The influence of system transparency on trust: Evaluating interfaces in a highly automated vehicle

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The Influence of System Transparency on Trust: Evaluating Interfaces in a Highly Automated Vehicle

Abstract

Previous studies indicate that, if an automated vehicle communicates its system status and intended behaviour, it could increase user trust and acceptance. However, it is still unclear what types of interfaces will better portray this type of information. The present study evaluated different configurations of screens comparing how they communicated the possible hazards in the environment (e.g. vulnerable road users), and vehicle behaviours (e.g. intended trajectory). These interfaces were presented in a fully automated vehicle tested by 25 participants in an indoor arena. Surveys and interviews measured trust, usability and experience after users were driven by an automated low-speed pod. Participants experienced four types of interfaces, from a simple journey tracker to a windscreen-wide augmented reality (AR) interface which overlays hazards highlighted in the environment and the trajectory of the vehicle. A combination of the survey and interview data showed a clear preference for the AR windscreen and an animated representation of the environment. The trust in the vehicle featuring these interfaces was significantly higher than pretrial measurements. However, some users questioned if they want to see this information all the time. One additional result was that some users felt motion sick when presented with the more engaging content. This paper provides recommendations for the design of interfaces with the potential to improve trust and user experience within highly automated vehicles.

Keywords: automated vehicles; trust in automation; user experience; system transparency;

Introduction

New technologies are making possible the introduction of automated vehicles (AVs), and substantial changes are expected to impact transportation and the vehicles as we know them. There is the perception that AVs will be able to handle the role of a driver better than a human (Gambino and Sundar, 2019). However, one of the key challenges for the introduction of complete autonomy is customer trust and acceptance of the automated system (Nordhoff et al., 2018). Trust in automation and attitudes towards AVs tends to deteriorate as the levels of automation increases (Hewitt et al., 2019; Rödel et al., 2014).

The industry and academics have been testing methods with the potential to improve levels of trust and acceptance of AVs (Noah et al., 2017). One of these methods is system transparency, when users are presented with information about the status of the system (Lee and See, 2004). Users trust technology more when they are able to understand the capabilities of the system, see how well it is performing and forecast future behaviour (Choi and Ji, 2015; Hoff and Bashir, 2015). Since information can improve trust (Cha et al., 2018), there are opportunities for research to investigate the trust levels in relation to the interfaces and information available for occupants of AVs.

Most research in system transparency has focussed on its impact on semi-autonomous systems where the human operator must take at least a supervisory role (Richards and Stedmon, 2016). In contrast, level-4 or 5 AVs demand no human operation or supervision (SAE, 2018).

With increased automation, the occupant(s) of highly automated vehicles (HAVs) will delegate the operational, tactical or strategic tasks to the driving system. Passengers will not be required to control the trajectory, manoeuvre the vehicle or plan the route as we currently do (Michon, 1985). System transparency in this context has no bearing on task completion or performance. Because occupants will be disengaged from the driving tasks, it is also expected that they may need to be less aware of potential hazards than a regular driver would (Haeuslschmid et al., 2016). It is not yet clear whether information displays of some kind will have to be provided for occupants of HAV to track the progress of the journey and know details of the intended route. Identifying what system transparency information needs to be communicated and how to do so could be a defining factor of the user experience of travelling in a HAV.

After an initial exploration, we observed the potential to investigate interesting factors regarding trust in automation. These factors included the comparison of diverse interfaces within a HAV, the use of a level 4 (SAE, 2018) vehicle, and the information provision for occupants of HAVs consisting of both hazards and vehicle’s behaviour. This exploration prompted the definition of our study aim, described below.

Aim

The aim of this research was to compare interface concepts created to convey hazard perception and intended behaviour to users of HAVs. A study was designed to explore the benefits and limitations of three different concepts for system transparency information in comparison with a baseline concept. The present study generated interface concepts and created working prototypes to be tested in actual HAVs. In trials, we compared these concepts and identified which of them produced the best user experience, and the ones most likely to satisfy user requirements of trust and acceptance.

To address the aims of this research, we performed a literature review conveying four main areas: system transparency information when handovers are required, system transparency information for higher levels of vehicular automation, information content, and types of interfaces conveying this information.

Literature review

Often, human-machine interfaces (HMI) are used to display visual aids to drivers, sensor performance, system health and the abilities of the vehicle. This information is especially useful for level-3 assisted driving, when the vehicle may need to hand the control to drivers during parts of the journey (SAE, 2018). Studies show that drivers who are provided with information when the system is “uncertain” can take back the control of vehicles faster (Helldin et al., 2013; Lyons, 2013), resulting in safer takeovers (Kunze et al., 2019). Driver distraction is a constant threat to safety in these cases, and they may need explicit warnings to regain control of vehicles (Banks and Stanton, 2016).

For AVs of levels 4-5, however, when vehicles can handle all traffic situations (SAE, 2018), occupants of vehicles may need no information about the road ahead, since there will be no handover process (Haeuslschmid et al., 2016). Interfaces may be only used for setting the destination of the vehicle (Oliveira et al., 2018). Nevertheless, interfaces can also present new possibilities that are not safety critical, for example the display of system transparency information in the attempt to increase trust in the automation (Diels and Thompson, 2018; Rezvani et al., 2016) and improve user experience and comfort (Elbanhawi et al., 2015; Lin et al., 2004).

Diels and Thompson (2018) attempted to identify user requirements for the interface of AVs across a number of potential use cases and indicated that users expect interfaces to provide two categories of information: situation awareness (what the vehicle sees) and behavioural awareness (what the vehicle is going to do). Miglani et al. (2016) conducted a simulator study to assess the impact of different levels of information presented in the HMI of an AV. Results showed participants wanted to be able to match environmental recognition information to what they could see in the environment through the windscreen. Current and upcoming events were also considered important and worth displaying.

The communication of potential or actual hazards has been tested using diverse strategies, for example using visual (Wiegand et al., 2019), audible (Wong et al., 2019), haptic (Ma et al., 2019), olfactory (Wintersberger et al., 2019) and multimodal (Geitner et al., 2019) interfaces. Recent technological developments permit the construction of interfaces featuring augmented reality (AR). Vehicular AR comprises visually transparent interfaces, usually on the windscreen, displaying information in a way that will not require drivers to look away from the road (Gabbard et al., 2014; Häuslschmid et al., 2019). There has been a growing interest in AR, and experiments show that these interfaces can work as a driver aid (Bark et al., 2014). Using driving simulators, studies has shown that graphical aids projected on the windscreen let drivers improve their visual attention to critical elements on the road ahead (Eyraud et al., 2015; Rusch et al., 2013; Shahriar and Kun, 2018) and increase the safety while driving (Large et al., 2019). Other research, utilising a virtual reality headset, provided diverse configurations of information to participants on the windscreen of the animated vehicle (von Sawitzky et al., 2019). Their results indicate that a preview of future behaviours of AVs can give time for occupants to process this information and lead to improved trust levels. However, there are important limitations and safety questions surrounding AR that are only visible when this technology is implemented on real windscreens. Researchers and the automotive industry acknowledge the challenges such as accuracy, lags in the presentation of information, focusing distance and parallax error (i.e. when overlaid images are misaligned with target objects) (Kun et al., 2017; Riener et al., 2018; Tufano, 1997).

This literature review indicated that there has been previous research into the HMI requirements of system transparency for AVs. However, these studies did not focus on comparisons of different interfaces displaying both environmental recognition and driving behaviour information specifically. They also tend to use virtual environments as the platform to test interactions. The exact user requirements for system transparency are not yet very clear. Therefore, we proceeded to design a study to understand the benefits of system transparency in fostering trust and acceptance, and to compare different interfaces presenting this information within HAVs.

Methods

Study design overview

The recruitment of participants was made via internal emails sent to employees of a large car manufacturer based in the UK. We obtained 25 participants (4 female) who took four short rides in an

HAV we referred to as a "pod". None of the participants had previously been in an automated pod. This study comprised a within-subjects design with repeated measures, where all participants tested all of the interfaces in random order. A mixed-methods approach was used, combining quantitative and qualitative instruments. Participants rode alone in the vehicle. The user trial was conducted in the Urban Development Lab (UDL), in Coventry. It consists of a 20m x 35m warehouse with partitions in the middle simulating three buildings and offering simulated corners and crossroads. Images of shop fronts were projected onto curtains on the walls of the arena to resemble a semi-pedestrianised area in a town centre (Figure 2). Ethics and risk assessment were performed and clearance granted under code RAN-R-041-A.

Tasks

Participants were first given a safety briefing, signed consent forms and completed a pretrial questionnaire on iPads before being led into the trial arena. Upon being seated in the pod, participants were told that the pod would make a 4-minute journey around the arena. Participants were asked to say the sentence "OK Pod, take me to Tesco" when the doors of the vehicle had been shut. Participants were not given instructions on where they should direct their attention during the journey, but they were asked not to use their mobile phones or any personal devices. Inside the vehicle, there was a radio to communicate with the research team should participants need, and they were assured that they could cancel the session at any time if they felt uncomfortable either via radio instructions or using emergency-stop buttons inside the pod.

After each ride, participants completed a post-condition questionnaire and had a short interview with a researcher. After completing all four journeys, participants filled in the post-trial questionnaire, took part in another interview to share impressions about their experience and ranked all the interfaces. Each trial took approximately 1.5 hours to complete (Figure 1).

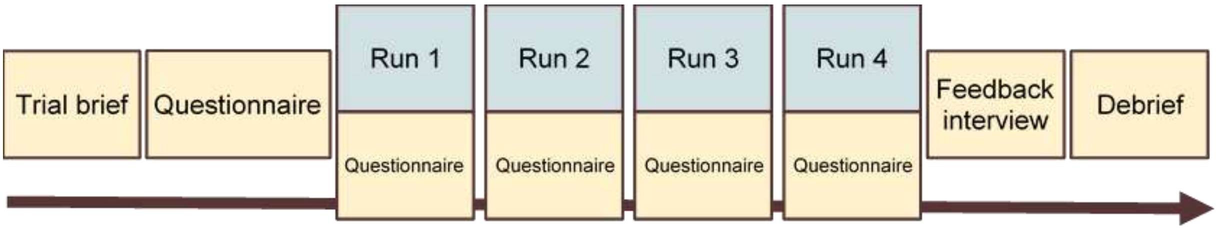

Figure 1 – Study design

Vehicle

The vehicle used during this study (Figure 2) is a level-4 HAV, meaning that it is capable of handling all driving tasks in certain scenarios (SAE, 2018). The vehicle was developed by RDM Group / Aurrigo and does not have pedals or steering wheel, so occupants have no control of its speed or trajectory other than an emergency-stop button. Although the pod is a level 4 HAV, the starting of the vehicle was controlled by the operators of the pod systems in a corner room behind a black mirror. When they had heard the voice command from the participant, one operator started the vehicle and the pod began its journey.

Figure 2 – Vehicle used during this study, manufactured by RDM / Aurrigo

Interactions

We created a number of interactions during the journeys to be displayed on the interfaces and populated the arena with the respective hazards. The elements in the screens reflected the items within the arena. Simulated pedestrians were placed in strategic places along the route for the trial using cardboard cutout figures. The vehicle would drive ten laps around the partitions of the circuit shown in Figure 3, taking seemly random turns at the junctions. Additionally, two of the researchers played the role of vulnerable road users, standing in specific places at specific times so that the pod would either stop for them or swerve around them. At the beginning of the journey and halfway through the 4-minute ride, the pod would stop for approximately 8 seconds as the results of a predetermined event where one of the researchers stood on the path of the vehicle. On the fifth and tenth laps, the vehicle had to swerve around a cyclist standing in the path of the vehicle.

The experiment used a "Wizard of Oz" manipulation (Steinfeld et al., 2009) where the vehicle conveyed the impression that it was capable of recognising the hazards, and presenting these in real-time to the user inside the vehicle. The vehicle was programmed to follow a specific path in the arena, pass by the cardboard cutouts and interact with the researchers. Overlay animations were created to display the recognition of these hazards and present the intended path of the vehicle to be displayed on the screens. In order to ensure the best possible alignment in relation to the real environment, a bespoke piece of software was created to synchronise the animations to waypoints that the pod would cross (x and y coordinates at any given time) within the laps. The software was thus largely "playing back" prerecorded animations synchronised to external events while giving the appearance that this process was occurring in real-time. Although deceptive, this Wizard of Oz technique is frequently used to test computational systems and AVs before the actual technology development (Habibovic et al., 2016; van Veen et al., 2017) especially where the technologies required are challenging or unfinished.

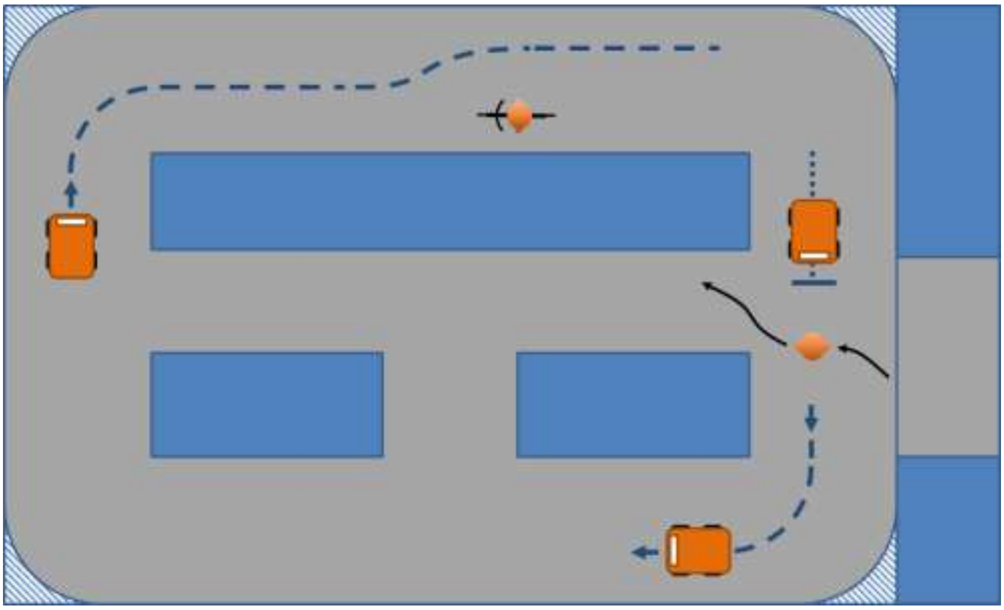

Figure 3 – Interactions with the researchers, i.e. swerving around the cyclist (top event), and braking to a stop to avoid a walking pedestrian (right hand side event).

Interfaces

On each of the pod trips, a different HMI was presented to the participant. The sequence of presentation was counterbalanced to avoid order effects. A baseline interface showed only simple journey information such as the weather, current time, estimated time of arrival and the set destination. The other three of these HMIs presented two main elements of information: system transparency information comprising what pedestrian hazard objects the pod had recognised in its environment; and the pod's intended path of travel in the environment. These two element groups were chosen because (i) the presentation of hazards tends to improve trust (Diels and Thompson, 2018; Rezvani et al., 2016), and (ii) showing the intended driving path and changes of direction improves user experience and minimises motion sickness (Elbanhawi et al., 2015; Lin et al., 2004). Details of these three HMIs are described below.

Baseline:

The Baseline HMI (Figure 4) showed the weather in the pod's current location, the current time, the estimated time of arrival, and the destination. A microphone symbol on the right-hand side indicated that the user can use voice commands to interact with the vehicle. A horizontal grey bar becomes progressively blue (filling left to right) to indicate the progress of the vehicle. When voice instructions were used, the microphone symbol pulsed to indicate it was "listening".

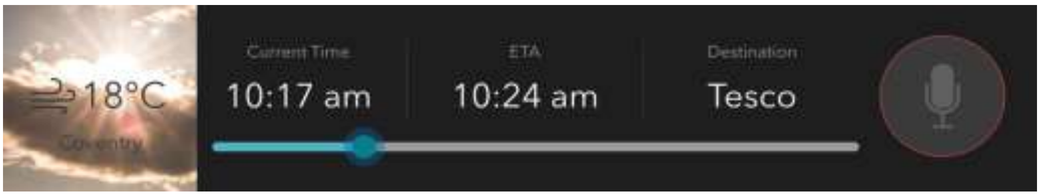

Figure 4 – Baseline interface displayed on a letterbox screen above the windscreen

Third-person Animation:

The Animation showed a bird's-eye or third person view of the pod moving around its environment (Figure 5). Pedestrian hazard objects (here, cardboard cutouts) were symbolised with orange rectangles. A yellow path projected in front of the vehicle shows its intended behaviour. When a hazard object moved into the vehicle's path, the yellow stripe gradually changed its shape to show a swerve or a stop. In the case of the researcher acting as a cyclist on the side of the road, the path rerouted around the hazard. For the pedestrian, the yellow stripe stopped short of the hazard to show where vehicle would come to a halt. The Animation HMI was shown on a 14" screen below the windscreen. The letterbox display above the windscreen contained the information presented in the Baseline condition.

Figure 5 – Animation interface displaying a 3D environment, hazards (orange rectangles) and the intended path (yellow stripe in front of the vehicle)

Camera Feed overlaid with information:

The Camera Feed showed a live Camera Feed from the front of the vehicle overlaid with hazard detection and intended behaviour information (Figure 6). Pedestrian hazard objects were again communicated with orange rectangles. A yellow stripe projected in front of the vehicle showed the vehicle's intended path and behaviour in the same way as the Animation concept. The Camera Feed HMI was also shown on a 14" screen below the windscreen. Above the screen, the Baseline display was still present.

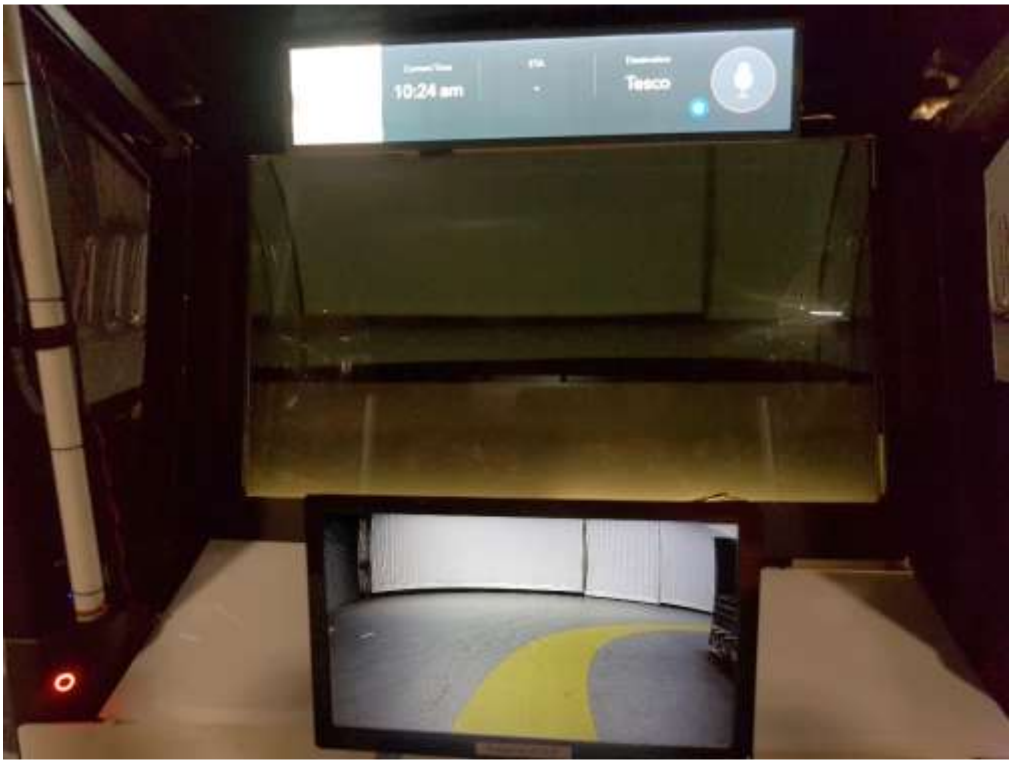

Figure 6 – Camera Feed interface showing live footage of the road ahead and the intended path in yellow. Hazards would also be shown in orange rectangles.

Augmented Reality (AR) windscreen:

The AR Windscreen concept used a 42” transparent LCD with control electronics from Pro Display positioned inside the vehicle in place of the regular windscreen (Figure 7). Hazards were communicated to users with the corresponding areas of the screen being presented with more transparency than the surrounding environment. This gave the effect of highlighting the hazard; this is illustrated in Figure 7, where the lighter-coloured rectangle around the cutout figure indicates that a pedestrian has been detected. A yellow path projected in front of the vehicle showed intended behaviour in the same way as the other two concepts. However, in the AR Windscreen concept, the intended behaviour was overlaid on the actual environment in front of the vehicle via the semi-transparent screen.

Given that the AR Windscreen sits between the observer and the object outside, it was configured so the images were aligned with the view of a person sat at a specific position in the centre of the vehicle. To minimise the known issues of parallax errors, participants were asked not to deviate too much from their initial position inside the vehicle, which was helped by the use of the seat belt. One additional measure was a foam headrest created to help participants keep their heads in the desired position in order for the system transparency information to be presented correctly.

Figure 7 – Augmented reality (AR) heads-up display semi-transparent screen showing hazards in the environment (highlighted rectangle) and the intended path (yellow stripe)

Data collection

Quantitative

Before entering the vehicle, participants completed four questionnaires measuring trust, intention to use the pod, perceived system transparency and perceived technical competence of the pod. After each interaction, participants completed the same four questionnaires, plus measurements of the satisfaction and usefulness of the interfaces. In the sections below, we detail the measurements comprising the quantitative data collection methods used in the study:

System trust

System trust was measured by Jian et al.'s (2000) Trust in Automated Systems scale, a questionnaire which uses twelve 7-point Likert scales ranging from 'not at all' to 'extremely'. Participants rank a series of statements on trust and distrust subscales, for example, "The autonomous pod is reliable" or "I am suspicious of the autonomous pod's intent, action or outputs". This scale was modified slightly so that questions directly referenced the autonomous pod specifically rather than e.g. the screens or displays.

Intention to use

Intention to use was measured via a subcomponent of the Choi and Ji (2015) 'Trust on adopting an autonomous vehicle' questionnaire. It comprises three questions such as "I plan to use the autonomous vehicle in the future". Participants rank their choices on a 7-point scale from 1 (strongly disagree) to 7 (strongly agree).

System transparency

System transparency, another subcomponent of the Choi and Ji (2015) questionnaire, comprised three 7-point scale questions. Those are, for example, "I believe that autonomous vehicle acts consistently and its behaviour can be forecast".

Technical competence

Technical competence was also measured using a subcomponent of the Choi and Ji (2015) questionnaire. Three questions included statements such as "I believe that the autonomous vehicle is free of error".

Usefulness

Usefulness was measured via a subcomponent of the Van der Laan (1997) Advanced Transport Telematics survey. The first five questions assess if the system is useful, good, effective, assisting or raising alertness, therefore encompassing usefulness of a system. It uses semantic differential scale questions, having five pairs of adjectives on a 5-point scale (e.g. useful/useless, effective/worthless).

Satisfaction

Satisfaction with the interface was also measured using the Van der Laan (1997) survey. The final four pairs of adjectives posed to participants measured if the system is pleasant, nice, likeable and desirable, thus assessing the level of satisfaction with a system. It also used a 5-point scale.

Qualitative

Participants were interviewed after experiencing each interface and at the end of the trial, using a post-interaction, semi-structured interview method (Kuniavsky et al., 2012) as shown in Table 1. The interviews were recorded, transcribed and imported into QSR International NVivo software to be coded into nodes, which are the units of information based on participants' statements (Braun and Clarke, 2006). Nodes were then grouped in categories, integrated and correlated to indicate relationships and develop conclusions (Glaser, 1965).

Post-condition questions

After each journey, the experimenter showed participants a printout of the interface they just saw and asked a few questions to understand users' impressions. They were asked what they thought about the information displayed on the interface and the methods of presenting the information, in terms of the vehicle's intended behaviour and the detected hazards. The experimenter also asked what participants liked and disliked about each specific interface they had experienced.

Post-trial questions

After riding the vehicle for the fourth time, and hence having experienced and evaluated all interfaces, participants were asked to rank each of the four HMIs in order of preference. Illustrative printouts of the HMIs were laid on the table and participants ordered them from most to least preferred. Participants were prompted to give their reasons for their choices. Participants were then asked to state which interfaces were better at communicating the vehicle's intentions, and, communicating the vehicle's awareness of hazards and risks ahead.

Table 1 – Questions used during the qualitative post-interaction, semi-structured interview

Phase	Questions
Post-condition *Experimenter shows interface*	What do you think about the information displayed on this interface? • How does it communicate intended behaviour? • How does it communicate hazards? What do you think about this method of presenting the information? • Hardware • System What do you like about this interface? What do you dislike about this interface?
Post-trial *Experimenter shows all interfaces*	Thinking about your experience in the vehicle, could you rank these interfaces, from most preferred to least preferred? • Why did you put this one first? • Why did you put this one last? Thinking about your awareness of the pod's behaviours, which interfaces are better to communicate its intentions, like the next turns? • Why? Thinking about trust in the capabilities of the vehicle to drive safely, which interfaces are better to communicate that the vehicle is aware of the hazards and risks ahead? • Why? Did you perceive any technical problems during this trial? Do you have suggestions or recommendations for the design of these interfaces? Do you have any questions about the study?

Results

Quantitative data

Quantitative data gathered from the questionnaires are shown in Table 3 shows the repeated measures ANOVA and indicates significant effects in all measurements apart from Satisfaction. Table 3 shows that statistically significant differences were found between the Pretrial and the three experimental interfaces (i.e. not the Baseline) for trust, system transparency and technical competence. The only interface to be significantly different from the Baseline was the AR Windscreen. When measuring intention to use, both the AR Windscreen and the Camera Feed have shown to be higher and significantly different from the Baseline. When comparing levels of perceived usefulness, both the Animation and the Camera Feed were significantly more useful than the Baseline condition. The sections below describe the individual measurements and the respective figures in more detail, with mean values and standard errors. The three experimental interfaces scored higher in almost all measurements in comparison with both the Pretrial and Baseline conditions. The only exception is that the Camera Feed scored marginally lower than the Baseline for satisfaction.

Table 2 – Results of repeated measures ANOVA are shown on the first row. The measurement of System Transparency violated the assumption of sphericity, therefore contains Greenhouse-Geisser correction (marked with [1]).

	Trust (Jian et al., 2000)	Intention to use (Choi and Ji, 2015)	System transparency (Choi and Ji, 2015)	Technical competence (Choi and Ji, 2015)	Usefulness (Van Der Laan et al., 1997)	Satisfaction (Van Der Laan et al., 1997)
Repeated measures ANOVA	$F(4, 96) = 3.688$, $p = .008$**	$F(4, 96) = 2.604$, $p = .041$*	$F(3.402, 81.646) = 4.195$, $p = .006$**[1]	$F(4, 96) = 4.32$, $p = .003$**	$F(3, 72) = 3.751$, $p = .0146$*	$F(3, 72) = 0.431$, $p = .7314$

*Table 3 – Paired-samples t-tests showing the pairs of conditions and the resulting t and p (2-tailed), df(24). Usefulness and satisfaction were not measured during the pretrial phase as they require prior interaction. Significant values are highlighted with * (p < .05) or ** (p < .01).*

	Trust (Jian et al., 2000)	Intention to use (Choi and Ji, 2015)	System transparency (Choi and Ji, 2015)	Technical competence (Choi and Ji, 2015)	Usefulness (Van Der Laan et al., 1997)	Satisfaction (Van Der Laan et al., 1997)
Pretrial – Baseline	-0.961, .346	0.514, .612	-1.415, .17	-1.893, .071		
Pretrial – Animation	-2.079, .049*	-0.569, .574	-3.245, .003**	-3.994, .001**		
Pretrial – Camera feed	-2.399, .025*	-1.213, .237	-3.283, .003**	-2.492, .02*		
Pretrial – AR Windscreen	-3.272, .003**	-1.868, .074	-3.766, .001**	-3.149, .004**		
Baseline – Animation	-1.061, .299	-1.346, .191	-1.216, .236	-1.217, .236	-2.996, .006**	-0.985, .335
Baseline – Camera feed	-1.438, .163	-2.074, .049*	-1.346, .191	-0.848, .405	-2.093, .047*	0.043, .966
Baseline – AR Windscreen	-2.572, .017*	-2.855, .009**	-1.569, .13	-1.273, .215	-1.903, .069	-0.451, .656
Animation – Camera feed	-0.799, .432	-1.281, .212	-0.471, .642	0.511, .614	0.637, .53	1.098, .283
Animation – AR Windscreen	-1.437, .164	-1.851, .077	-0.516, .61	0.323, .749	1.749, .093	0.528, .602
Camera feed – AR Windscreen	-0.754, .458	-1.017, .319	0, 1	-0.173, .864	0.810, .426	-0.448, .658

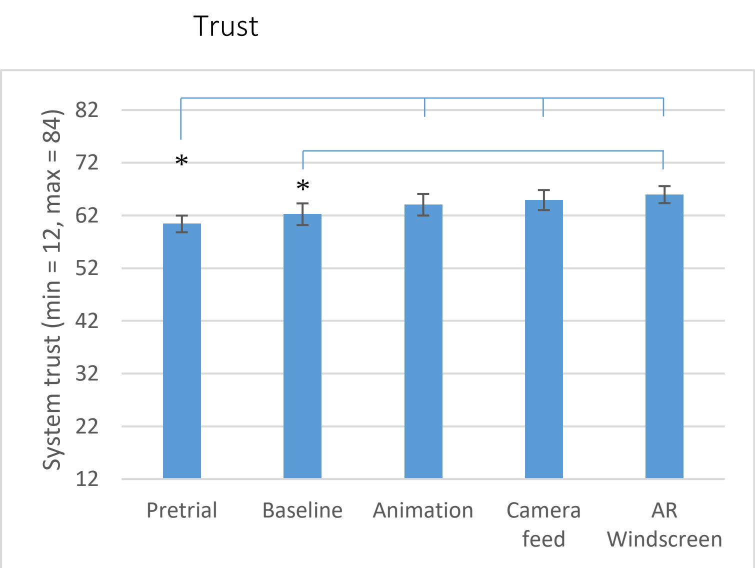

Figure 8 – Trust levels before any interaction (Pretrial) and after the interactions with each of the interfaces, using the trust inventory (Jian et al., 2000). The whiskers represent the standard error, and the min and max values on the y-axis indicate the minimum and maximum scores of the trust inventory (12 questions scored from 1 to 7). The star symbol (*) shows where the results are significantly different (at .05).

Pairwise comparisons revealed statistically significant differences between Pretrial (*M* = 60.4, *SD* = 7.9) and Animation (*M* = 64.04, *SD* = 10.22) *p* = .049, Pretrial and Camera Feed (*M* = 64.92, *SD* = 9.51) *p* = .025, and pretrial and AR Windscreen (*M* = 65.96, *SD* = 8.07) *p* = .003. In all cases, Pretrial scores for Trust in Automated Systems were significantly lower, indicating that trust increased over Pretrial expectations after exposure to the HMI concepts. Pairwise comparisons also revealed a statistically significant difference between Baseline and AR Windscreen, *p* = .017.

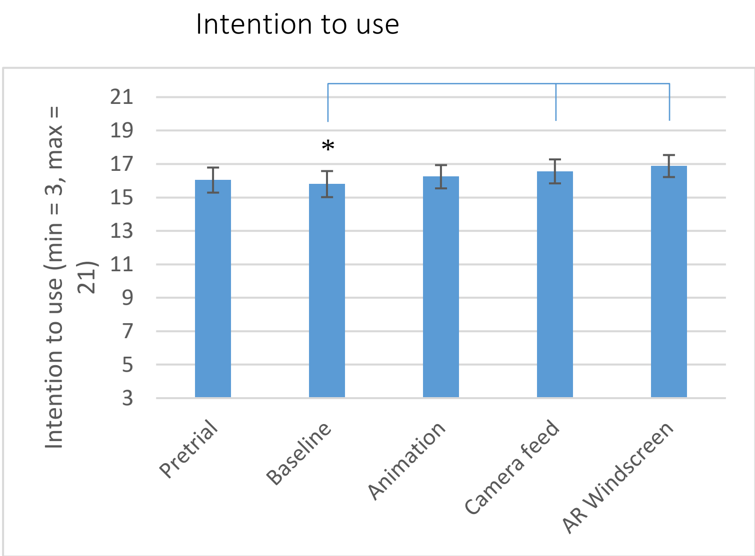

Figure 9 – Intention to use the vehicle before and after the interaction with the interfaces (= significantly different)*

Pairwise comparisons revealed statistically significant differences only between Baseline (*M* = 15.80, *SD* = 8.89) and Camera Feed (*M* = 16.56, *SD* = 3.58) *p* = .049, and Baseline and AR Windscreen (*M* = 18.88, *SD* = 3.3) *p* = .009.

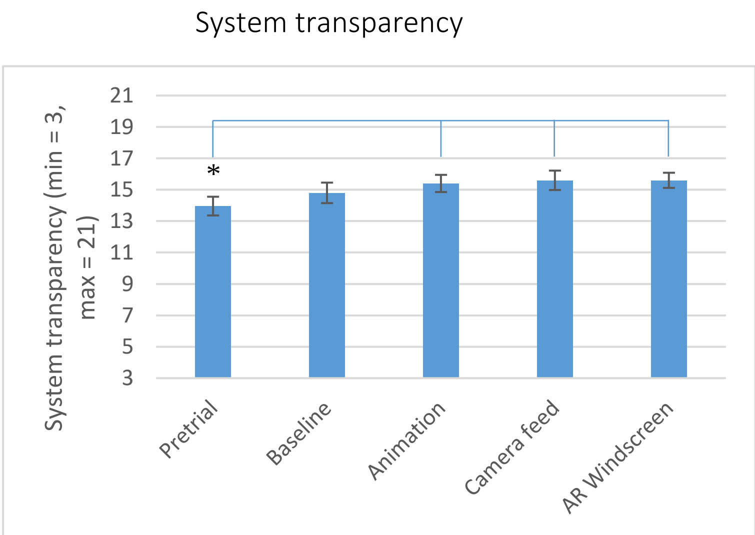

Figure 10 – Perceived system transparency before and after the interaction with the interfaces (= significantly different)*

Pairwise comparisons revealed statistically significant differences between Pretrial (*M* = 13.96, *SD* = 2.89) and Animation (*M* = 14.4, *SD* = 2.74) *p* = .003, Pretrial and Camera Feed (*M* = 15.6, *SD* = 3.1) *p* = .003, and Pretrial and AR Windscreen (*M* = 15.6, *SD* = 2.41) *p* = .001.

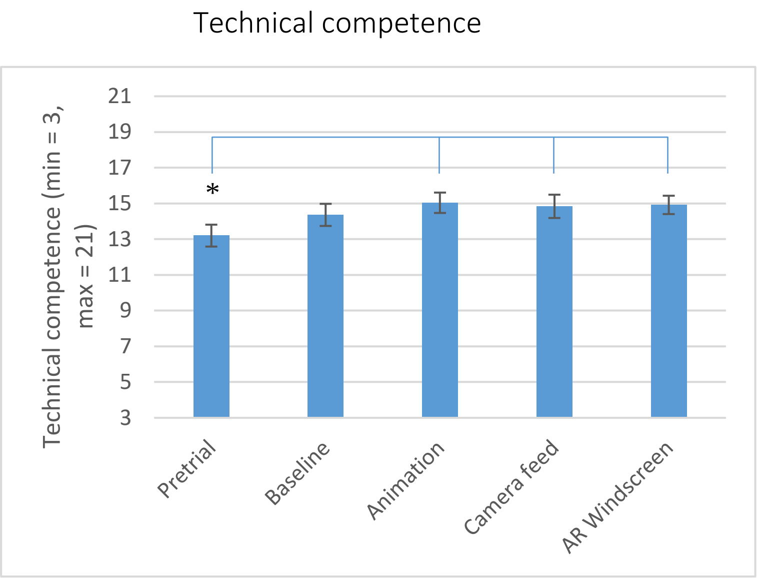

Figure 11 – Perceived technical competence before and after the interaction with the interfaces (= significantly different)*

Pairwise comparisons revealed statistically significant differences between Pretrial (*M* = 13.2, *SD* = 3.07) and Animation (*M* = 15.04, *SD* = 2.85) *p* = .001, Pretrial and Camera Feed (*M* = 14.84, *SD* = 3.26) *p* = .02, Pretrial and AR Windscreen (*M* = 14.92, *SD* = 2.57) *p* = .004.

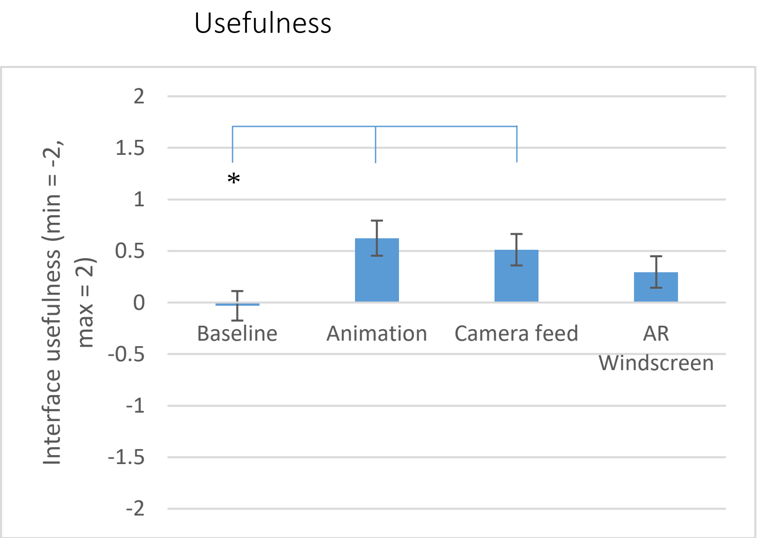

Figure 12 – Usefulness of the three interfaces in comparison with the Baseline condition (= significantly different)*

Pairwise comparisons revealed a statistically significant difference between the Animation concept (*M* = 0.62, *SD* = 0.71) and the Baseline (*M* = -0.03, *SD* = 0.76) *t*(24) = -2.996, *p* = .006, and a between the Camera Feed concept (*M* = 0.52, *SD* = 0.76) and the Baseline *t*(24) = 2.0933, *p* = .047.

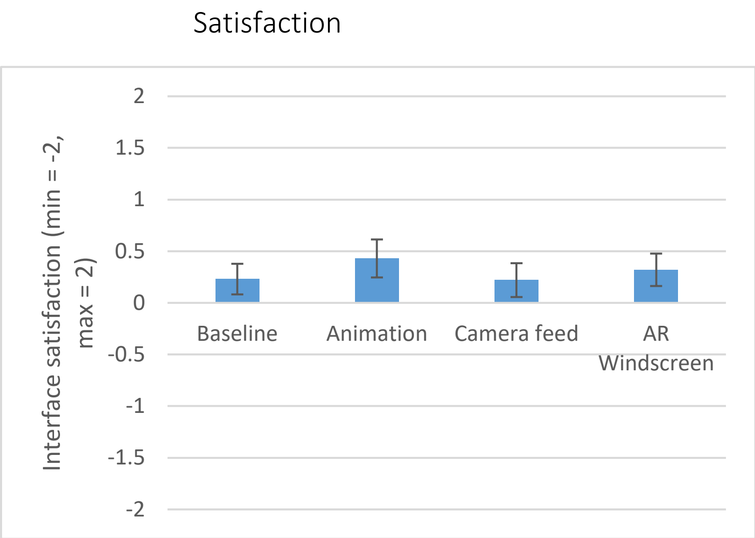

Figure 13 – Satisfaction with the three interfaces in comparison with the Baseline condition

The effect of HMI on rating of interface satisfaction was not statistically significant at the .05 significance level.

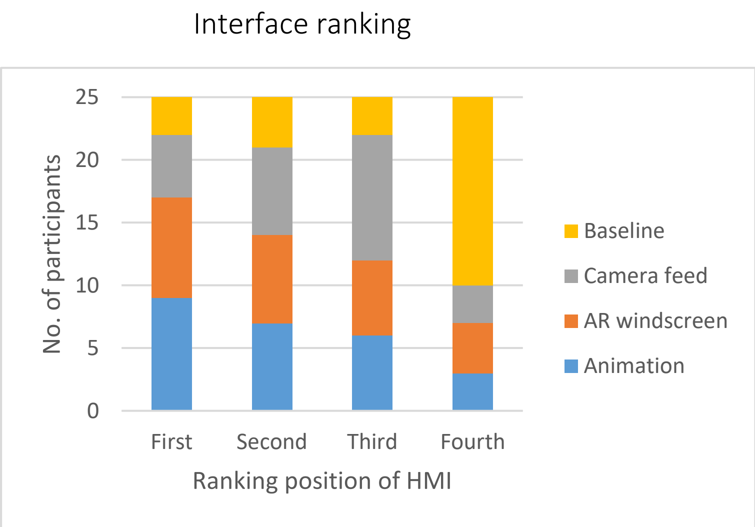

Figure 14 – Order of preference for the three interfaces and Baseline condition

Figure 14 shows that the Animation and AR Windscreens were chosen more often as first and second interfaces in order of preference during the interview process. A chi-square test was performed on the relationship between HMI and ranking of preference, giving $\chi^2(3) = 10.584$, $p < .014$. It indicates that that there was an overall effect of HMI in terms of preference. Post hoc analysis with Wilcoxon signed-rank tests was conducted with a Bonferroni correction applied, resulting in a significance level set at $p < .012$. Median ranking for each interface, from 1 to 4 (first to fourth place) were 2.12 (Animation), 2.24 (AR Windscreen), 2.44 (Camera feed) and 3.20 (Baseline). There was a statistically significant difference in ranking only between the Animation and Baseline ($Z = -2.592$, $p = .010$).

Qualitative data

From the interviews conducted with all participants, we gathered the general comments about the use of system transparency in HAVs as tested during this study. Table 4 presents a summary of the coded data from the interview with the 25 participants. By tagging each statement on the transcripts, we created 141 codes, which are units of information from qualitative data. After being grouped and classified in themes, we present below these themes and respective quantity of mentions gathered from the interviews. Some participants reported the same issue repeated times, therefore the quantity of mentions shown in Table 4 is sometimes larger than the sample size.

Participants acknowledged that the interfaces can be positive as they show hazards, where the vehicle is going, and what is happening ahead and around the vehicle. However, some negative aspects were also mentioned by all participants. For example, ten of them said that occupants of these vehicles may want to sit back and relax, do some work or look outside, which is partially disturbed by the presence of the interfaces. Nine participants said there is no need to flag every potential hazard and that they do not want to follow what the vehicle is doing or will do, especially if they cannot act upon the information received. Participants added the concept that trust develops over time: after a number of interactions and observations of how the pod handled them, they felt no further need to be shown hazards or the path of the vehicle.

Table 4 – Pros and cons of all the system transparency concepts, by quantity of mentions

Overall comments			
Positive	Mentions	Negative	Mentions
It shows hazards	42	I want to sit back and relax, read, work, look outside	12
It shows where it's going	34	It doesn't need to flag everything, only real threats	12
It shows me what is happening	7	Trust comes with time, after a while I don't need to see it anymore	11
		I don't want to second-guess what the system is doing	7
		There is no point in showing me this if I can't control the vehicle	4

We reviewed participants' comments in relation to each of the four interface concepts independently and separated them in terms of negative and positive towards the interfaces, as shown in Table 5.

Animation: The greatest benefit of this concept was found to be its ability to show a bird's-eye view of the environment around and in front of the pod. However, participants commented that they had to look down and then back up to relate to the hazards shown in the screen. They were also glancing at the screen too often, which could cause mild levels of motion sickness in some participants. Those reported having to avoid concentrating on the screen and looking outside instead.

Camera Feed: Whilst some participants liked that the Camera Feed view showed a clear and real image of 'what the pod was seeing', most felt that they looked at it too much. Together with the image distortion caused by the wide-angle camera lens, the interaction with the Camera Feed caused some participants to indicate the potential for motion sickness, similarly to the Animation.

AR Windscreen: Arguably, the main benefit of the AR Windscreen was that users could see the information whilst looking through the windscreen. However, a number of negative points were raised by participants. These mainly involved the technical implementation challenges for this concept, such the image being too dark with poor contrast and hence not highlighting the hazard clearly enough, and that the AR elements were sometimes not aligned with the environment outside.

Table 5 – Negative (left column) and positive (right column) aspects of each interface concept, with the respective quantity of mentions

Animation			
Positive	Mentions	Negative	Mentions
Shows 360 degrees	27	Have to look up to know what it has seen	12
Shows threats early, far ahead	15	Looking too much	12
Clear, good contrast, accurate	10	Motion sickness	6
Gives confidence	6	No realness, like videogame	5
No realness so no need to be perfect	2	Doesn't tell if things are real threats, no depth on hazards, no indication of the type of hazard	5
Similar to familiar satnav	2	Ring, glow around the pod confusing	4
		Costly to implement	4
Camera Feed			
Positive	Mentions	Negative	Mentions
Clear image	12	Looking too much, distracting	21
Realness, the camera shows what is in front	11	Overlay a bit off	13
Gives confidence, trust	4	Motion sickness, image distorted	13
Engaging	2	Narrow angle of vision, only shows things in front of vehicle	7
		Have to look up to know what it had seen	6
		Repetition of what we can see outside	3
AR Windscreen			
Positive	Mentions	Negative	Mentions
See through the windscreen, look outside	21	Image dark, poor contrast, poor highlights, basic	28
No motion sickness	8	When turning, the path goes to the side almost disappearing from the screen	18
Realness, gives confidence	7	Overlay a bit off in relation to hazards	13
Not intrusive, comfortable	2	Path took a large part of the screen, distracting, I was looking too much, I wanted to see through	12
		Narrow angle of vision, doesn't show things outside the screen	9
Baseline			
Positive	Mentions	Negative	Mentions
Useful, enough information	19	Want to see where I'm going or what is happening	15
I want to look outside	10	Doesn't show that it's aware of hazards	14
Relaxing	7	Basic, boring, not much information	10

Discussion

The quantitative data gathered from participants in this study show that, from pre- to post-trials, the level of trust, perceived system transparency and technical competence of the vehicle increased after seeing any of the three experimental conditions: Animation, Camera Feed and AR Windscreen. No significant differences were seen between the Pretrial and the simple Baseline screen in any of the measurements. This result indicates that levels of trust, perceived system transparency and technical competence were increased if the vehicle showed any of the three experimental interfaces tested in this study.

Participant rankings of the screens demonstrated that there was a preference for the system transparency concepts over the Baseline. Explanations for these rankings confirmed that most participants wanted to see upcoming manoeuvres and hazards identified. However, similarly to previous studies (Diels and Thompson, 2018; von Sawitzky et al., 2019), a minority of our participants declared that continuing to present system transparency information is not necessarily a benefit, and may even represent a negative aspect once they have become familiar with HAVs. After the four runs in the vehicle, our participants started to ponder if they would really require the information about hazards and intended path of a vehicle being constantly visible. Interfaces are important aids while users learn how AVs work and behave (Forster et al., 2019; Oliveira et al., 2019b), but may not be needed once they learn to trust the technology.

Interface designers have also to find a fine balance between what to present to increase trust without overloading users, taking in consideration the level of automation of the vehicle. The provision of configurable or adaptive screens can facilitate the adjustment of its contents according to immediate needs (Ulahannan et al., 2020). For high or full autonomy, occupants may not need or want system transparency information at all.

Animation

When measuring the perceived usefulness of the interfaces, the Animation concept had the highest score among the tested interfaces (Figure 12). This may be a reflection of the bird's-eye view from above displaying hazards all around the vehicle. However, in terms of intention to use, scores of the Animation interface were the lowest and not significantly higher than the Baseline (Figure 9). This score may be explained by the need for users to correlate the outdoor environment to the scene they saw on the interface, requiring some learning on the part of the user in order to interpret the icons and objects. Participants complained that the Animation concept was too engaging, and they were looking at it too much, which could explain complaints about the onset of motion sickness. Further discussion about this issue is presented below.

Camera Feed concept

The Camera Feed concept scored significantly higher than the Baseline concept on intention to use and usefulness (Figure 9 and Figure 12 respectively). This can be explained by the fact that it was a clear image showing the actual environment in front of the vehicle. However, the Camera Feed was third in participant rankings, behind both the Animation and AR Windscreen concepts. To some extent, this interface has the same limitation as the Animation since it requires participants to glance between the interface and the actual environment. The highly visual nature of the display with high clarity and sharpness of the images was also a negative point because it brought attention to the screen and participants found themselves staring at it. It could be a reason for some participants' concerns about motion sickness, similarly to the Animation interface. Additionally, the Camera Feed concept was criticised for having a wide angle of vision and therefore deforming the images, if compared to a natural view of the world. Thus, maybe using a different camera with less fisheye-effect would have made a difference here, or that 360 degree views are more suited for shorter, more specific driving scenarios (such as low speed manoeuvring), rather than constant visuals for routine driving.

AR Windscreen

The AR Windscreen stood out in terms of trust as being the interface with the highest score and a significant difference in perceived trust to the Baseline, whereas the other interfaces were not significantly different with respect to trust (Figure 8). This result shows potential for AR technology to increase trust, similarly to suggestions by previous studies (e.g. Bark et al., 2014). Therefore, for the participants of this study, an AR Windscreen performed better to increase trust than using other traditional screens within the vehicle. On the comparison ranking of interfaces, the AR Windscreen was second, closely following the Animation. Participants explained that the semi-transparent screen allowed them to see the outside environment and the information on the screen at the same time.

Nevertheless, the usefulness of the AR Windscreen concept was ranked as not much higher than the Baseline. Most negative comments about the AR Windscreen reflected the fact that it was a prototype interface and suffered from technical limitations such as a dark, poorly contrasted image. These issues reflected the difficult implementation of AR technology, which have been long known to the research community (Tufano, 1997).

Motion sickness

One particularly important result from this study is that participants mentioned the onset of motion sickness, mainly when interacting with the Animation and Camera Feed concepts. None of the participants felt uncomfortable enough to stop the experiment. Nevertheless, some mentioned having to avoid looking at the screens at some point to minimise the negative effects.

This result is rather unexpected given that the content of the interfaces has been suggested to alleviate motion sickness: if interfaces show the intended trajectory and next changes of direction, they can improve the user experience and minimise motion sickness (Elbanhawi et al., 2015; Lin et al., 2004). In addition, motion sickness is more prominent in simulated and immersive environments than in actual AVs (Lackner, 1992; Smyth et al., 2020).

The computer used for processing the images was placed inside the vehicle to minimise communication latency, and all animations were rendered at 30 frames per second, therefore unlikely to be the source of motion sickness. However, our users were focusing on the screens within the vehicle and consequently missing its actual movements, resulting in conflicts between passengers' vestibular motion detection and visual sensory systems (Elbanhawi et al., 2015). We also acknowledge that the content presented on a bright screen within a dark vehicle was probably too engaging and exacerbated the risks of motion sickness. This adverse effect can impair user experience and wellbeing, even though it is not safety-critical in our specific study: occupants of HAVs will not need to regain the control of the driving task, as is the case with semi-automated vehicles. The importance of motion sickness may be aggravated in the future if HAVs are to drive more assertively (Oliveira et al., 2019b).

Limitations and future work

We acknowledge that this research presented a number of limitations which could have had implication for the findings. The various concepts used during this study were created by a multidisciplinary team to provide the platform for answering the research questions. The vehicles, screen hardware and software used during our experiments were all prototypes and run via a Wizard of Oz manipulation rather than real-time, genuine functionality. These design solutions were necessary given the difficulty of implementing some of these technologies (Arnold et al., 2019; Riener et al., 2018).

Another limitation involved the setting for this study. The indoor environment containing controlled safety features could have given a sense of security to our participants. It is known that lab settings may provide different results from the real world (Levitt and List, 2007). However, our results present comparison between the different interfaces and show how they score against each other, without making generalisations about their performance in the real world.

In the specific case of AR Windscreens, there are numerous challenges to be addressed. The precise alignment of objects and image focus for the point of view of one user is problematic (Tufano, 1997), let alone for more than one occupant in HAVs. Additional problems were generated by the current hardware available for creating the effect of AR. The screen is semi-transparent and not as clear as a regular windscreen, making the environment outside dark. Due to the size of the screen, the objects highlighted and path were only on a narrow angle towards the front of the vehicle. However, these issues might just be specific to this implementation, which could be rectified for future uses. One recommendation would be that instead of trying to be more precise with the overlays, the interface could give some margin for errors by reducing its precision. Increasing the size of the highlight boxes would give more leeway for error.

The opportunistic sampling strategy and recruitment process used during this study meant that the demographics of our participants might not represent the general population especially well, nor the target customers for HAVs. We obtained mainly male able-bodied participants working for a car manufacturer, but not necessarily engineers by vocation, or AV early adopters. A more diverse population with a balanced gender and controlled age ratio could be invited to participate in future studies. However, due to the nature of insurance contracts, only employers of the partner car manufacturer could be recruited. We also recognise that this research had a moderate number of participants, despite indications of significant statistical differences being observed.

Future studies could make use of longitudinal methods to evaluate the evolution of user experience and trust and formulate definite recommendations for the design of system transparency interfaces by continuously optimising and integrating successful or preferred features from other concept designs. It is well accepted that users form and modify their judgments about a system over time (Venkatesh et al., 2010), and thus research in human-computer interaction should give more attention to the study of changes over time (Oliveira et al., 2019a; Ulahannan et al., 2020).

The risk of motion sickness should also be evaluated, as it is a strong negative aspect for any interface design. The current study demonstrated the presence of motion sickness because participants were staring at the Animation and Camera Feed interfaces. Future research could analyse in more detail where people's visual attention is (Geitner et al., 2017) and correlate this information with the resulting user discomfort (Smyth et al., 2020) to inform the design interfaces that attract user attention only when required.

Conclusion

Based on the quantitative results of the current trial, a diverse picture emerged. The AR Windscreen interface generated slightly higher trust levels than the other interfaces, and significantly higher compared to baseline. The Animation and Camera Feed were perceived as more useful than the Baseline. On a direct comparison, the Animation and AR Windscreen were chosen as the best interfaces more often than the Camera Feed. All three concepts were seen as delivering system transparency and giving the vehicle the perception of technical competence. However, none of the interfaces was ranked as particularly more satisfying than the others or the baseline.

The results show that, as long as the technical limitations can be overcome in future vehicles, the AR Windscreen is the most promising technology to increase trust in HAVs by effectively relaying system transparency information to occupants. Especially if the AR can be adaptive to user needs and reflect differing levels of information needs over time. However, it may be that by the time reliable object detection is feasible and AR Windscreens are satisfactorily implemented, trust in autonomy may have significantly advanced, making system transparency information obsolete.

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