. Expanding the age and experience range in future work would help address this limitation. Next, as a preliminary study, we used the text-based eHMI to ensure the interpretability of the eHMI and to isolate the effects of tone. Future research could extend these findings by exploring multimodal eHMIs, combining text with graphical icons, colour-coded signals, or dynamic animations, potentially capturing attention more effectively and catering to diverse driver preferences and cognitive strategies. Moreover, integrating physiological and eye-tracking measurements could provide deeper insights into drivers' real-time responses to various eHMI formats. Finally, considering the significant cross-cultural differences identified in previous studies [16], future research should examine the generalizability and effectiveness of explicit intention communication strategies across diverse cultural and regional traffic contexts.

5 CONCLUSION

Though an increasing number of commercially available vehicles are equipped with eHMIs, most of them are used for entertainment purposes. Exploring the role of eHMI from the vehicle-to-vehicle communication perspective can potentially benefit traffic safety and efficiency. As one of the first studies focusing on expressing lane-changing intentions to facilitate vehicle-to-vehicle interaction among human drivers, we explored the eHMI designs with different tones to facilitate vehicle-to-vehicle interaction in lane-changing scenarios. The results validated the effectiveness of explicitly expressing drivers' intentions through eHMIs and indicated that different eHMIs tones might yield different behaviours in lane-changing events and result in different levels of user acceptance. Our research has laid a foundation for future research to gain a deeper insight into eHMI design and enhance its applicability across diverse real-world traffic scenarios.

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References

[1] Claudia Ackermann, Matthias Beggiato, Luka-Franziska Bluhm, Alexandra Löw, and Josef F Krems. 2019. Deceleration parameters and their applicability as informal communication signal between pedestrians and automated vehicles. *Transportation Research Part F: Traffic Psychology and Behaviour* 62 (2019), 757–768.

[2] Daniel Ames, Alice Lee, and Abbie Wazlawek. 2017. Interpersonal assertiveness: Inside the balancing act. *Social and Personality Psychology Compass* 11, 6 (2017), e12317.

[3] Kristen D. Anderson. 2010. *Framing Traits: The Role of Personality in Framing Effects.* Master's thesis. University of Nebraska - Lincoln, Lincoln, NE. https://digitalcommons.unl.edu/poliscitheses/5/

[4] Pavlo Bazilinskyy, Dimitra Dodou, and Joost De Winter. 2019. Survey on eHMI concepts: The effect of text, color, and perspective. *Transportation Research Part F: Traffic Psychology and Behaviour* 67 (2019), 175–194.

[5] Klaus Bengler, Michael Rettenmaier, Nicole Fritz, and Alexander Feierle. 2020. From HMI to HMIs: Towards an HMI Framework for Automated Driving. *Information* 11, 2 (2020). https://doi.org/10.3390/info11020061

[6] John Brooke et al. 1996. SUS-A quick and dirty usability scale. *Usability Evaluation in Industry* 189, 194 (1996), 4–7.

[7] Penelope Brown and Stephen C Levinson. 1987. *Politeness: Some Universals in Language Usage.* Vol. 4. Cambridge University Press.

[8] Jerry M Burger, Nicole Messian, Shebani Patel, Alicia Del Prado, and Carmen Anderson. 2004. What a coincidence! The effects of incidental similarity on compliance. *Personality and Social Psychology Bulletin* 30, 1 (2004), 35–43.

[9] Juan Carmona, Carlos Guindel, Fernando Garcia, and Arturo de la Escalera. 2021. eHMI: Review and Guidelines for Deployment on Autonomous Vehicles. *Sensors* 21, 9 (2021). https://doi.org/10.3390/s21092912

[10] Mark Colley, Jan Henry Belz, and Enrico Rukzio. 2021. Investigating the effects of feedback communication of autonomous vehicles. In *13th International Conference on Automotive User Interfaces and Interactive Vehicular Applications.* 263–273.

[11] Shuchisnigdha Deb, Daniel W Carruth, and Christopher R Hudson. 2020. How communicating features can help pedestrian safety in the presence of self-driving vehicles: Virtual reality experiment. *IEEE Transactions on Human-Machine Systems* 50, 2 (2020), 176–186.

[12] Shuchisnigdha Deb, Lesley J Strawderman, and Daniel W Carruth. 2018. Investigating pedestrian suggestions for external features on fully autonomous vehicles: A virtual reality experiment. *Transportation Research Part F: Traffic Psychology and Behaviour* 59 (2018), 135–149.

[13] Debargha Dey, Azra Habibovic, Andreas Löcken, Philipp Wintersberger, Bastian Pfleging, Andreas Riener, Marieke Martens, and Jacques Terken. 2020. Taming the eHMI jungle: A classification taxonomy to guide, compare, and assess the design principles of automated vehicles' external human-machine interfaces. *Transportation Research Interdisciplinary Perspectives* 7 (2020), 100174. https://doi.org/10.1016/j.trip.2020.100174

[14] Debargha Dey, Marieke Martens, Berry Eggen, and Jacques Terken. 2019. Pedestrian road-crossing willingness as a function of vehicle automation, external appearance, and driving behaviour. *Transportation Research Part F: Traffic Psychology and Behaviour* 65 (2019), 191–205.

[15] Sofie Ehrhardt, Daniel Graeber, Nadine-Rebecca Strelau, and Barbara Deml. 2023. Evaluation of the communication means of lateral driving dynamics at motorway slip roads. *at-Automatisierungstechnik* 71, 4 (2023), 269–277.

[16] Sofie Ehrhardt, Natasha Merat, Michael Daly, Albert Solernou Crusat, and Barbara Deml. 2024. Comparing implicit communication via longitudinal driving dynamics: a cross-cultural study in Germany and the UK. *Transportation Research Part F: Traffic Psychology and Behaviour* 102 (2024), 278–293.

[17] Sofie Ehrhardt, Raphael Roß, and Barbara Deml. 2023. Implicit communication on the motorway slip road: A driving simulator study. In *Proceedings of the Human Factors and Ergonomics Society Europe Chapter Proceedings Conference, Liverpool, UK.* 26–28.

[18] Jongseong Gwak, Keisuke Shimono, and Yoshihiro Suda. 2025. How encounter timing affects the impact of eHMI on surrounding drivers during automated truck merging. *Transportation Research Part F: Traffic Psychology and Behaviour* 110 (2025), 182–194.

[19] Azra Habibovic, Victor Malmsten Lundgren, Jonas Andersson, Maria Klingegård, Tobias Lagström, Anna Sirkka, Johan Fagerlönn, Claes Edgren, Rikard Fredriksson, Stas Krupenia, et al. 2018. Communicating intent of automated vehicles to pedestrians. *Frontiers in Psychology* 9 (2018), 1336.

[20] Kai Holländer, Ashley Colley, Christian Mai, Jonna Häkkilä, Florian Alt, and Bastian Pfleging. 2019. Investigating the influence of external car displays on pedestrians' crossing behavior in virtual reality. In *Proceedings of the 21st International Conference on Human-Computer Interaction with Mobile Devices and Services.* 1–11.

[21] Chunxi Huang, Xiao Wen, Dengbo He, and Sisi Jian. 2022. Sharing the road: how human drivers interact with autonomous vehicles on highways. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, Vol. 66. SAGE Publications Sage CA: Los Angeles, CA, 1437–1441.

[22] Seulbin Hwang, Kibeom Lee, Hyeongseok Jeon, and Dongsuk Kum. 2022. Autonomous vehicle cut-in algorithm for lane-merging scenarios via policy-based reinforcement learning nested within finite-state machine. *IEEE Transactions on Intelligent Transportation Systems* 23, 10 (2022), 17594–17606.

[23] Jieun Lee and Tatsuru Daimon. 2025. Not Always Good: Mitigating Pedestrians' Less Careful Crossing Behavior by External Human-Machine Interfaces on Automated Vehicles. *International Journal of Human–Computer Interaction* 41, 8 (2025), 4528–4540. https://doi.org/10.1080/10447318.2024.2352212

[24] Seong Hee Lee, Nicholas Britten, Avram Block, Aryaman Pandya, Malte F. Jung, and Paul Schmitt. 2023. Coming In! Communicating Lane Change Intent in Autonomous Vehicles. In *Companion of the 2023 ACM/IEEE International Conference on Human-Robot Interaction* (Stockholm, Sweden) *(HRI '23)*. Association for Computing Machinery, New York, NY, USA, 394–398. https://doi.org/10.1145/3568294.3580113

[25] Yee Mun Lee, Ruth Madigan, Chinebuli Uzondu, Jorge Garcia, Richard Romano, Gustav Markkula, and Natasha Merat. 2022. Learning to interpret novel eHMI: The effect of vehicle kinematics and eHMI familiarity on pedestrian'crossing behavior. *Journal of Safety Research* 80 (2022), 270–280.

[26] Kung-Yee Liang and Scott L Zeger. 1986. Longitudinal data analysis using generalized linear models. *Biometrika* 73, 1 (1986), 13–22.

[27] Hailong Liu, Zhe Zeng, and Takahiro Wada. 2025. Where Do Passengers Gaze? Impact of Passengers' Personality Traits on Their Gaze Pattern Toward Pedestrians During APMV-Pedestrian Interactions with Diverse eHMIs. arXiv:2502.02792 [cs.HC] https://arxiv.org/abs/2502.02792

[28] Victor Malmsten Lundgren, Azra Habibovic, Jonas Andersson, Tobias Lagström, Maria Nilsson, Anna Sirkka, Johan Fagerlönn, Rikard Fredriksson, Claes Edgren, Stas Krupenia, et al. 2017. Will there be new communication needs when introducing automated vehicles to the urban context?. In *Advances in Human Aspects of Transportation: Proceedings of the AHFE 2016 International Conference on Human Factors in Transportation, July 27-31, 2016, Walt Disney World®, Florida, USA*. Springer, 485–497.

[29] Karthik Mahadevan, Sowmya Somanath, and Ehud Sharlin. 2018. Communicating awareness and intent in autonomous vehicle-pedestrian interaction. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*. 1–12.

[30] Natasha Merat, A Hamish Jamson, Frank CH Lai, and Oliver Carsten. 2012. Highly automated driving, secondary task performance, and driver state. *Human Factors* 54, 5 (2012), 762–771.

[31] Austin Lee Nichols and Jon K Maner. 2008. The good-subject effect: Investigating participant demand characteristics. *The Journal of general psychology* 135, 2 (2008), 151–166.

[32] Martin T Orne. 2002. On the social psychology of the psychological experiment: With particular reference to demand characteristics and their implications. (2002).

[33] Raja Parasuraman and Victor Riley. 1997. Humans and automation: Use, misuse, disuse, abuse. *Human Factors* 39, 2 (1997), 230–253.

[34] Angus Eugene Retallack and Bertram Ostendorf. 2019. Current understanding of the effects of congestion on traffic accidents. *International Journal of Environmental Research and Public Health* 16, 18 (2019), 3400.

[35] Robert Rosenthal and Ralph L Rosnow. 2009. *Artifacts in behavioral research: Robert Rosenthal and Ralph L. Rosnow's classic books.* Oxford University Press.

[36] Anna Schieben, Marc Wilbrink, Carmen Kettwich, Ruth Madigan, Tyron Louw, and Natasha Merat. 2019. Designing the interaction of automated vehicles with other traffic participants: Design considerations based on human needs and expectations. *Cognition, Technology & Work* 21 (2019), 69–85.

[37] Jinjuan She, Jack Neuhoff, and Qingcong Yuan. 2021. Shaping pedestrians' trust in autonomous vehicles: an effect of communication style, speed information, and adaptive strategy. *Journal of Mechanical Design* 143, 9 (2021), 091401.

[38] Neville A Stanton, Alexander Eriksson, Victoria A Banks, and Peter A Hancock. 2020. Turing in the driver's seat: Can people distinguish between automated and manually driven vehicles? *Human Factors and Ergonomics in Manufacturing & Service Industries* 30, 6 (2020), 418–425.

[39] Viswanath Venkatesh and Michael G Morris. 2000. Why don't men ever stop to ask for directions? Gender, social influence, and their role in technology acceptance and usage behavior. *MIS Quarterly* (2000), 115–139.

[40] Liu Yang, Xiaomeng Li, Wei Guan, H Michael Zhang, and Lingling Fan. 2018. Effect of traffic density on drivers' lane change and overtaking maneuvers in freeway situation—A driving simulator–based study. *Traffic Injury Prevention* 19, 6 (2018), 594–600.

[41] Sam Zadeh Darrehshourian. 2021. Communicating the stopping intent of an autonomous truck: The interplay between content size, timing and truck speed.

[42] Zuduo Zheng, Soyoung Ahn, and Christopher M Monsere. 2010. Impact of traffic oscillations on freeway crash occurrences. *Accident Analysis & Prevention* 42, 2 (2010), 626–636.