HMI for autonomous vehicles in traffic

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Executive Summary

The purpose of the study was to investigate how the "driving behaviour" characteristics of AV cars affect users' understanding, trust and acceptance of AD in different situations. An experimental study was conducted on the AstaZero test course where 18 participants experienced two consecutive AV-test runs with two different driving behaviours – 'Defensive' and 'Aggressive'. The vehicle had a Wizard of Oz-setup, meaning that it was controlled by a (to the participant) hidden test driver. Each test run included nine situations of which seven were considered as possibly 'critical' traffic situations from a user trust perspective. Data on users' trust in and experience of AV was collected by means of different questionnaires, an adapted UX curve, and personal interviews. The results show that he driving behaviour of an AV affects users´ trust in the AV. The 'Defensive' driving behaviour was in general rated highest regarding perceived trust as predictability was perceived as higher since it more clearly showed its intentions. The 'Aggressive' driving behaviour was however in some situations assessed as the more effective but in other situations as unpredictable. The results demonstrate the importance of considering the vehicle as a whole when designing the HMI.

Background

Vehicle systems are rapidly getting more advanced and several car manufacturers as well as other companies are already testing fully autonomous vehicles (AVs) in order to reduce energy consumption and at the same time increasing both safety and comfort for the users (Payre, Cestac, & Delhomme, 2016). However, studies have showed that in order to reap the full benefits of automation the user must first trust the AV; trust being a fundamental part of acceptance (Ghazizadeh, 2012) and an important factor in understanding the users' reliance on automation (Dzindolet, 2003). For the interaction between the user and the AV to become as favourable as possible an appropriate level of trust is needed (Lee & See 2004). Too high a level of trust in a system, in relation to the system's capacity, can lead to misuse, i.e. operating the system in an unintended way (Itoh, 2012)(Sheridan, 2006). On the other hand, if the user's trust in the system is too low, it may lead to disuse, i.e. choosing to not use the system at all (Parasuraman, 1997). Trust is also a dynamic concept, changing over time (Ekman et al., 2018) by a continuous fluctuation regarding the perceived system performance throughout different situations, which in turn changes the user's reliance strategy (Hoff & Bashir, 2016).

When trying to understand and solve issues related to drivers´ trust in AV-systems, focus has often been on the graphical user interfaces (GUI) and what the effect the GUI has on the users' level of trust when presenting system uncertainty (Helldin, 2013; Beller, 2013), showing information about system actions (Koo, 2014), having different levels of system transparency (Ekman, 2016) and anthropomorphic approaches (Haeuslschmid, 2017; Waytz, 2014).

A recent study on anthropomorphism showed no significant difference regarding the level of trust in the different AV concepts, but indicated instead that the users' level of trust depended primarily on the behaviour of the vehicle (Aremyr et al., 2018). This could be compared to when travelling as passenger in a human operated vehicle. The vehicle´s behaviour, hence how the driver operates the vehicle in terms of brakes, turns and positions the car in the lane, affects how competent as well as how trustworthy the driver is perceived by the passenger. Some research has already shown that lane positioning and lateral steering behaviour of AD vehicles is important in conveying the capabilities of the system (Merat, 2012; Price, 2016) and a study by Lee (2016) indicates that an unfavourable lane positioning of an AD vehicle lowers the user's trust. In addition, Dikmens (2016) has shown that uncomfortable acceleration and deceleration in AV's driving behaviour has led users to change back to manual driving again. This notion highlights the importance to not only focus on the GUI but to also consider the effect of the AV´s driving behaviour on users´ trust.

Purpose, Research Questions

The purpose of the study was to investigate how the "driving behaviour" characteristics of AV cars affect users' understanding, trust and acceptance of AD in different situations. The following research questions were posed:

RQ1: How does the car's 'behaviour' in terms of, e.g. acceleration and steering performance influence drivers' trust in and acceptance of AV?
RQ2: How does the car's 'behaviour' in specific conflict situations influence drivers' trust in and acceptance of AV?

Method

The study was conducted on the AstaZero test course where 18 participants experienced two consecutive AV-test runs with two different driving behaviours. The vehicle had a Wizard of Oz-setup, meaning that it was controlled by a (to the participant) hidden test driver. The test course included a rural- and as well an urban section. Each test run took approx. 15 minutes to complete and included nine situations of which seven were denominated as possibly 'critical' traffic situations from a user trust perspective. The seven situations (see no. 2-8 in Figure 1) were stopping for a red light, overtaking a moving vehicle, stopping for a person waiting to cross a zebra-crossing, passing a cyclist, driving onto a highway, passing oncoming traffic and driving through a roundabout.

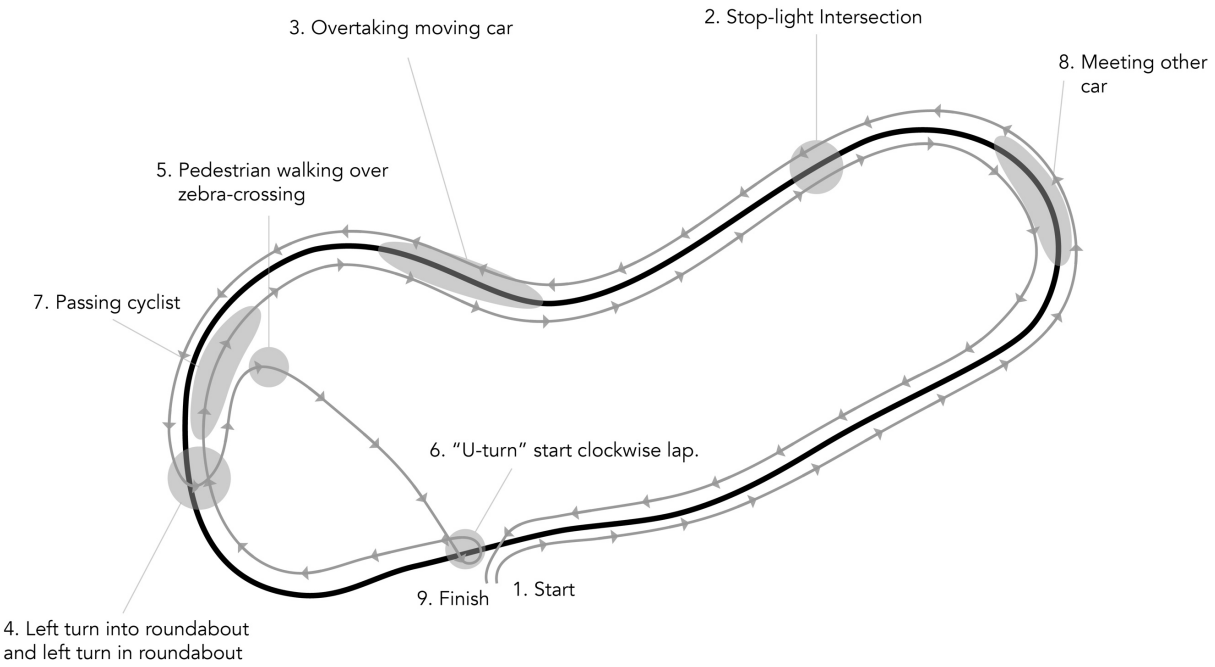


Figure 1 – Test course with situations

Participants

The 18 participants taking part in the experiment were between 20 and 55 years old (mean 36,7; SD=11.1), consisting of 10 men and 8 women. The participants were recruited from the Gothenburg area through a newspaper advertisement. The only inclusion criterion was a valid driver's license.

Driving behaviours

The two distinctly different driving behaviours consisted of a 'Defensive' behaviour and an 'Aggressive' behaviour. These AV-driving behaviour differed in several ways, e.g. in acceleration, deceleration and distance kept to other objects (Table 1).

Table 1 – AV driving behaviours.

	Defensive Driving Behaviour	Aggressive Driving Behaviour
Starting & stopping	Keep the vehicle rolling (avoid standstill)	Start & stop (comes to full stop)
Acc./Decell. pattern	Avoid heavy acc./decell.	Heavy acc./decell.
Lane positioning	Early indicate right or left turn (through positioning in lane)	Indicate late right or left turn (through positioning in lane)
Distance to objects	Keep longer distance (lateral & longitudinal) to other objects	Keep shorter distance (lateral & longitudinal) to other objects

Procedure

The AV-test runs were conducted in an order, where half of the participants started with the 'defensive' and half started with the 'aggressive' driving behaviour.

Data was collected during two different phases; a peri-trial phase and a post-trial phase (see Figure 2). The peri-trial phase included two parts and four data collection methods. The first part was conducted during the test run in the AV, and included a *Likert scale* on trust combined with a *Think-aloud procedure* (cf. (Charters, 2003). The participants rated what level of trust they felt in the seven critical situations (i.e. passing a cyclist, stopping for a red light, stopping for a pedestrian crossing the street etc.) and then elaborated on why they felt this way. The second part was completed directly after each test run using a *Trust Questionnaire* (based on Jian, Bisantz, & Drury, 2000) and a method referred to as the *'Trust curve',* an adaptation of the UX-curve (Kujala, Roto, Väänänen-Vainio-Mattila, Karapanos, & Sinnelä, 2011). The Trust Questionnaire focused on assessing the participant´s overall trust in the AV during each of the respective test runs. The participants were then asked to draw a curve symbolising their level of trust during the test run and to mark out situations that affected their trust in the AV the most. The post-trial phase, finally, included an interview with the participant, where the 'Trust Curve' was used as a mediating tool to allow the participant to further reflect on and discuss the levels of trust in the AV during specific situations as well as their overall trust.

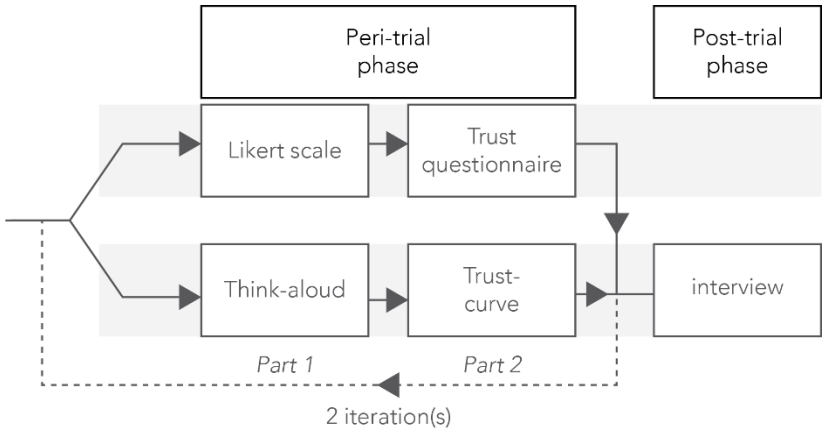


Figure 2 – Data collection methods during peri-trial phase and post-trial phase.

Results

The participants' ratings of trust in the system were generally high.. In the trust questionnaire, 'Defensive' got a median score of 6 and 'Aggressive' got a median score of 5,5. The data from the ratings of situational trust shows a similar result; 'Defensive' got a median score of 6 and 'Aggressive' got a median score of 5.

Table 2 shows the number of participants that rated their trust one point or more than one point higher in one compared to the other driving behaviour. The result is divided per item and by test order. The result

shows that more participants rated their trust in 'Defensive' higher than their trust in 'Aggressive'. The biggest differences between the driving behaviours concerned

- the item 'I think the driving behaviour of the self-driving car was predictable', where 61% of the participants agreed more regarding 'Defensive' (5 participants +1 point and 6 participants >+1 point) whilst 11% agreed more regarding 'Aggressive' (2 participants +1 point), and
- the item 'If the car worked like this, I would let it drive by itself', where 56% of the participants agreed more regarding 'Defensive' (3 participants +1 point and 7 participants >+1 point) whilst 11% agreed more regarding 'Aggressive' (2 participants +1 point).

The results also show that the participants agreed to a higher degree with the statements regarding the 'Defensive' and the 'Aggressive' driving behaviour when experiencing the respective driving behaviour in the first test run.

Table 2 - Results from the Trust questionnaire

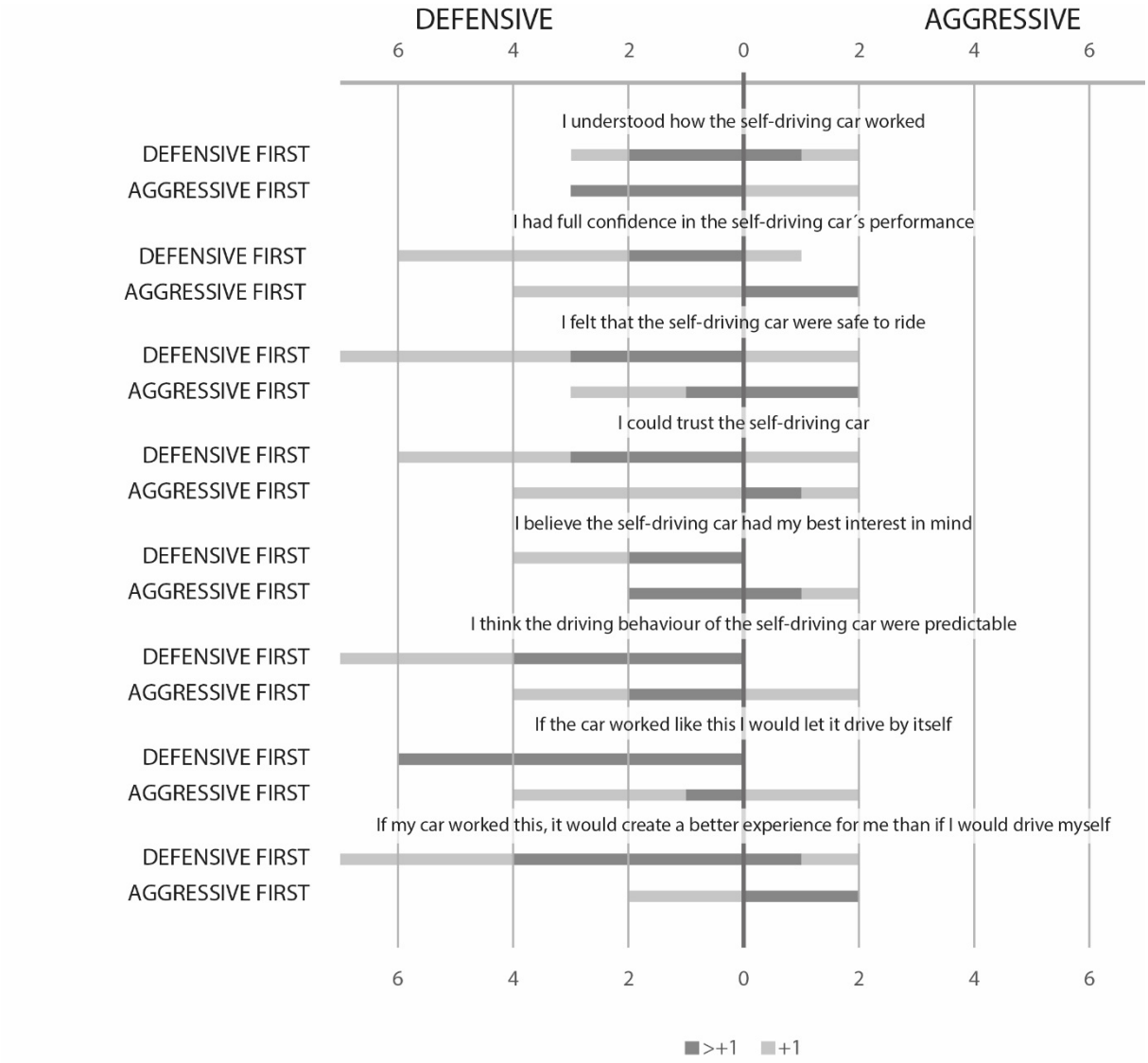
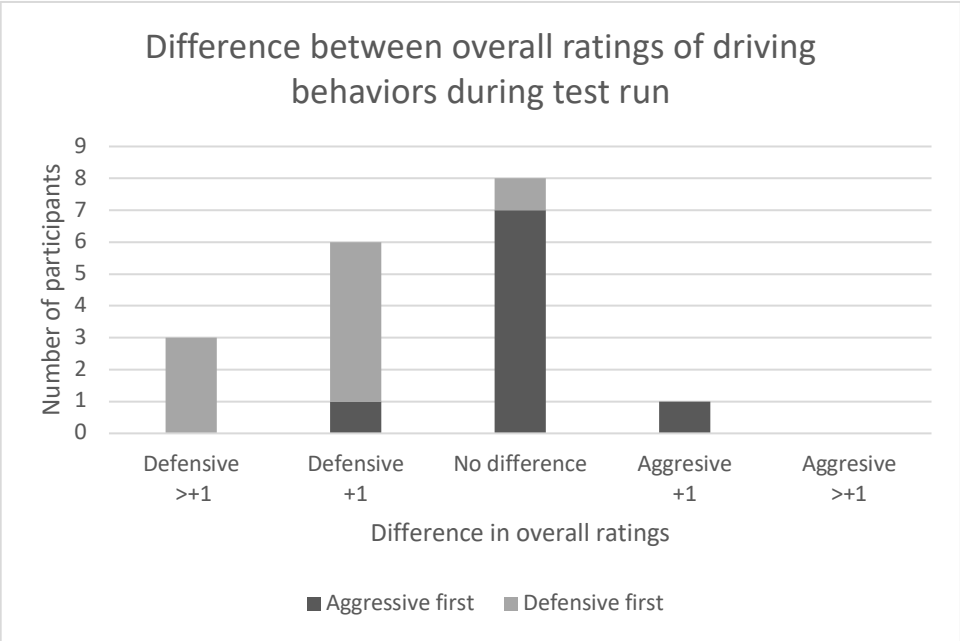


Table 3 shows the difference between the overall ratings of trust of the respective driving behaviours collected during the test run. Nine of the participants rated 'Defensive' higher, eight rated them equally and one rated 'Aggressive' higher. The result also shows that when the participants started with the 'Defensive' their trust was rated higher. However, the participants who started with 'Aggressive' showed no difference in overall ratings.

Table 3 – Results from the Situational Trust Assessment



The results from the qualitative data collection methods indicated that the predictability of the automation is of importance for how much trust the participants felt, several of the participants wanted to be in the "information-loop" regarding the intentions of the automated vehicle. 'Defensive' was in general perceived as more trustworthy since this behaviour showed the car's intentions earlier as well as in a calmer manner. The results also indicate that the perceived intelligence of the automation depended on the situations. In critical situations, a 'Defensive' behaviour was preferred since it more clearly showed the intention(s) of the car (e.g., early slow down for pedestrian). In non-critical situations, the 'Aggressive' behaviour was preferred since it was perceived as more effective (e.g., narrow turn in roundabout).

In summary, the study showed that the driving behaviour of the automated vehicle affected the participants' trust but also that people experienced the autonomous car as 'a whole'. Hence, vehicle dynamics and driving patterns need to be considered as an essential part of the user interface of the car to create trust as well as comfort (holistic term) – the entire autonomous car is the interface to the user.

Conclusion and outlook

In conclusion, the driving behaviour of an AV affects users´ trust in the AV. The 'Defensive' driving behaviour was in general rated highest regarding perceived trustworthiness. The predictability were perceived as greater for the 'Defensive' driving behaviour since it more clearly showed its intentions, allowing the participant to reflect on and prepare for upcoming action. The driving behaviour also affects the perceived intelligence of the AV: the 'Defensive' behaviour in certain situations was deemed safe and in other situations unnecessary slow and therefore unintelligent. The 'Aggressive' driving behaviour on the other hand was in some situations assessed as effective and in others as unpredictable. Thus, the result shows that it is important to not only focus on GUI´s when designing AV and the HMI but to consider the vehicle as a whole.

It is essential to continue to investigate the effect of AV driving behaviour on users and users acceptance and trust in AV, also in even more naturalistic contexts than what can be achieved at AstaZero, i.e. in everyday normal traffic.

Lessons learned and experience from testing at AstaZero

The experiment has shown the importance to use a real test track (in comparison to a simulator) when investigating trust related issues – since there needs to be perceived risks for trust to even be necessary. Being able to use the AstaZero test track allowed a more naturalistic way of investigating the effect of AV driving behaviour. This is a highly important factor in understanding the Human-Machine Interaction (HMI) between user and vehicle. The setup and collaboration with the staff at AstaZero worked very well and the test track allowed for different types of traffic situations which were important for the experiment. Issues concerned administrative matters. One issue concerned uncertainties regarding what expenses were covered by the application and what were not (e.g. petrol etc.). Another issue concerned what was referred to as 'AstaZero agreement'.

Publication and dissemination

Ekman, F., Johansson, M., & Karlsson, I.C.M. (2018): Understanding Trust in an AV-context: A Mixed Method Approach. In: Proceedings of the 6th Humanist Conference, The Hague, Netherlands, 13-14 June 2018.

Ekman, F., & Johansson, M., Strömberg, H., Bligård, L-O & Karlsson, I.C.M. (forthcoming): Investigating the impact of vehicle behaviour on users' trust in and experience of autonomous driving. Paper to be submitted to Transport Research Part F.

Ekman, F., & Johansson, M., Strömberg, H., Bligård, L-O & Karlsson, I.C.M. (forthcoming): The Mexican Standoff – The Interrelationship between Trust, Responsibility and Control in AVs. Paper to be submitted.

Johansson, M., Ekman, F., Bligård, L-O, Strömberg, H. & Karlsson, I.C.M. (forthcoming): Is it Me or The Situation – Comparing the Effect of Individual and Situational Factors Regarding Trust in AVs. Paper to be submitted.

Johansson, M., Ekman, F., Bligård, L-O, Strömberg, H. & Karlsson, I.C.M. (forthcoming): Talking AD - An investigation of users' understanding of an autonomous vehicle. Paper to be submitted.

Johansson, M., Ekman, F., Bligård, L-O, Strömberg, H. & Karlsson, I.C.M. (forthcoming): Hearing What Isn´t said – Users Understanding of AV Driving Behaviour. Paper to be submitted to Transport Research Part F.

Participating partners and contact persons

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- Volvo Car Corporation (VCC)