Do Drivers have Preconceived Ideas about an Automated Vehicle's Driving Behaviour?

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ABSTRACT

This study investigated drivers' preconceived notions about manoeuvres of Automated Vehicles (AVs) compared to manually driven vehicles (MVs) using a pseudo-coupled driving simulator. The simulator displayed a message indicating the state of approaching vehicles (AV/MV) in a bottleneck scenario, while participants were informed that the MV was controlled by an experimenter using another simulator, despite all trials having the same preprogrammed behaviours. Results showed that the types of AV/MV did not impact participants' subjective responses. Communication through kinematic cues of the AV/MV was effective, with higher perceived safety, comprehension, and trust reported for approaching vehicles that yielded with an offset away from participants. Perceived safety and trust of the AV were also higher for trials with a light-band external Human Machine Interface (eHMI). This study highlights the value of both explicit and implicit cues for the communication of AVs with other drivers.

KEYWORDS

AV-MV communication, AV behaviour, Implicit communication, eHMI, Bottleneck Road

1 INTRODUCTION

In the foreseeable future, it is anticipated that SAE Level 4/5 Automated Vehicles (AVs) [1] will be integrated within our urban areas, interacting with other manually driven vehicles (MVs). As a result, we will encounter mixed traffic scenarios where AVs and human road users (i.e., MVs, pedestrians, and cyclists) will have to interact with each other on the road (see Figure 1). For these interactions to be safe and seamless, it is crucial to understand how drivers of MVs would behave when encountering AVs versus MVs. Since AVs will not be controlled by humans, they may also need to communicate their intention to other road users, when interacting in shared space, especially if both actors are intending to occupy the same road space as a result of their movement [2].

Recent studies have demonstrated that the ability of human road users to interpret the intentions of vehicles is heavily influenced by implicit longitudinal and lateral cues. Specifically, longitudinal cues include changes in speed, deceleration rate, and stopping distance [3], [4], [5], [6], [7], [8], while lateral cues include time and direction of lateral movements [6], [9]. Recent studies have also shown that communication via external human-machine interfaces (eHMIs) can provide information about an AV's yielding intentions, improving drivers' confidence to make faster crossing decisions

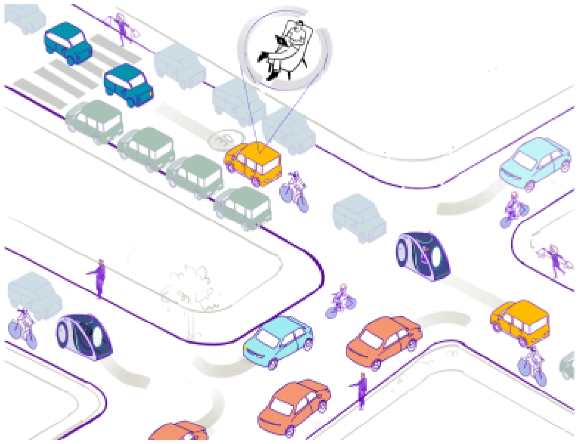

Figure 1: A mixed traffic setting, including AVs in urban roads

[10], and increasing their subjective perceived safety and acceptance of AVs [11]. This is particularly true for scenarios which need road users to cooperate with each other to negotiate the right-of-way. Examples of externally presented visual messages, mostly used to study AV interaction with Vulnerable Road Users (VRUs) such as pedestrians, include different types of lighting [32], [16], text [12], [13], symbols [14], or anthropomorphic signals [15] on the vehicle, or projections on the road [16], [17]. Auditory signals such as voice, horn, engine sound [18] and verbal messages [19] have also been used to communicate the AV's intention. Rettenmaier et. al., (2020) [30] reported that an eHMI deployed on the AV's bumper increased traffic efficiency on bottleneck roads. However, to date, compared to the extensive focus on eHMIs for AV-VRU interactions, little is known about the use of such interfaces for drivers of MVs, especially for more ambiguous scenarios which require communication and cooperation between the AV and MV. Dey et al., 2021 [16] reported that eHMIs are less effective in resolving ambiguities for vehicles travelling at higher speeds. Thus, whether the value seen for eHMIs in AV-VRU communication is the same as that required for AV-MV communication is currently unknown.

Automated vehicles have the potential to significantly enhance driver and road safety, and reduce crashes and injuries [20]. However, integrating these vehicles into our current traffic environment, and introducing them to other road users presents a challenge, particularly in ambiguous situations with uncertain right-of-way scenarios, such as bottleneck roads, unmarked intersections, or residential junctions without traffic lights [21]. For scenarios where traffic is moving at a slow pace, or where the right-of-way is ambiguous, human road users sometimes make use of explicit signals from drivers, such as hand gestures, head motions, or flashing lights of the vehicle [22]. But this can be a problem for higher level AVs which do not currently have any means of communicating intent [23], [24] Recent studies have also shown that more implicit forms of communication by the AV, such as a slight lateral deviation or pitching of the vehicle are useful for illustrating yielding intention [6], [9], [25].

It has been argued that once a vehicle is identified as being automated, other road users may experience some confusion, demonstrate hesitancy, or even take advantage of the AV, which does not yet behave according to local and social norms of the road [26], [27]. Studies have reported that participants had a greater intention to bully AVs than to bully other human drivers if driverless vehicles are programmed to follow the law [28], [29]. However, a Wizard of Oz study found that there was little difference in pedestrians' decision-making time, when comparing their interactions between automated and conventional vehicles [27].

To date, a few studies have been conducted to investigate driver behaviour and communication strategies between AVs and MVs at bottleneck roads. These include driving simulator studies [11], [30], video-based online surveys [31] and field tests [10]. Regarding vehicle kinematics, one-step and two-step deceleration, and driving to the edge of the road have been used to demonstrate a vehicle's yielding behaviour, while maintaining speed and acceleration, and driving to the centre of the road tend to indicate a vehicle's non-yielding behaviour [6], [9]. Studies have also reported that earlier braking by an approaching vehicle can reduce efficiency losses caused by unnecessary braking manoeuvres [7], while lateral offset (driving to the edge of the road) increases traffic safety and efficiency [6], [9].

Based on these studies, the aim of the current experiment was to address some of the research gaps which remain in this context. In particular, we wanted to investigate if drivers' subjective feelings about an approaching vehicle are based on its kinematic behaviour, or whether its identity (i.e., whether it is labelled as an AV or MV) influences this subjective response. To understand how yielding and lateral deviation affect subjective feelings, the approaching vehicles displayed two yielding behaviours and two non-yielding behaviours combined with different types of lateral deviation. The following research questions were addressed:

1. Do drivers have preconceived ideas about an AV's driving behaviour when interacting with an AV at a bottleneck road?
2. How does the AV's behaviour influence human drivers' subjective feelings?
3. How does an eHMI on AVs influence human drivers' subjective feelings?

2 METHOD

2.1 Participants

Following approval from the University of Leeds Ethics board (Ref: LTTRAN-151), a total of 40 participants (12 female, 28 male) with a mean age of 34.65 years (SD = 14.81; range = 21-79) were recruited to take part in this experiment. The requirement for participation was the possession of a UK driver's license for at least one year. The average driving experience of participants was 12 years (SD = 12.61) and 8506.25 miles per year (SD = 7473.01). The study invitation was distributed via mailing lists at university sampling pools. Participants were compensated £15 for their time.

2.2 Apparatus

This experiment was conducted using a fixed-based coupled simulator at University of Leeds (see Figure 2), which provided a controlled and safe environment for investigating driving behaviours. Each

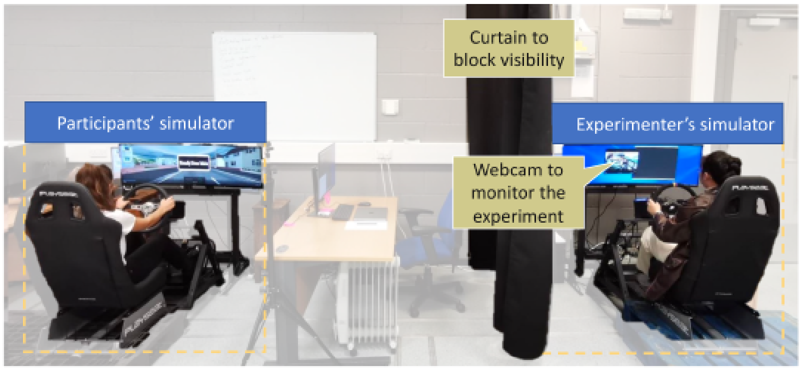

Figure 2: Coupled (pseudo-linked) driving simulators, showing the participant and experimenter, blocked by a curtain.

Figure 3: The tag shown on the participant's monitor at the start of each trial, which stated whether the approaching vehicle was an AV or MV

simulator had a 49-inch 32:9 (3840 x 1080 pixels) monitor, a sliding seat, and a steering wheel with buttons, used to start the trials. The accelerator and brake pedals were placed on a stable Next Level Racing®Wheel Stand DD. The scenario and the vehicle behaviours, including engine sound were programmed on Simulator3, an in-house developed software. A black opaque curtain was used to separate the participant and the experimenter, and they were asked not to talk with each other during the study. The participants were informed that their driving simulator was connected to the experimenter's driving simulator (coupled), so they would drive in the same virtual environment. The experimenter used a webcam to monitor the participant. For the MV trials, the experimenter pretended to drive by pressing the gas/brake pedals, creating the right sounds to trick participants into believing that the experimenter was controlling the approaching vehicles (see below for further details).

2.3 Experimental design and scenarios

For this study, we focused on a bottleneck road, an ambiguous driving scenario which needs human drivers to negotiate with each other as they try to pass through a single lane, created by parked cars in a two-lane urban road. Drivers are therefore required to negotiate the right-of-way through the bottleneck.

A within-subjects design was used, where all participants experienced 32 trials (presented randomly) involving three independent variables as follows (see Table **??**).

- Type of approaching vehicle (AV/MV).
- Approaching vehicle's kinematic behaviour (Yielding without offset, Yielding with "away offset" / Non-yielding without offset, Non-yielding with "towards offset").
- eHMI status (present/absent).

2.3.1 Type of approaching vehicle. A message was presented on the driving scene at the start of each trial to inform drivers whether they would encounter an Automated or Manually Driven vehicle (see Figure 3), although as outlined, the behaviour of the vehicle was controlled by the software, for all trials.

2.3.2 Vehicle kinematics. As shown in and 4 and 5**,** at the start of the trial, the ego and approaching vehicle were positioned 50m away from the bottleneck. The ego vehicle was placed at the center of the lane at the start of the trial, while the approaching vehicle was 1.25m from the edge of the road, to allow its easy detection by the participants. Both vehicles' initial speed was 15 mph (ca. 6.71m/s). The participant pressed a button on the steering wheel to begin a trial. The approaching vehicle then began travelling when the ego vehicle was 5m away. For the yielding without offset conditions, the approaching vehicle decelerated at a constant rate, when it was 30m from the bottleneck, stopping when it was 10m away from the bottleneck. In the yielding with 'away offset' conditions, the approaching vehicle deviated away from its initial lateral position and towards the ego vehicle, by 1m, during this linear deceleration (see 4). However, if the participant decided not to pass the bottleneck, the approaching vehicle drove through the bottleneck after 5 s.

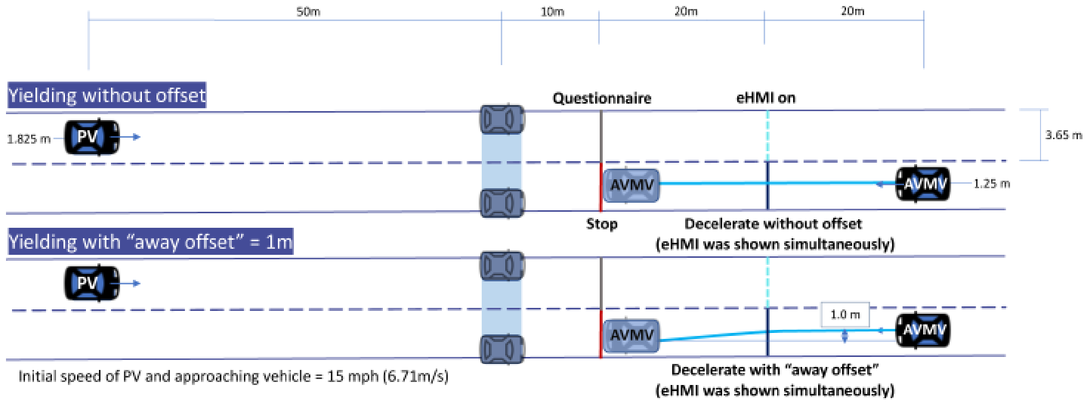

Figure 4: Approaching vehicle's yielding behaviours

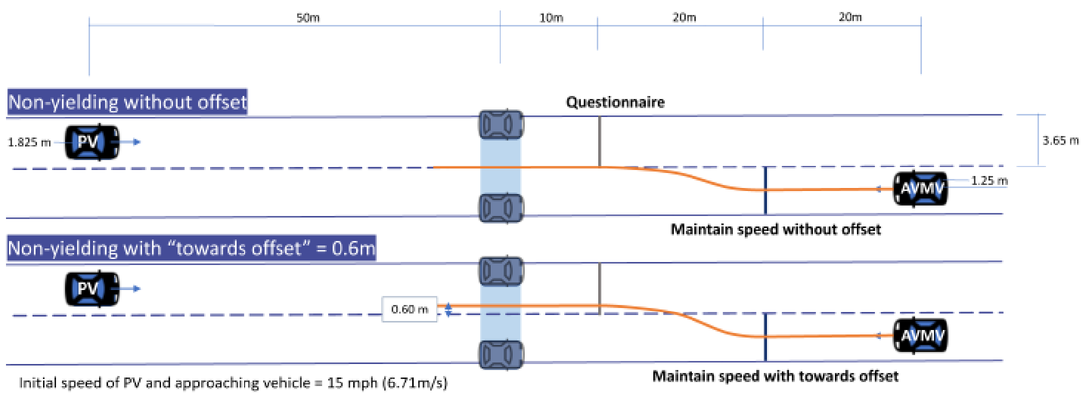

Figure 5: Approaching vehicle's non-yielding behaviours

In the non-yielding without offset trials, the approaching vehicle maintained its speed and started to steer to the middle of the bottleneck, when it was 30m from the bottleneck. In the non-yielding with "towards offset" conditions, the approaching vehicle maintained its speed and deviated an additional of 0.6m to the right (see Figure 5).

2.3.3 External Human-Machine Interface (eHMI). In this study, a cyan light-band, located at the bottom of the approaching vehicle's windshield, was used to indicate the AV's intention to yield, which could improve the MV driver's comprehension of the AV's behaviour [12], [32], as depicted in Figure 6. Participants were told the meaning of the eHMI before the experiment. The eHMI was presented in conjunction with the AV's deceleration, which was 30m before the bottleneck for both types of yielding trials.

2.4 Post-trial ratings

After each trial, participants saw a short set of questions on the driving scene (see Figure 7), and were asked to use a 5-point Likert scale: 1 "strongly disagree"- 5 "strongly agree", to rate their trust, comprehension and feelings of safety about the approaching vehicle/eHMI. Participants provided a verbal response for each question, which was manually recorded by the experimenter. After answering the questionnaire, participants pressed the button on the steering wheel to start the next trial.

2.5 Procedure

Participants received a participation information sheet by email around 48 hours prior to the experiment. Upon arrival at the lab, they completed a demographic survey and a practice session to familiarise themselves with the simulator and the experimental setup. Participants then began the experiment when they were ready, interacting with the approaching vehicle. For each trial, they were asked to decide whether they could pass through the bottleneck or yield for the approaching vehicle. If participants did not pass the bottleneck for over 5 seconds after the approaching vehicle had yielded, the approaching vehicle would start to drive and pass through the bottleneck. Each trial ended automatically, 10 m after drivers passed the bottleneck. A 5-point Likert Scale questionnaire measuring feelings of safety, comprehensibility, and trust towards the approaching vehicle was completed after each trial (Figure 7). Participants took part in a short interview after the last trial and were then paid and thanked for their participation. The entire study took approximately 60 minutes to complete.

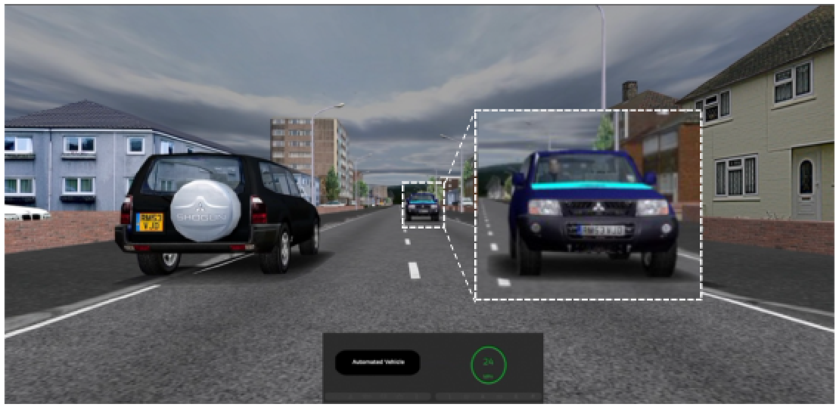

Figure 6: The eHMI presented for some of the yielding trials

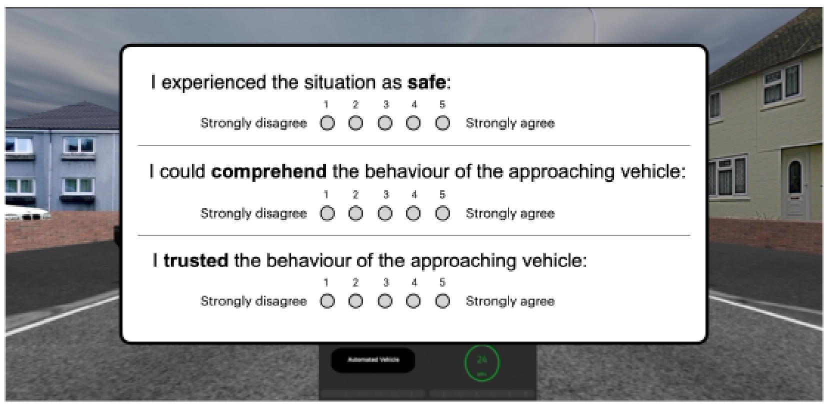

Figure 7: The post-trial questionnaire used after each trial

3 RESULTS

The data was prepared using MATLAB R2022a and MS Excel 16.72, and SPSS 25 was used for the statistical analysis. Given the differences in kinematic patterns of the yielding and non-yielding trials, two separate analyses of variance were conducted to investigate the impact of the independent variables, on participants' subjective responses. For yielding trials, a 3 x 2 repeated measures ANOVA was conducted to examine the impact of the types of approaching vehicle (AV with eHMI, AV without eHMI, MV), and behaviours (yielding without offset, yielding with "away offset") on subjective responses. For non-yielding trials, a 2 x 2 repeated measures ANOVA was conducted to evaluate the effect of the types of approaching vehicle (AV without eHMI, MV), and behaviours (non-yielding without offset, non-yielding with "towards offset") on subjective ratings, see Table 1. The repeated measures ANOVA was used to do the analysis considering its robustness against a violation of the normal distribution [33]. If sphericity was violated (Mauchly's test: $p < .001$), Greenhouse Geisser corrections were used for degrees of freedom. The alpha level was .05. Cohen's d was calculated as a measure of the effect size [34]. Partial eta squared (ηp^2) are reported, where .01 is considered to be a small effect, .06 is a medium effect, and .14 indicates a large effect [34]. Only the results from the post-trial questionnaire are included in this paper.

3.1 Perceived safety of the situation

For the yielding trials, there was a significant main effect of vehicle type, whereby the AVs with eHMI were rated safer than AVs without eHMI ($p < .001$). No significant difference was found between AV without eHMI and MV. There was also a significant main effect of approaching vehicle's yielding behaviour on responses, whereby approaching vehicles with 'away offset' were rated safer than those without an offset ($p < .001$). There was no significant interaction. The analysis showed no significant main effects or interactions for the non-yielding trials (see Figure 8 and Table 1).

3.2 Comprehension of approaching vehicle's behaviour

For yielding trials, results showed a significant main effect of vehicle type, whereby the AVs with eHMI were rated more comprehensible, than AVs without eHMI ($p < .001$). No significant difference was found between the AV without eHMI and MV trials. There was a significant main effect of approaching vehicle's yielding behaviours, whereby the behaviour of the approaching vehicles yielding with

Table 1: Repeated measures ANOVA of participants' subjective feelings across vehicle types, behaviours and eHMI presence (N=40), * p < .05, ** p < .01, *** p < .001

	F	df	p	ηp^2	F	df	p	ηp^2
	Yield				Non-yield			
"I experienced the situation as safe"								
Vehicle types	15.054	2 (78)	< **.001*****	.279.	.526	1 (39)	.957	.000
Behaviours	45.169	1 (39)	< **.001*****	.537	.003	1 (39)	.473	.013
Vehicle types * behaviours	2.318	2 (78)	.105	.056	1.760	1 (39)	.192	.043
"I could comprehend the behaviour of the approaching vehicle"								
Vehicle types	32.989	2 (78)	< **.001*****	.458	.002	1 (39)	.963	.000
Behaviours	70.778	1 (39)	< **.001*****	.645	6.706	1 (39)	**.013****	.147
Vehicle types * behaviours	13.816	2 (78)	< **.001*****	.262	.393	1 (39)	.534	.010
"I trusted the behaviour of the approaching vehicle"								
Vehicle types	22.905	2 (78)	< **.001*****	.370	1.183	1 (39)	.283	.029
Behaviours	69.454	1 (39)	< **.001*****	.623	.228	1 (39)	.636	.006
Vehicle types * behaviours	8.028	2 (78)	< **.001*****	.171	.072	1 (39)	.789	.002

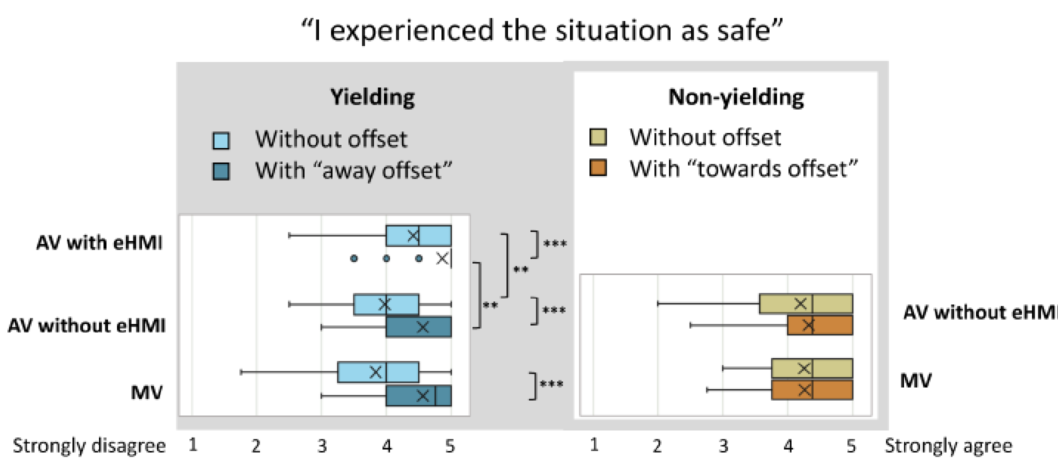

Figure 8: Participants' perceived safety of the approaching vehicle (N=40)

'away offset' were rated as more comprehensible than those without offset ($p < .001$). There was also a significant interaction effect, with the AVs with eHMI being rated as more comprehensible when they yielded without an "away offset" ($p < .001$).

For non-yielding trials, results showed there was no significant main effect of vehicle type, but there was a significant main effect for non-yielding behaviours. Here, approaching vehicles with 'towards offset' were rated more comprehensible than without offset ($p = .013$). There was no significant interaction effect, shown in Figure 9 and Table 1.

3.3 Trust in approaching vehicle's behaviour

For yielding trials, there was a significant main effect of vehicle type, with higher trust ratings given for AVs with eHMIs, than those without an eHMI ($p < .001$). No significant difference was found between the AV without an eHMI and the MV. There was also a significant main effect of approaching vehicle's yielding behaviours, with the approaching vehicles that displayed an 'away offset' being rated as higher for trust, compared to those without an offset ($p < .001$). There was a significant interaction between vehicle type and kinematic behaviour. Even though yielding AVs with eHMI had higher trust ratings than AVs without eHMI (Applicable to two yielding behaviours, i.e., yielded without offset and with "away offset"), the presence of the eHMI improved drivers' trust more when the AV yielded without the "away offset". For non-yielding trials, there was no significant main effect or interactions, regarding trust ratings (see Figure 10 and Table 1).

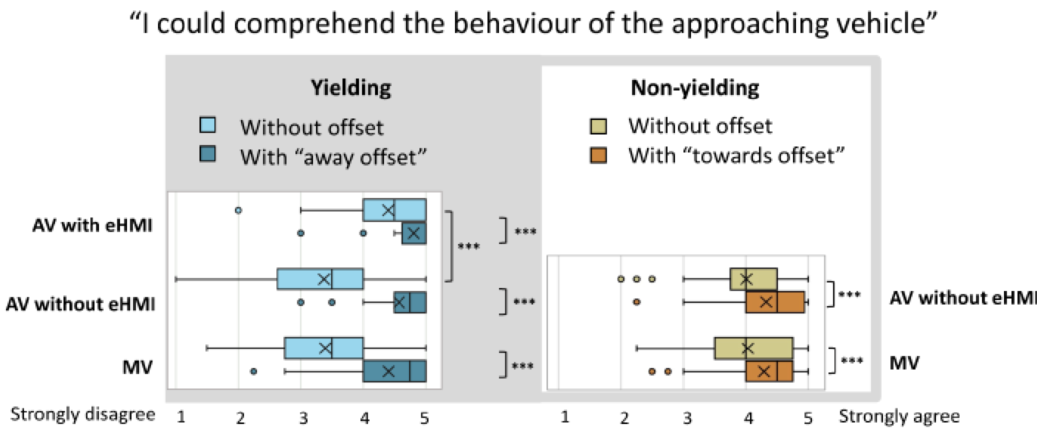

Figure 9: Participants’ comprehension of the approaching vehicle’s behaviours (N=40)

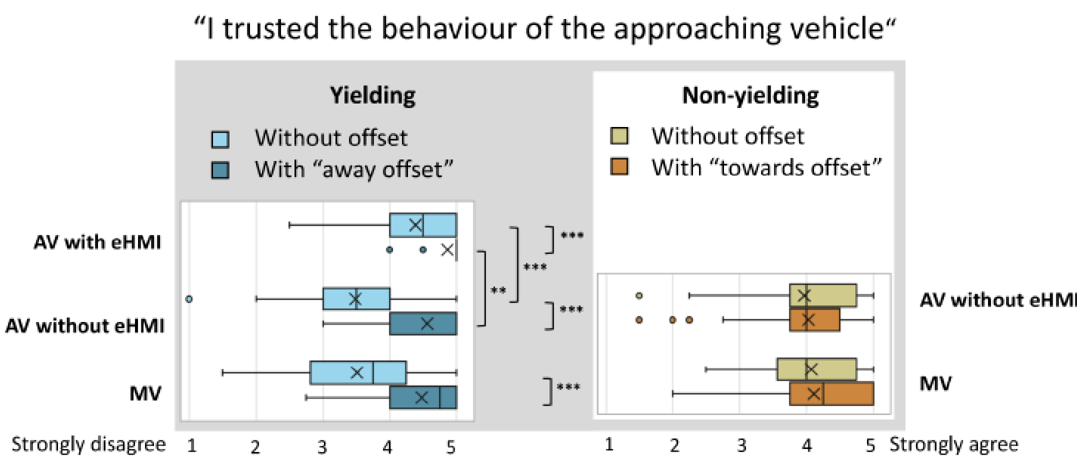

Figure 10: Participants’ trust in the approaching vehicle’s behaviours (N=40)

4 DISCUSSION

This distributed driving simulator study was designed to investigate the effect of the type of approaching vehicle (AV vs MV), its kinematic features (i.e., its longitudinal and lateral behaviours), and the presence of an eHMI, on drivers’ subjective feelings during a bottleneck scenario. After each encounter with the approaching vehicle, drivers used a 5-point Likert scale to report on their trust, perceived safety, and comprehension of the approaching vehicle’s behaviour. Although the behaviour of the AV and MV was exactly the same, and always controlled by the simulator software, a simple message at the start of each drive was used to lead drivers into believing that the vehicles were controlled by the computer or another driver, respectively.

We found that knowing if a vehicle was automated or manually driven did not affect drives’ perceived safety, comprehension and trust. This suggests that drivers’ subjective feelings about an approaching vehicle in a bottleneck road are based on its kinematic behaviour, rather than whether it is labelled as a computer- or human-driven vehicle, especially if the two vehicles look exactly the same. This finding is in line with the results of [5].

Our participants felt significantly safer and reported a significantly higher comprehension and trust when the approaching vehicles yielded with an “away offset”, compared to the yielding without offset trials. This finding supports results from previous studies which report that the addition of lateral movements for a yielding vehicle provides a clear additional cue to other road users, when compared to longitudinal cues alone. This is especially for ambiguous scenarios, such as bottleneck roads [7], [9]. Our study also showed that the presence of a “towards offset” improved drivers’ comprehension of the vehicles’ behaviour in non-yielding conditions. Future studies should explore the further use of such lateral deviations for communication of AV intention, in a wider range of scenarios.

In terms of the value of eHMIs, the presence of an eHMI improved drivers' perceived safety and trust of a yielding AV, regardless of whether this was accompanied by an "away offset". However, subjective response for comprehension of the AV with an eHMI was only high during the "no offset" conditions, eHMI did not impact drivers' comprehension of the approaching AV's behaviour when the AV yielded with the "away offset". These results are not line with the results of Rettenmaier & Bengler (2021) [6], who found that participants' comprehension of approaching AVs with an eHMI improved with and without an away offset. Our results suggest that the lateral deviation of the yielding vehicle in isolation was quite powerful in itself, with additional messages from an eHMI possibly causing some confusion about the vehicle's intentions. This result stresses the importance of using intuitive kinematic behaviour for AVs to communicate intention [4], and confirms these can be a better solution than potentially misleading externally presented messages [35].

In terms of limitations, this study only focused on evaluating drivers' subjective feelings about the approaching vehicles. Future studies would benefit from investigating how drivers behave in these scenarios, using vehicle metrics, also assessing if objective and subjective responses correlate. Finally, understanding if drivers' perceived safety, comprehension and trust for approaching vehicles is determined by a vehicle's shape or other external features is important, to establish if vehicles that look more like an AV are treated differently to those that look more like conventional vehicles.

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