Investigating the Effects of Automated Driving Styles and Driver's Driving Styles on Driver Trust, Acceptance, and Take Over Behaviors

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Autonomous Vehicle (AV) technology has the potential to significantly improve driver safety. Unfortunately, driver could be reluctant to ride with AVs due to the lack of trust and acceptance of AV's driving styles. The present study investigated the impact of driver's driving style (aggressive/defensive) and the designed driving styles of AVs (aggressive/defensive) on driver's trust, acceptance, and take-over behavior in fully autonomous vehicles. Thirty-two participants were classified into two groups based on their driving styles using the Aggressive Driving Scale and experienced twelve scenarios in either an aggressive AV or a defensive AV. Results revealed that drivers' trust, acceptance, and takeover frequency were significantly influenced by the interaction effects between AV's driving style and driver's driving style. The findings implied that driver's individual differences should be considered in the design of AV's driving styles to enhance driver's trust and acceptance of AVs and reduce undesired take over behaviors.

INTRODUCTION

Autonomous Vehicles (AV) provide several potential beneficial outcomes, such as reducing injuries, improving mobility, and releasing drivers from driving tasks (Favarò, Nader, Nader, & Tripp, 2017). However, these benefits may not be realized until AVs are successfully implemented into road traffic and accepted by the public (Körber, Baseler, & Bengler, 2018). Recent surveys suggest that the public's trust and acceptance of AVs needs to be enhanced (König & Neumayr, 2017; Kyriakidis, Happee, & de Winter, 2015; Schoettle & Sivak, 2014). For example, Kyriakidis, Happee, & de Winter (2015) suggested that concerns of software hacking, legal issues and safety affect driver's trust and acceptance of AV technology. A survey published more recently by American Automobile Association (2019) reported that 71% of drivers in U.S. were afraid of riding with fully autonomous vehicles. Therefore, it is crucial to understand factors that affect driver's trust and acceptance of AVs.

Existing studies have focused on various interface design factors that have effects on driver's trust and acceptance of AVs, however, the discussions on *driving styles of automated vehicles* have not received attention until recently. Manual driving styles were defined as a driver's preferred way of driving that develops into driving habits over time (Kleisen, 2011; Elander, West, & French, 1993). The operational definition of driving styles includes a driver's preference of steering and acceleration, choices of velocity and headway distance, and how strictly they obey the traffic laws (Sagberg, Selpi, Bianchi Piccinini, & Engström, 2015). Bellem, Schönenberg, Krems, & Schrauf, (2016) analyzed drivers' maneuvers metrics in the manual driving and found drivers could perceive the differences in driving styles based on the maneuver metrics (e.g., acceleration, jerk, quickness). In a follow-up study that investigated automated driving styles to generate greater comfort, researchers found driver preferred a smooth driving style including a symmetrical acceleration profile with small acceleration rate and a lane change profile with low jerks and early motion feedback (Bellem, Thiel, Schrauf, & Krems, 2018). Lee, Liu, Domeyer, & DinparastDjadid (2019) examined three driving styles of autonomous vehicles (e.g., aggressive, moderate, and conservative) on driver's trust in intersection negotiations. The study revealed that drivers pressed the brake pedal more frequently when driving an aggressive AV and pressed the gas pedal more frequently when driving a defensive AV, both as the indicators of their dissatisfaction of the driving styles of AVs.

These studies mainly focused on driver's subjective evaluation on different designed automated driving styles regarding comfort and trust. However, little research has been done to investigate how driver's personality regarding their driving styles (e.g., aggressive and defensive) would influence their propensity to take back control, trust and acceptance of fully autonomous vehicles. Fully AV's driving styles might align or against drivers' driving styles. The discrepancy between the driver's driving styles and AV's driving styles may could influence their trust and acceptance of an AV's driving behavior, which in turn affect driver's takeover behavior frequency and the use of AVs. To be more specific, aggressive drivers prefer a higher speed, a smaller time headway and gap, larger longitudinal and lateral accelerations, and are more likely to disapprove of other's driving behavior; whereas drivers with a defensive automated driving style may be the opposite (Sagberg et al., 2015). Therefore, aggressive drivers may not accept AVs with a defensive driving style and take over vehicles more frequently than desired. In comparison, defensive drivers may not trust or accept AVs with an aggressive automated driving style and give up the automation functions entirely. Although the effect of risky driving style on driver's comfort evaluation of acceleration and lane change profiles was examined in Bellem et al (2018), drivers were not provided the functions to actually take over control of the vehicles, nor did driver's trust and acceptance of AV's driving styles were studied. Moreover, existing studies focused on vehicle maneuvers in simple scenarios, such as accelerate, lane change, and cross intersections straightly. The current study expands the analysis of automated driving styles in hazard scenarios and AV's behavior in other scenarios such as turning behaviors at intersections and responses towards traffic light.

In this study, we aim to study the impact of driver's driving styles and AV's driving styles on driver's trust, acceptance, and take-over behaviors in normal and hazardous scenarios when riding with a fully AV. We expect drivers would have higher trust and acceptance of AVs and take back control less frequently when AV's driving style aligns with the driver's driving style.

METHOD

Participants

Thirty-two participants (16 males and 16 females) participated in this study. Participants were required to be native English speakers and have held a driver's license for at least 2 years. Participants were classified into aggressive drivers and defensive drivers with Aggressive Driving Scale (ADS) (Krahe and Fenske, 2002). They were recruited from the general public via Penn State's StudyFinder website and compensated for $10/hour for this study. The study was approved by the Institutional Review Board at Pennsylvania State University.

Apparatus

A driving simulator (STISIM Drive® M300WS-Console system) was used in this study. It comprises a Logitech Momo® steering wheel with force feedback (Logitech Inc, Fremont, CA), a throttle pedal, and a brake pedal. The STISIM simulator is installed on a Dell Workstation (Precision 490, Dual Core Intel Xeon Processor 5130 2 GHz). Driving scenarios were presented on a 27-inch LCD with 1920×1200-pixel resolution. The automated driving system was implemented by STISIM Drive Open Module (OM) programming.

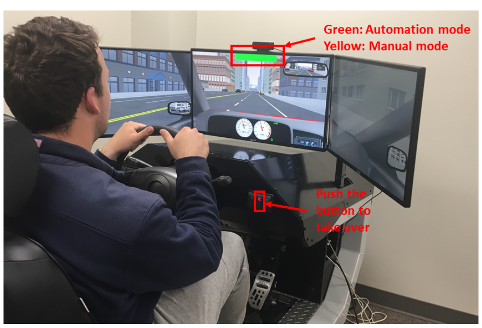

Figure 1. The STISIM Driving Simulator.

Materials

Aggressive Driving Scale (ADS). This 24-item scale was developed by Krahé & Fenske (2002) and validated in Zhang, Houston, & Wu (2016) to assess aggressive driving behaviors. Participants indicated the frequency of the aggressive behaviors they engaged in by rating each statement on a 5-point scale ("0" = never to "4" = very often). Participants were pre-screened based on their ADS scores, and those who were identified as aggressive and defensive drivers were recruited in this experiment. Drivers were classified as aggressive drivers when ADS ≥ 30 for male drivers and ADS ≥ 21 for female drivers, and defensive drivers when ADS ≤ 23 for male drivers and ADS ≤ 13 for female drivers (Krahé & Fenske, 2002; Krahé, 2005).

Checklist for Trust between People and Automation (Jian et al., 2000). This questionnaire was used to evaluate 12 potential factors of trust between people and automated system, including 'deception', 'underhanded manner', 'suspicion', 'beware', 'harm', 'security', 'integrity', 'dependable', 'reliability', 'entrust', 'familiarity' on a 7-point scale ('1' = not at all to '7' = extremely).

Propensity to Trust Questionnaire. This questionnaire was a six-item self-report scale developed by Sinha, Curran, Merritt, & Ilgen (2008) to assess individual propensity to trust machines. The item responses were on a 7-point scale ranging from 1 (strongly disagree) to 7 (strongly agree). An example item is, "I am likely to trust a machine even when I have little knowledge about it." The scale reliability was reported with a α of 0.86.

System Acceptance Questionnaire (Van Der Laan et al., 1997). This nine-item questionnaire was designed to measure driver acceptance of new technology with two dimensions, usefulness and satisfaction. Participants were required to evaluate systems by rating on a 5-point scale from -2 to +2 (e.g. '-2' = useful to '2' = useless).

Evaluation of driving parameters of AVs. This survey was developed by authors to measure participant's evaluation on the AV driving parameters that were manipulated to create two automated driving styles, such as speed, deceleration, turning angle, and time headway to lead vehicle. It was used to indicate driver's perception of the AV's driving styles to be either defensive (e.g., '0' = extremely slow speed) or aggressive (e.g., '8' = extremely fast speed) on a 9-point scale. The reasons of their take over behaviors were recorded if there was any during the drive.

Subjective evaluation of AVs. This survey was developed by authors to measure participant's subjective feeling of their AV driving experience after finishing all AV driving tasks, including comfort, preference, similar with me, and safety, on a 9-point scale ('0' = strongly disagree to '8' = strongly agree). At the end of the questionnaire, an open question was designed to collect the participants' opinions on how the design of the AVs should be improved to increase their trust to AVs.

Experimental Design and Scenarios

The experiment adopted a 2×2 between-subjects design with participant's driving style (aggressive vs. defensive) and autonomous vehicle's driving style (aggressive vs. defensive) as independent variables. Each participant only experienced one AV's driving style. As it shown in Table 1, driving parameters were manipulated to create an aggressive and a defensive AV's driving style for eight normal and four hazardous scenarios. The values of the parameters were adopted from several literatures that investigated driver's driving styles on the aggressive-defensive dimension (Deffenbacher et al., 2003; Hong et al., 2009; Hill et al., 2014; Yan, et al., 2007).

Table 1. Values of driving parameters for AVs

	Aggressive AV	Defensive AV
Average speed (ft/s)	76.31	66
Acceleration (ft/s^2)	6.379	5.468
Deceleration – approaching intersection (ft/s2)	-7.143	-3.712
Turning speed – Right (ft/s)	16.126	10.625
Turning angle – Right (rad/s)	0.664	0.438
Turning speed – Left (ft/s)	21.813	19.192
Turning angle – Left (rad/s)	0.385	0.339
Lane change angle (rad/s)	1.326	1.182
Time to collision to lead vehicle – Hazard 1 (s)	2.5	4.5
Deceleration– Hazard 1 (ft/s^2)	20	10.393
Deceleration– Hazard 2 (ft/s^2)	24.13	24.13
Deceleration/Acceleration-Hazard 3	6.379	-3.712
Deceleration- Hazard 4 (ft/s^2)	-7.143	-3.712
Distance to collision – Hazard 4 (ft)	32.43	81.33

An urban environment was simulated with two lanes on each direction of the roadways, moderate traffic density (13 vehicles/ (mile · lane), dense buildings and pedestrians walking along the roads. The posted speed limits were 45mph.

As it shown in Table 2, eight normal driving scenarios and four hazardous scenarios were designed for participants to experience the AV driving. The hazard events were selected and redesigned based on the Autonomous Vehicles Accidents Report (Favarò, et al., 2017; Favarò, Eurich, & Nader, 2018). All 12 tasks were divided into 4 blocks with the sequence of being balanced with a Latin Square design across four experimental conditions. Since we expected participants might take over AVs more frequently in the hazard scenarios, the hazard scenarios were designed at the end of each block so that drivers can easily recall and report the reasons of their taking over behaviors after each block. For conventional vehicle driving task, participants were asked to experience the same 8 normal driving scenarios.

Table 2. Scenarios in autonomous vehicle driving task

Block	Scenario
1	Drive straightly 1. Turn right at red light 2. Stop in front of the stop sign **Hazard 1: Slow lead vehicle brakes down**
2	Drive straightly 3. Turn right at green light 4. Go straight at green light **Hazard 2: Pedestrian runs into the road**
3	Drive straightly 5. Turn left at red light 6. Go straight at yellow light **Hazard 3: Vehicle on the adjacent lane cuts in**
4	Drive straightly 7. Turn left at green light with oncoming traffic 8. Go straight at red light **Hazard 4: Jam traffic**

Dependent Variables

The dependent variables in this study included participants' evaluations of the AV's driving parameters, driver's trust and acceptance of AV's driving styles, their subjective attitude of the AVs on comfort, preference and safety, and driver' take over frequency and take over performance. Driver's manual driving performance were also measured in this study.

Procedure

Participants who responded to advertisements were pre-screened regarding their driving styles with Aggressive Driving Scale (ADS) with after provided verbal consents. Participants who were identified as either aggressive drivers or defensive drivers were recruited to participate the experiment. Upon arriving, participants gave their written consent and then filled out the *Demographic Questionnaire* and *Propensity of Trust,* as well as the pre-test trust scale, "*Checklist for Trust between People and Automation*". Before the formal testing, they received an introduction to the experiment and the automated driving system. They were then given a 15-min practice session to familiarize themselves with driving simulator manually. After the practice, participants were instructed to complete a conventional vehicle driving task, including driving on an open road, following slow lead vehicle, and turning at intersections.

Afterward, participants were instructed to complete an AV driving task on the simulator. They were trained with a 5-min practical session to learn about how to switch between automation modes and manual-driving modes. In the formal experiment, participants were asked to drive the AV with the assigned driving style in an urban environment, and they experienced four blocks of the driving scenarios in a balanced order. During the drive, they could push the button to switch between automation mode and manual-driven mode freely. However, in order to ensure drivers to experience the AV's driving style for all designed scenarios, the vehicle will switch back from manual-driven mode to automation mode after 2500 feet of manual driving if a driver took over the vehicle. After each block, participants were asked to evaluate the designed driving parameters of AVs and explain the reasons why they take over control of the AVs if there was any.

After all the experiment, participants filled out several questionnaires, including *Subjective Evaluation of AV*, Post-Test *Trust Scale*, and *System Acceptance Questionnaire*. The total experiment time is 75-90 min.

RESULTS

This paper presented the preliminary results of the study regarding driver's trust, acceptance, and subjective attitude on AV's driving styles. Driver's take over frequency were also analyzed in this paper. Thirty-two participants were assigned into four group based on their own driving style and AV's driving style. The mean age of the aggressive AV-aggressive driver group was M = 24.25 (SD = 7.03). The mean age of the defensive AV-aggressive driver group was M = 22.13 (SD = 2.36). The mean age of the aggressive AV-defensive driver group was M = 21.88 (SD = 2.75). The mean age of the defensive AV-defensive driver group was M = 25.25 (SD = 4.89). In each group, gender was balanced.

Drivers' Trust to AVs

To analyze the effects of AVs' and drivers' driving style on driver's trust, a two-way ANCOVA was conducted on driver's post-test trust to AVs with drivers' trust propensity and pre-test trust to AVs as covariates. As shown in Figure 2, results indicated a significant interaction effect between AV's and driver's driving style on driver's trust to AVs ($F(1, 26) = 7.65$, $p = .01$, $\eta_p^2 = .23$). For simple effect, aggressive drivers trusted aggressive AVs significantly more than defensive drivers ($F(1, 26) = 6.85$, $p = .02$, $\eta_p^2 = .21$), whereas defensive drivers trusted defensive AV significantly more than aggressive AVs ($F(1, 26) = 4.72$, $p = .04$, $\eta_p^2 = .15$). No significant main effect of AV's or driver's driving style on driver's trust to AVs was found ($F(1, 26) = .11$, $p = .75$; $F(1, 26) = .92$, $p = .35$).

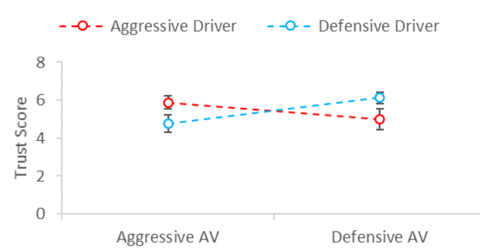

Figure 2. Effects of AV's and driver's driving style on trust.

Drivers' Subjective Evaluation of AVs

To analyze the effect of AV's driving styles and drivers' driving style on drivers' subjective evaluation of AVs, two-way ANOVAs were conducted for each subjective variable, including comfortability, preference, and safety.

Comfortability. The results indicated a significant interaction effect between AV's and driver's driving style on their comfortability ($F(1, 28) = 6.42$, $p = .02$, $\eta_p^2 = .19$). To be more specific, aggressive drivers felt more comfortable riding in an aggressive AV compared with defensive drivers ($F(1, 28) = 7.04$, $p = .01$, $\eta_p^2 = .20$), whereas defensive drivers felt significantly more comfortable when driving a defensive AV than an aggressive AV ($F(1, 28) = 7.77$, $p = .01$, $\eta_p^2 = .22$). No main effects for AV and driver's driving style on driver's comfortability when driving AVs ($F(1, 28) = 1.98$, $p = .17$; $F(1, 28) = 1.49$, $p = .23$).

Preference. The significant interaction effect between AV's and driver's driving style was found on their preference ($F(1, 28) = 4.29$, $p = .05$, $\eta_p^2 = .13$). For simple effect, aggressive drivers preferred aggressive AV significantly more than defensive drivers ($F(1, 28) = 5.74$, $p = .02$, $\eta_p^2 = .17$), whereas defensive drivers preferred defensive AV marginally more than aggressive AV($F(1, 28) = 3.99$, $p = .056$, $\eta_p^2 = .13$). Results did not find any significant main effects for AV's driving styles ($F(1, 28) = .57$, $p = .46$) and driver's driving style ($F(1, 28) = 1.74$, $p = .20$) on driver's preference to AV.

Safety. As shown in Figure 3, results showed the significant effect of AV's driving style on how drivers felt safe during AV driving ($F(1, 28) = 6.17$, $p = .02$, $\eta_p^2 = .18$), and the main effect of driver's driving style on safety was not significant ($F(1, 28) = .48$, $p = .49$). The significant interaction effect between AV's and driver's driving style was found on their subjective safety ($F(1, 28) = 6.17$, $p = .02$, $\eta_p^2 = .18$). For simple effect, aggressive drivers felt significant safer than defensive drivers when driving aggressive AVs ($F(1, 28) = 5.06$, $p = .03$, $\eta_p^2 = .15$), and defensive drivers felt significantly safer when driving defensive AVs compared with driving aggressive AVs ($F(1, 28) = 12.34$, $p = .002$, $\eta_p^2 = .31$).

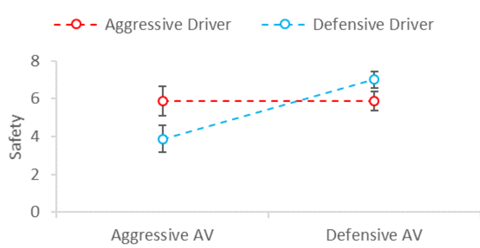

Figure 3. Effects of AV's and driver's driving style on safety.

Drivers' Acceptance of AV's driving styles

Two ANOVAs were conducted to examine the effects of AV's driving styles and drivers' driving style on the usefulness and satisfaction dimensions of drivers' acceptance of AVs, respectively. The interaction effects between AV's and driver's driving style were found marginally significant on usefulness ($F(1, 28) = 3.96$, $p = .056$, $\eta_p^2 = .12$) and significant on satisfaction ($F(1, 28) = 4.84$, $p = .04$, $\eta_p^2 = .15$), respectively. No significant main effects of either AVs' driving styles or driver's driving styles were found on either of the dimensions.

As it shown in Figure 4, the results indicated that drivers accept AVs better when AV's driving styles align with drivers' driving styles with the usefulness and satisfactions scores being higher than the scores when aggressive driver drives a defensive AV and when defensive driver drives an aggressive AV.

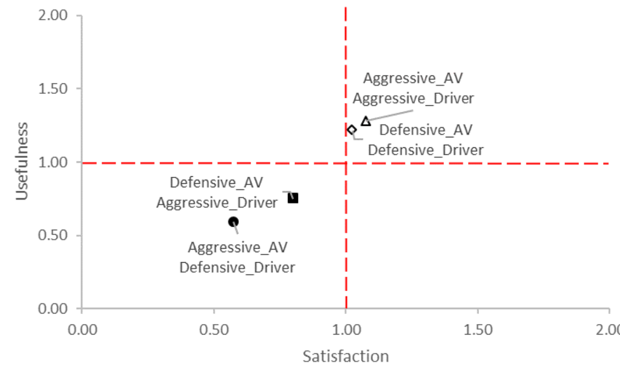

Figure 4. Average usefulness and satisfaction scores for each experiment condition.

Takeover frequency

To analyze the effect of AV's and driver's driving style on their takeover frequency during the driving task, a 2*2 Chi-Squared Test of Independence was conducted. As shown in Figure 5, the significant interaction effect between AV's and driver's driving style was found on their takeover frequency ($\chi^2(1) = 6.53$, $p = .01$). In specific, aggressive drivers took over significantly more frequently than defensive drivers when driving a defensive AV ($\chi^2(1) = 6.53$, p = .01), whereas defensive drivers took over significantly more frequency when driving an aggressive AV compared with driving a defensive AV ($\chi^2(1) = 8.00$, $p = .005$).

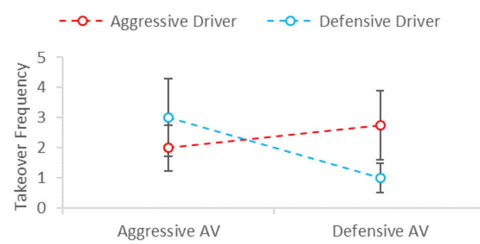

Figure 5. Effects of AV's and driver's driving style on takeover frequency.

DISCUSSION AND CONCLUSION

The present experiment suggested both AV's driving style and driver's driving style were influential factors on driver's trust, acceptance, and takeover behavior.

For driver's trust to AV, there was a significant interaction effect between AV's driving style and driver's driving style. It shows that drivers whose driving styles are compatible with AV's driving style trust more on the automated vehicle systems. This result could be explained by Hoff & Bashir (2015)'s trust model for automation that the extent to how automation performs in consistent with the operator's expectation could influence their trust to this system. When drivers ride with automated vehicles, driver's trust could be affected by how AV's driving behaviors fit driver's expectation, which are generally compatible with driver's own driving behavior. To be more specific, aggressive drivers have significantly more trust on aggressive AVs compared with defensive drivers. Defensive drivers have more trust on defensive AVs than aggressive AVs. The results also indicated that drivers feel more comfortable and prefer driving the AVs with a compatible driving style. AV's driving styles affected driver's evaluation on the safety, indicating defensive drivers feel unsafe when riding with an aggressive AV, whereas aggressive drivers feel no differences when riding with an aggressive AV and a defensive AV. Therefore, the design of AV's driving styles should be customized to be compatible with drivers' own driving styles to certain degree while under the consideration of driver safety in order to improve driver's trust and subjective attitude on AVs.

The acceptance of AVs was examined on the dimension of usefulness and satisfaction. The results illustrated that drivers perceived both design of AVs to be useful regardless of their own driving styles since the usefulness scores in all of four experiment conditions are above zero (neutral). However, drivers showed better satisfaction with AVs when the designed AV's driving styles align with their own driving styles than that when AV's driving styles differ from driver's driving styles. Therefore, driver's individual differences should be considered in the design of AV's driving styles to enhance drivers' acceptance of AVs.

Moreover, the study present some of the first evidence on how the design of automated driving styles interacting with driver' driving styles affects driver's take over behavior in AVs. The findings of the study suggested that drivers took over AVs more frequently when the AV showed a different driving style from their own. By further analyzing their takeover reasons, it revealed that aggressive drivers took over defensive AVs more frequently because they wanted to drive at a faster speed, a higher acceleration rate, or preferred to control vehicles by themselves. In comparison, defensive drivers took over aggressive AVs more frequently because they felt uncomfortable, unsafe or anxious. Therefore, the design of AV's driving styles could be improved to be compatible with driver's driving styles, especially for certain maneuvers such as the acceleration after stopped at the intersection, in order to reduce drivers' take over behavior and increase driver's uses of AVs. On the other hand, the study revealed the need for future research to explore techniques to mitigating the potential of aggressive behavior in automated vehicles.

In summary, this study brought insights into the design of AV's driving style to promote drivers' trust and acceptance of AVs and reduce undesired take over behaviors. It is recommended to design the AV's driving styles that are align with the drivers' driving style when safety is considered.

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