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The Roles of Driving Style and Initial Trust on Trust Towards Automated Vehicles

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ABSTRACT

User trust and acceptance are critical for the success of Automated Vehicles (AVs) in enhancing road safety and reducing driver workload. This study aims to investigate the influence of AV style (careful or aggressive) and driver style (careful or aggressive) on trust in AVs, while considering the role of initial trust level. A questionnaire-based survey was conducted with 204 participants, and responses were analyzed utilizing a Linear Mixed Model (LMM) with AV style, driver style and initial level as fixed effects. Two significant two-way interactions were observed: between driver style and AV style, and another between initial trust and AV style on trust. Specifically, careful AVs were rated with a higher trust than aggressive AVs by both driver groups. Additionally, aggressive drivers trusted aggressive AVs more than careful drivers, but careful AVs gain the same trust. Interestingly, participants with medium initial trust exhibited a less divergence in trust between different AV styles, yet the trust gaps between different trust groups consistently existed. These findings underscore the importance of aligning driver style, AV style, and initial trust levels to cultivate heightened trust in AVs.

Keywords: Automated vehicle, Driving style, Initial trust, Trust

INTRODUCTION

The rapid advancements in deep learning algorithms, improved sensing devices, and vehicular communication technology have created favorable conditions for the development of autonomous vehicles (AVs). Numerous studies have shown that Level-3 AVs hold great potential to revolutionize future transportation with enhanced safety (Wang et al., 2020; Hirose et al., 2020), comfort (Moody et al., 2020), and efficiency (Singleton, 2018). However, despite the more mature technology and lower probability of error, widespread adoption of Level-3 AVs remains challenging. Existing research indicates that a lack of trust is still a key barrier to the successful adoption of AVs (Xu et al., 2018; Zhang et al., 2021b).

Previous studies found that trust in AVs is influenced by the driving styles of AVs, with people tending to trust more careful AVs (Ekman et al., 2019; Lee et al., 2021; Oliveira et al., 2019) than aggressive ones. Additionally, studies showed that different drivers have varying expectations and trust in AVs due to individual differences (Zhang et al., 2021a), and individuals tend

to exhibit higher trust in entities that are similar to themselves. For instance, drivers tend to trust the AVs that have human-like appearances (Verberne et al., 2015) and behaviours (Li et al., 2020). Given that AVs' and human drivers' behaviours reflect their driving styles, one could hypothesize that drivers are inclined to trust in AVs that match their own driving style. However, prior research in this area showed divergent conclusions. Some studies indicated that drivers showed high acceptance for AVs with styles similar to their own (Haghzare et al., 2021; Sun et al., 2020; Ma and Zhang, 2021), while others suggested that both careful and aggressive drivers tended to trust careful AVs (Ekman et al., 2019).

Initial trust is another crucial factor affecting trust towards AVs (Hoff and Bashir, 2015; Zhang et al., 2020). Previous research consistently indicated that individuals with higher initial trust tend to sustain elevated trust after interacting with AVs (Manchon et al., 2021; Manchon et al., 2022; Ma and Zhang, 2021). Specifically, in the study by Manchon et al., (2021), the trust gap between high and low initial trust drivers is persistent, both after interacting with aggressive and careful AVs. Additionally, Manchon et al., (2021) observed an interaction between AV style and initial trust in AV trust. Low initial trust drivers showed a more decrease of trust in the aggressive AVs than high initial trust drivers, while this difference was not observed in careful AVs. The underlying assumption might be that initial trust would adjust the trust gaps between the AV style.

Questions such as whether a specific driving style elicits higher levels of trust universally, or if trust in AVs varies among different drivers based on their preferences and initial trust, remain largely unknow. It is, therefore, important to investigate how initial trust, driver style and AV style affect users' trust. For this purpose, we conducted an online questionnaire study.

METHOD

Participants

This study employed the services of Wenjuanxing (www.wjx.cn) for sample collection and recruited 205 adult drivers holding Chinese driver's licenses to participate in the survey.

Materials

Simulated Driving Scenarios

The UC-WINROAD software was utilized to develop simulated driving scenarios in which AVs drove either aggressively or carefully when dealing with typical driving events. Six driving events, namely car following, overtaking, yielding to pedestrians, obstacle avoidance, dilemma zone at traffic lights, and intersection right-of-way, were developed. In the first three events, the differences between aggressive and careful driving styles primarily pertained to driving parameters such as speed and distance. In the latter three events, the two driving styles were differentiated based on driving decisions such as go or stop choice. To ensure that user perception and preference would not

be influenced by AV failures, no accidents were presented in the scenarios. Table 1 presents the specific settings of how aggressive and careful AVs dealt with these events.

Questionnaire

The entire questionnaire consists of four sections. The first section included questions to measure basic information about the participants, such as age, driving experience, and gender. The second section adopted the 10-item Initial Trust Scale (ITS) to measure initial trust towards AVs (Manchon et al., 2021). Following was the Violation Subscale from the Driving Behaviour Questionnaire (V-DBQ) (Zhang et al., 2009) to assess the driving style of the participants. The last section presented participants with six driving scenarios. Following the approach used by Holthausen et al., (2020), participants were sequentially shown two driving styles for each current driving event before transitioning to the subsequent driving event. The order of driving styles for the same event was counterbalanced to avoid any bias. Following the viewing of each driving video, participants were asked to rate their trust towards the specific AV in the video, using the 4 items adapted from the Trust Questionnaire (Sun et al., 2021). The 7-point Likert scale was used for all questions except for the demographic information related questions.

Statistical Analysis

The study employed the k-means clustering analysis to classify drivers into different driving style and initial trust groups. Afterward, a Linear Mixed Model (LMM) was utilized to analyze the dependent variables, as the sample sizes across classified groups were uneven. In the LMM, initial trust level, driver style and AV style were modeled as fixed effects, while sample ID and scenarios were modeled as random effects.

RESULTS

A total of 205 responses were initially collected and 1 response was removed from further analysis due to all its questions had the same score. Of the remaining 204 participants, 81 were male, and 123 were female drivers. The average age of the participants was 31.94 years (SD = 5.78). Among them, the majority (n = 181) had obtained a college degree or higher, and almost all participants (n = 198) were currently employed (see Table 2).

Driver Classification

Participants were classified into different driving styles based on their standardized V-DBQ scores. The NbClust function in R suggested that the optimal number of clusters was 2. As a result, we classified the participants into 2 groups using K-Means clustering analysis, with 133 being classified into the first group and 71 into the second group. An inspection of the item scores (Figure 1) indicated that the first group showed higher scores on all V-DBQ items than the second group. Therefore, the first group was as labeled as aggressive drivers, and the second group as careful drivers.

Similarly, based on ITS scores and as recommended by the NbClust function, 3 initial trust groups, labelled as high, medium, and low, were identified.

Table 1. Scenarios in the AV driving task.

Scenario	Description	Differentiation		Origin
		Aggressive AV	Careful AV	
Car following	The AV follows a vehicle ahead on the solid line road (e.g., on a bridge, inside a tunnel).	$T_H = 0.9s$, $a_{max} = \pm 1.96\ m/s^2$	$T_H = 1.7s$, $a_{max} = \pm 3.675 m/s^2$	(Sun et al., 2021)
Overtaking	The AV overtakes a slow-moving vehicle.	$T_L = 3.5s$	$T_L = 6s$	(Alarcon et al., 2016)
Yielding to pedestrians	The AV approaches a zebra crossing with a stop sign and gives priority to pedestrians crossing the road.	$D_S = 5m$	$D_S = 10m$	(Jayaraman et al., 2019)
Dilemma zone at traffic lights	The AV approaches an intersection with traffic signals. The traffic signal is displaying a flashing green light, signifying an upcoming change to yellow.	Pass	Stop	(Papaioannou, 2007)
Intersection right-of-way	The AV reaches an intersection without traffic signals and encounters a vehicle approaching from left road of the intersection at an equidistant position and equal velocity.	Accelerate and pass	Decelerate and yield	(Li et al., 2021)
Obstacle avoidance	The AV confronts an obstacle abruptly emerging in its designated lane. Concurrently, vehicles behind the AV are swiftly progressing in both the AV's lane and the adjacent safety lane.	Immediately change lane	Stop and yield, then change lane	(Hang et al., 2021)

Note. T_H = time headway, T_L = lane change time, a_{max} = maximum acceleration, D_S = stop distance

Table 2. Summary of demographic variables.

Variables		Statistics (n = 204)
Age (Mean (SD))		31.94 (5.78)
Driving license (Mean (SD))		6.28 (3.72)
Gender	Male	81
	Female	123
Education	High school and below	6
	Junior college /Undergraduate	181
	Graduate	17
Occupation	Students	5
	Employed	198
	Unemployed	1

The item scores of the three groups are presented in Figure 2, and the average ITS score for each group was 5.53 (SD = 0.23), 4.22 (SD = 0.17) and 2.61 (SD = 0.33), respectively. The number of participants in each group was 79, 79, and 46, respectively.

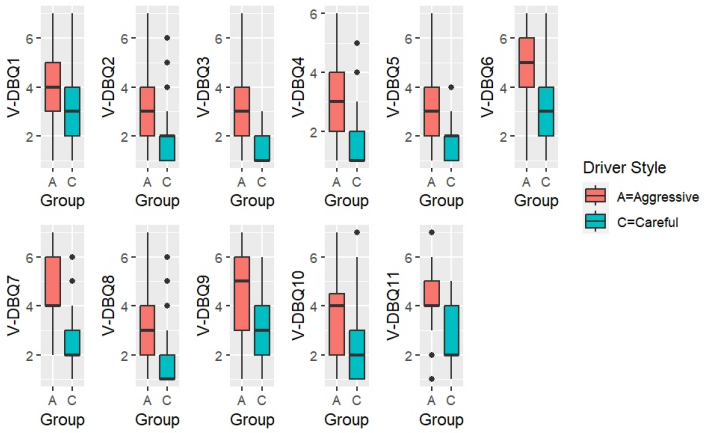


Figure 1: Categorization of driver styles by V-DBQ item scores.

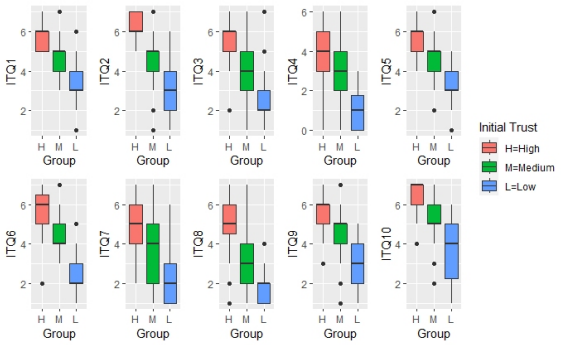


Figure 2: Categorization of initial trust by V-DBQ item scores.

Effects of Driver Style, Initial Trust, and AV Style

A marginal R^2 of 0.36 and a conditional R^2 of 0.49 in LMM indicated fixed effects explained the primary variance. The results of the Fixed Effects in LMM are showed in Table 3. A significant interaction effect between AV style and driver style on their trust in AVs ($p < .001$) and a significant interaction effect between initial trust level and AV style on their trust in AVs ($p = .023$).

As shown in Table 4, the baseline trust score (careful AV, careful driver and high initial trust) is 6.04 points. Findings reveal that aggressive AV results in a 2.04-point decrease in trust compared to the baseline ($p < .001$). Moreover, compared to the high initial trust group, the trust score of the drivers with the medium initial trust level decreased by 0.57 points ($p<0.001$) and that of the low initial trust drivers decreased by 1.14 points ($p<0.001$). In particular, aggressive AVs increase trust by 0.72 points for aggressive drivers compared to careful drivers ($p < 0.001$).

Table 3. Tests of fixed effects.

Variables	NumDF	DenDF	F-value	p
Initial Trust	2	198.00	1050.55	**<.001*****
AV Style	1	2233.00	28.31	**<.001*****
Driver Style	1	198.00	1.83	.178
AV Style × Driver Style	1	2233.00	28.31	**<.001*****
AV Style × Initial Trust	2	2233.00	3.76	**.023***
Driver Style × Initial Trust	2	198.00	0.66	.518
AV Style × Driver Style × Initial Trust	2	2233.00	1.31	.270

Note. ***p <. 001, **p <.01, *p <.05, +p <.1

Table 4. Estimates of fixed effects.

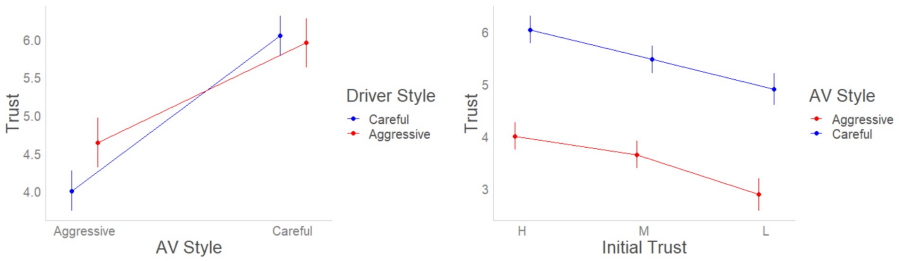
Variables	β	S.E.	t	Df	p	[95% CI]
(Intercept)	6.04	(0.13)	45.42	73.4	**<.001*****	[5.65, 6.30]
A-AV	−2.04	(0.10)	−21.48	2233.0	**<.001*****	[−2.23, −1.85]
A-Driver	−0.09	(0.17)	−0.52	323.8	.60	[−0.43, 0.25]
M-IT	−0.57	(0.14)	−3.98	323.8	**<.001*****	[−0.85, −0.29]
L-IT	−1.14	(0.17)	−5.82	323.8	**<.001*****	[−1.47, −0.81]
A-AV: A-Driver	0.72	(0.16)	4.46	2233.0	**<.001*****	[0.41, 1.04]
A-AV: M-IT	0.22	(0.14)	1.59	2233.0	.11	[−0.05, 0.48]
A-AV: L-IT	0.02	(0.16)	0.13	2233.0	.90	[−0.29, 0.33]
A-Driver: M-IT	−0.20	(0.24)	−0.80	323.8	.42	[−0.67, 0.28]
A-Driver: L-IT	0.03	(0.28)	0.11	323.8	.91	[−0.53, 0.59]
A-AV: A-Driver: M-IT	−0.09	(0.23)	−0.40	2233.0	.69	[−0.54, 0.36]
A-AV: A-Driver: L-IT	−0.42	(0.27)	−1.59	2233.0	.11	[−0.95, 0.10]

Note. A-AV: Aggressive AV, A-Driver: Aggressive Driver, M-IT: Medium Initial Trust, L-IT: Low Initial Trust. ***p <. 001, **p <.01, *p <.05, +p <.1

For the AV style × driver style interaction, the follow-up pairwise comparison analysis suggested that drivers reported higher levels of trust towards careful AVs compared to aggressive AVs, regardless of their own driving style

(both p <.001), as shown in Figure 3 (a). Additionally, aggressive drivers showed greater trust towards aggressive AVs compared to careful drivers (p = .002), but showed equal trust in careful AVs as careful drivers (p = .559).

Similarly, in the AV style × initial trust interaction, the pairwise comparisons with Bonferroni-corrected adjustments revealed that drivers reported higher trust score (all p <.001) towards careful AVs compared to aggressive AVs, regardless of their initial trust level. Moreover, drivers with higher initial level always report greater trust (all p<.05) than drivers with lower initial trust, regardless the AV style. However, as showed in Figure 3 (b), drivers with medium level of initial trust tend to show a less difference in trust between careful AV and aggressive AV.



(a) AV style × Driver style (b) AV style × Initial trust

Figure 3: Two-way interactions on trust.

DISCUSSION

The present study investigated the effects of AV style, driver style, and initial trust on drivers' trust. Particularly, participants were exposed to different AV style by watching videos in which AVs dealt with driving events with either careful or aggressive styles. The two driving styles were differentiated based not only on driving parameters in non-dilemma scenarios but also on AV decision-making characteristics in the dilemma situations. The significant rating differences in attitude towards these two types of AVs suggested the effectiveness of the style manipulation.

Based on the results, we found that careful AVs were perceived as more trustworthy, corroborating previous research findings reported by Ekman et al., (2019). A possible contributing factor to the perceived higher trustworthiness of the careful AV was that drivers feel safer, as we created the careful AV with more careful driving decision such as longer following distance, and perceived safety is considered the foundation of trust in AVs (Zhang et al., 2019). We also found that aggressive drivers trusted aggressive AVs more compared to careful drivers, which is consistent with Ma and Zhang (2021). One possible explanation is aggressive drivers might have a higher acceptance of risk to achieve efficiency or prefer AVs align with their driving expectations and driving characteristics.

With regard to the effects of initial trust, the primary finding was the trust gap between initial trust groups persisted, confirming the significant role of initial trust in trust formation. This finding is consistent with the previous study (Manchon et al., 2021). However, drivers with medium initial trust

were less sensitive to AV style than high and low initial trust driver. Possible drivers with more trust preference tend to show more preference in AV style.

The above findings have some practical implications. One is AV Style is the important factor in building the trust in AV and suggested AV manufacturers always prioritize driving safety and caution in the production of AV. Another is different drivers show various preference in AV styles. AV manufacturers should consider offering options for AV personalization to cater different demands and preferences, ultimately improving the user trust and experience in their products.

This study has several limitations. First, it utilized an online video questionnaire as a preliminary exploration method, which may exist certain discrepancies with real-world experience. Additionally, the subjective nature of the employed scales may introduce some biases in the classification of drivers' driving styles, potentially affecting the reliability of the research results.

CONCLUSION

This study comprehensively considered the impact of initial trust, driver style and AV style on AV trust. The finding indicated that careful AVs were perceived as more trustworthy than aggressive AVs, irrespective of driver styles. Moreover, aggressive drivers exhibited higher trust in aggressive AVs compared to careful drivers. In addition, the trust difference between initial trust groups is sustained, and medium initial trust drivers were slightly less influenced by AV style compare drivers with more trust preference. These results emphasize the importance of driving style and initial trust in shaping drivers' trust in AVs. Understanding these factors can inform the design and development of AV technology, fostering and maintaining higher levels of trust and acceptance among drivers and contributing to its successful integration on the roads.

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