International Journal of Sustainable Transportation

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/ujst20

Cyclist and pedestrian trust in automated vehicles: An on-road and simulator trial

John Parkin, Fiona Crawford, Jonathan Flower, Chris Alford, Phillip Morgan & Graham Parkhurst

To cite this article: John Parkin, Fiona Crawford, Jonathan Flower, Chris Alford, Phillip Morgan & Graham Parkhurst (2023) Cyclist and pedestrian trust in automated vehicles: An on-road and simulator trial, International Journal of Sustainable Transportation, 17:7, 762-774, DOI: 10.1080/15568318.2022.2093147

To link to this article: https://doi.org/10.1080/15568318.2022.2093147

INTERNATIONAL JOURNAL OF SUSTAINABLE TRANSPORTATION
2023, VOL. 17, NO. 7, 762–774
https://doi.org/10.1080/15568318.2022.2093147

Cyclist and pedestrian trust in automated vehicles: An on-road and simulator trial

John Parkin[a], Fiona Crawford[a], Jonathan Flower[a], Chris Alford[b], Phillip Morgan[c], and Graham Parkhurst[a]

[a]Centre for Transport and Society, University of the West of England, Bristol, UK; [b]Health and Social Sciences, University of the West of England, Bristol, UK; [c]Human Factors Excellence (HuFEx), Cardiff University, Cardiff, UK

ABSTRACT

Automated vehicles (AVs) need to be trusted by cyclists and pedestrians where they will share the road. To test trust, cyclists and pedestrians, and a comparison cohort of drivers, observed trials of both a road and simulator AV undertaking three common priority-based maneuvers: a right turn into a side road, overtaking a parked car, and passing over a pedestrian priority (zebra) crossing. The AV made the maneuvers either giving way, or not giving way, to a pedestrian or cyclist. One hundred and thirty-four participants aged 18 to 79 years were recruited based on being predominantly either a pedestrian, cyclist, or driver in their regular road use. For the on-road trials, the cyclist and pedestrian participants observed the AV maneuvers from the adjacent footway, and the driver participants observed from inside the AV. In the simulation environment, all participants were inside the automated vehicle. Trust scores were higher when participants observed a maneuver where the AV had to give way to a cyclist, and this can be linked with the re-assurance provided by the behavior of the AV in such an encounter. There was no significant difference in trust by road user type (cyclist, pedestrian or driver), age or driving experience, suggesting messaging to road users about the impacts of automated vehicles need not be differentiated by road user type. There was some evidence of differences in trust, especially for more complex maneuvers, between the on-road trial and the simulator, suggesting a need for caution in reliance on simulation-only experiments.

ARTICLE HISTORY
Received 30 April 2021
Revised 19 June 2022
Accepted 20 June 2022

KEYWORDS
Automated vehicle; bicyclist; pedestrian; simulator; trust

Introduction

The need to understand pedestrian and cyclist trust

The design and development of automated vehicles (AVs) has accelerated, particularly over the past 10 years or so, and we are in a decade where their deployment in some countries has begun, at least on a small-scale. Despite research relating to user acceptance, experience, and other human factors (including trust), there has been little research on other road users who need to co-habit with AVs. These road users include pedestrians and cyclists, who may have different levels of trust because they are the ones most at risk from threats caused by motor traffic (WHO, 2018; Pammer et al., 2021), and understanding AVs from their perspective is important.

This research investigates how cyclists and pedestrians trust AVs in common priority-based road maneuvers including:

- a turn into a side road;
- overtaking a parked car; and
- passing over a pedestrian priority crossing.

We also explore whether trust differs depending on whether the AV did or did not give way to the other road users. The public highway is a drive on sight system. The most complex issues for road users, and AVs within the highway, is dealing with priority situations. The rules of the road define priority, but the road users have to make complex judgements about their own speed, the speed of others, distances, and times it will take to make maneuvers. These priority situations are more challenging to deal with than the more straightforward situations where control is imposed (for example, with signal control).

Despite the possible emergence onto streets of AVs, walking and cycling have significant benefits, and therefore will continue to exist as modes (Nisenson, 2017). Medina-Tapia and Robusté (2019) modeled cities assuming the implementation of AVs and concluded that cities would still need to promote walking and cycling because of their benefits.

Safety contributes to trust, and Hakimi et al. (2018) identified seven trust related attributes of AVs from the literature as follows: safety of humans; cyber security; data privacy; reliability; operational performance; satisfaction and

CONTACT John Parkin john.parkin@uwe.ac.uk Centre for Transport and Society, University of the West of England, Frenchay Campus, Coldharbour Lane, Bristol, BS16 1QY, UK.

Supplemental data for this article can be accessed online at https://doi.org/10.1080/15568318.2022.2093147.
This article has been republished with minor changes. These changes do not impact the academic content of the article.

experience and economic value. Henschke (2020) abstracts instrumental notions of trust to the level of 'public' trust in the whole socio-technical system. He argues that an understanding of the nature and level of trust in automated vehicles is required, because this will determine the nature of their design and regulation. The establishment of trust in a new system, and also what happens when there is a loss of trust, is important for the success of a system (see Schaefer et al., 2016 for a review). Trust is also a fundamental aspect impacting public acceptance and uptake of automated vehicles, whether as a passenger on a public service vehicle, or a purchaser and users of a private vehicle, or a road user such as a cyclist or pedestrian. Lastly, the attribution of trust to an AV is also dependent on situational and psychological variables, including mood, expectations and beliefs, social norms, physical comfort and personal disposition (Paddeu et al., 2020).

Questionnaire and photo- or video-elicitation studies

Many studies have adopted only questionnaire-based methodologies to assess trust in AVs as a general concept (Rödel et al., 2014; Kyriakidis et al., 2015; Abraham et al., 2017), or specifically in relation to being a road user who is made to feel vulnerable by the road environment (Pammer et al., 2021). Using a qualitative approach and a questionnaire, Nordhoff et al. (2020) explored safety perceptions of AV shuttle passengers. They also explored passengers' perceptions of the AV's safety performance in relation to pedestrians and cyclists, but the respondents' situation was one step removed from being these other road users. Also in shuttles, Paddeu et al. (2020) found higher trust at the slower of two speeds and when facing forwards rather than backwards. Other studies are one further step removed from the user and seek expert opinion; for example, on externally mounted 'human-machine interfaces' (eHMIs) (Tabone et al., 2021).

Hagenzieker et al. (2020) used responses to photographs taken from the perspective of a bicycle and asked cyclists how sure they were that they would be detected by an AV compared with manually driven cars in five conflicting maneuvers at priority (i.e. give way or yield) junctions. The authors describe the participants as having cautious dispositions toward AVs because the respondents did not think they would be detected and responded to by AVs any better than by human drivers. In related work, Vlakveld et al. (2020) used video of imminent collisions between AVs and cycles to elicit views from cyclists about their intentions and how confident they would be. This was followed by a questionnaire about trust in technology and automated vehicles. Compared with a manually driven car, they found that participants said they would yield more often when the approaching car was an automated car, but they would yield less often when the AV communicated its intention.

Simulator studies

Simulator studies (Körber et al., 2018) and on-the-road studies (Endsley, 2017) have explored driver trust in level 3 autonomy (Society of Automotive Engineers, 2018), but frequently excluding pedestrians and cyclists (Abe et al., 2016). Gold et al. (2015) and, as part of the same stream of research as we report here, Morgan et al. (2017) were concerned with drivers who were being handed back control. In a simulator, Rad et al. (2020) found pedestrians who had higher trust in AVs were more willing to cross a road before an approaching AV had stopped completely. There was no difference by gender and an enhanced effect for younger people (but the sample was predominantly younger men). People who showed rule-abiding behavior were also more likely to cede priority to the approaching AV.

The nature of interaction and communication

Interactions in the urban environment between AVs and cyclists and pedestrians were considered by Parkin et al. (2018). They identified twenty-five questions of research interest in the following areas: other road users' perceptions about the quality of the detection and decision making of AVs; changes in perceptions of risk within motor traffic as a result of AVs; the responses of pedestrians and cyclists in terms of attention allocation and intention; how signaling between users may need to develop; the mediating influences of infrastructure layout and road user regulation. They noted however, that the true extent of many responses and adaptations in behavior to AVs may become clear only with a high proportion of AVs in the motor traffic mix.

In terms of detection and decision making, correctly identifying cyclists and pedestrians is a challenging task for AVs (Mannion, 2019). Fairley (2017) suggests that AVs have a particular problem in accurately understanding the orientation of cyclists. Riaz and Niazi (2017) and Riaz et al. (2018) identify the importance of predicting intentions and imitating behaviors. Saleh et al. (2017) note that the understanding of intent of automated vehicles is critical for trusted encounters, i.e. an 'interaction concept' is required (Schneemann & Gohl, 2016).

Rasouli and Tsotsos (2018) suggest that intent can only be deduced from effective communication. Focusing on communications strategies, Stanciu et al. (2018) found from a literature review that there are a number of non-verbal techniques employed by drivers, pedestrians, and cyclists ranging from 'formal' use of technology (such as turn signal equipment – e.g., indicators) to 'informal' gestures and eye contact (e.g., waving to a pedestrian to cross the road). In the context of shared space, Merat et al. (2018) report responses to a questionnaire from people observing a demonstration of Level 4 autonomous operation (Society of Automotive Engineers, 2018 – i.e., AVs that can drive autonomously in most but not all settings). They found that knowledge that the vehicle had detected other road users was important, with lights and audible beeps being preferred as signals to text or spoken messages.

A number of researchers have tested communications features in simulation: a walking silhouette, 'braking' in text, and verbal messages (Deb et al., 2017); visual, auditory and haptic devices (Mahadevan et al., 2018, Mahadevan et al., 2019); and externally mounted eHMI devices (Nuñez

Velasco et al., 2019). In the context specifically of crossing a carriageway, AlAdawy et al. (2019) show that in 90% of the cases they tested, pedestrians cannot determine the gaze of the driver. They conclude pedestrians take crossing decisions based solely on the kinematics of the vehicle, and hence communication may not be quite as significant an issue as presumed.

Pedestrians may assume that an AV will always 'give way' and this can lead to decreased crossing gap acceptance or the 'freezing robot' problem when an AV cannot progress (Fox et al., 2018; Palmeiro et al., 2018). Hence, there are practical operational reasons for understanding interactions, as well as safety reasons.

The context of use: infrastructure

Blau et al. (2018) used a stated-preference survey to understand cyclists' preferences for infrastructure facility type in the presence of automated vehicles and found that a known preference for separated facilities is magnified when the motor vehicle is automated. In their questionnaire survey, Merat et al. (2018) found that most pedestrians felt safer when automated vehicles were in designated lanes rather than in shared space, and the majority assumed they had priority over the AV in shared space. Extending this work, Madigan et al. (2019) used video analysis to understand interactions patterns between AVs and pedestrians and cyclists in order to help develop communication and infrastructure recommendations. When available, pedestrians and cyclists left as much space as possible between their trajectories and the AV's presumed trajectory, perhaps suggesting some level of concern.

Grembek et al. (2018) noted the complexity of junction interactions and suggested that collisions result from an information deficiency. They therefore developed a proposal for an 'intelligent' intersection to improve the passage of cyclists and pedestrians. Camara et al. (2018) studied pedestrians crossing the road at both marked and unmarked crossings to predict pedestrian 'assertiveness' and found that speed, observations by the pedestrian, and pedestrian head-turning were factors in identifying whether the pedestrian or the vehicle would proceed first.

The current study: aim and research questions

In summary, much of the research to date has focused on pedestrians at crossings or in shared space, and despite the extensive considerations given to communications, the review by Ezzati Amini et al. (2021) points to the wide range of factors that influence the decision making of pedestrians in their interactions with AVs. The effect on trust of whether AVs give way or not requires more investigation from the perspective of road users outside of the AV.

There is little research considering interactions between AVs and cyclists and pedestrians in complex on-carriageway situations common in the real-world. These include priority junctions and parked vehicles. These are challenging situations for an AV to negotiate, and they are different and more complex than simpler crossing situations (especially when those crossings are under signal control). In the context of junctions, the maneuver requires the AV to turn from one route to another, while at the same time ceding priority to other road users as required. Overtaking a parked vehicle requires use of the opposite lane, which may be occupied by another approaching vehicle, for example a cycle. This requires complex data and calculation not only of the AVs own trajectory, but also the anticipated trajectory of the on-coming vehicle. It is these complex, but everyday urban situations, which this research addresses.

Research to understand pedestrians' and cyclists' responses to date has used either questionnaires, simulation only, or photo-elicitation. There is a gap to extend the research to include understanding of trust in the real world and, by comparison, in simulation for pedestrian and cyclist encounters with the AVs.

The work presented in this paper builds on previous work in the same research project on AV hand-back of control to a driver (Morgan et al., 2017), and encounters between manually driven motor vehicles and AVs in on-road trials and a simulated environment (Morgan et al., 2018).

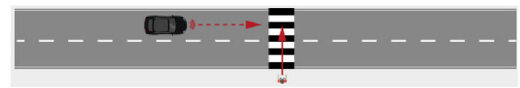
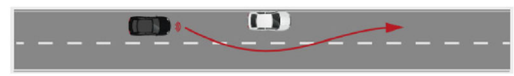
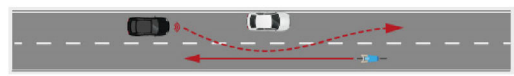
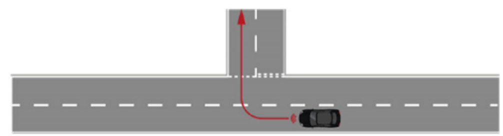
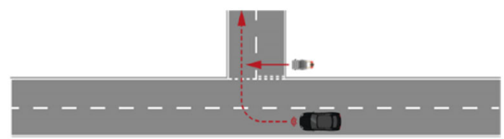
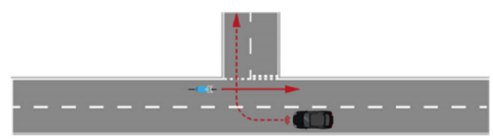
The research presented in this paper therefore extends current understanding of trust in automated vehicles by evaluating pedestrians' and cyclists' trust in AVs in comparison to drivers' trust in situations involving pedestrians and cyclists. It is also rare in doing so in both simulated and real-world environments with a high degree of comparability. The research questions are as follows:

1. How does road user trust in an AV vary depending on the maneuver being undertaken, and whether or not the AV needs to give way to pedestrians and cyclists?
2. How does trust in an AV vary depending on road user type and experience (pedestrians and cyclists compared with drivers)?
3. How does trust in an AV vary depending on whether the platform is a road vehicle or a simulator?

Our main hypothesis was that trust in the AV will be higher for maneuvers involving pedestrians or cyclists because participants would perceive and process how the AV behaves in those encounters and be assured. We anticipated differences in trust scores amongst the range of participant types and experience, and this is because they predominantly use different parts of the highway, with pedestrians being on the footway and drivers and cyclists using the carriageway, and are at generally greater risk within the highway. We hypothesize that trust will be higher in the simulator because it is a fixed platform and does not include exposure to real-world vehicle movement with its inherent risks.

The rest of the paper is organized as follows. Section 2 describes the methodology. Section 3 provides the results, which are discussed in Section 4. Section 5 provides concluding remarks.

Table 1. Description of the seven events.

Location of event	Encounter type	Type of event	Depiction
Priority (zebra) crossing	None	1) Passing over a pedestrian priority (zebra) crossing	
	Pedestrian	2) Stopping for a pedestrian at a zebra crossing	
Parked car	None	3) Overtaking a parked car	
	Cyclist	4) Giving way (yielding) to an oncoming cyclist before overtaking a parked car	
Side road junction	None	5) Turning right into a side road	
	Pedestrian	6) Giving way (yielding) to a crossing pedestrian before turning right into a side road	
	Cyclist	7) Giving way (yielding) to an on-coming cyclist before turning right into a side road	

Note: On-road the pedestrian pushed a buggy and the cyclists towed a trailer, but this was not the case in simulation.

Materials and methods

Participants

One hundred and thirty-four participants took part, with an age range of 18 to 79 years (M 50.4; SD 15.9). Forty-eight people (35.8%) were female. Two did not hold a driving license (required for driver participants, but not for others). Driving experience, for those who had it, ranged from 10 months to 59 years (M 31.2; SD 15.9). Twenty-four participants (18%) were classified as older adults (65 or more years).

Participants were recruited specifically on the criterion of either being self-declared predominantly drivers, cyclists or pedestrians. Most of the population will drive, walk, and cycle at some point. Our strategy was to recruit from this large population pool rather than the more exceptional pool of people who might strictly only ever use one means of traveling. Participants were asked to consider the trials from the point of view of their predominant method of road use.

Experimental design

Participants observed trials in simulation and on University of the West of England, Bristol campus roads of three common maneuvers: a right turn into a side road, overtaking a parked car, and passing over a pedestrian priority (zebra) crossing. The participants who were drivers observed interactions from the vehicle. The participants who were pedestrians and cyclists observed the interactions from a vantage point near the road where they could clearly see the AV and the relevant people acting as the pedestrian and cyclist undertaking the maneuvers. In the simulation, the participants observed from within the vehicle. To help maintain their role, the cyclist participants pushed their cycle from vantage point to vantage point and wore any cycling clothing or protective gear they had arrived in. In addition, a cycle was 'transported' on a rack on the back of the vehicle in the simulator to help maintain the cyclist in that viewpoint. The maneuvers of the AV took place with and without the need to give way to the actor pedestrian or actor cyclist, and created seven types of event, as summarized in Table 1. We define an **event** is an automated vehicle **maneuver** at one of three **locations**, and that **maneuver** occurs either with or without an **encounter** with a pedestrian or cyclist. Each event is replicated on-road and in simulation.

A repeated measures design was utilized, albeit with the participants who were predominantly drivers making observations from within the road vehicle, while pedestrians and cyclists were outside the road vehicle. The experiment consisted of a circuit containing the seven events in Table 1, completed three times on-road and twice in the simulator. Participants therefore observed twenty-one (7 by 3) events in total in the on-road trials and fourteen (7 by 2) in the simulator. The study had three independent variables (IVs):

Figure 1. Images of an encounter in the on-road trial and in the simulator.

i) the platform, with two levels, on-road and Simulator; ii) the road user role, with three levels: driver, cyclist or pedestrian; iii) the type of event, with seven levels (see Table 1).

The left-hand image in Figure 1 shows the AV in the real-world waiting for the actor cyclist to pass before overtaking a parked vehicle. The right-hand image in Figure 1 shows the avatar pedestrian in the simulator crossing the mouth of the side road. The avatar is walking away from the AV which is waiting to turn right into the side-road.

A partial counterbalancing method was employed to control for the order of the platforms, and this was to allow for comparisons of possible transfer or carryover effects between platforms (e.g., participant 1 performed the AV first then Simulator second, participant 2 performed the Simulator first and then the AV second). Participants were randomly allocated to groups, although each trial was observed by one driver, one cyclist and one pedestrian participant. The order in which participants observed the events was the same, and this was constrained by the layout of the campus roads. The order was (see Table 1 for numbers): (1) passing over a pedestrian priority (zebra) crossing, (5) turning right into side road, (6) giving way to a crossing pedestrian before turning right into a side road, (7) giving way to an oncoming cyclist before turning right into a side road, (4) yielding to an oncoming cyclist before overtaking a parked car, (3) overtaking a parked car, (2) stopping for a pedestrian at a zebra crossing. This order was replicated in the simulator.

Measures

The Dependent Variable (DV) is the trust rating which was collected directly after each event that was observed. Twenty-one trust ratings (seven events times three runs) were obtained from the on-road trials and fourteen (seven events times two runs) from the simulator trials, with the two-run simulator restriction used to limit the development of simulator sickness. The ratings used an 11-point Likert scale (0 = no trust ranging to 10 = complete trust) based on the following questions:

> "You have just … .

1. Crossed an empty pedestrian crossing, (Table 1, event 1)
2. Turned right into an empty side road, (Table 1, event 5)
3. Turned right into a side road with a pedestrian crossing the junction, (Table 1, event 6)
4. Turned right into a side road with an on-coming cyclist, (Table 1, event 7)
5. Overtaken a parked car with an on-coming cyclist, (Table 1, event 4)
6. Overtaken a parked car with no on-coming traffic, (Table 1, event 3)
7. Crossed a pedestrian crossing with a pedestrian crossing, (Table 1, event 2)

> … . on a scale of 0-10, where 0 is 'no trust' and 10 is 'complete trust', rate how much you trusted the AV during the manoeuvre (sic)."

The framing of these questions is appropriate for the driver in the AV in the real world, and the driver, pedestrian and cyclist in the simulator. For the pedestrian and cyclist when they were observing the maneuvers in the 'real world' from outside the vehicle, the question was adapted to: "The AV has just crossed an empty pedestrian crossing … ", and so on and so forth. The supplementary material provides the four logging sheets for the simulator and the real world, and for the drivers and pedestrians/cyclists respectively.

Participants recorded feelings of nausea in the Simulator (Reinhard et al., 2017). They were also asked to reflect on their experience and provide responses to a short qualitative questionnaire. An online (Qualtrics®) driver experience survey (time since holding a full driving license, miles driven annually, miles driven monthly, and driving frequency per week) and Trust in Automation Checklist (Jian et al., 2000) were self-administered.

Apparatus

The platforms were an adapted BAE Systems Land Rover Bowler 'Wildcat' automated vehicle (the 'AV'), and a Williams F1 Advanced Engineering modified Land Rover Evoque Sport fixed-base Simulator developed by BAE Systems with significant iηut from Bristol Robotics Laboratory as part of the project. The systems operated at the Society of Automotive Engineers (2018) Level 3. The vehicle can sustain the automated driving system (ADS) for the entire dynamic driving task (DDT) with the expectation that a DDT fall-back-ready user is receptive to ADS-issued requests to intervene, but intervention was not needed in

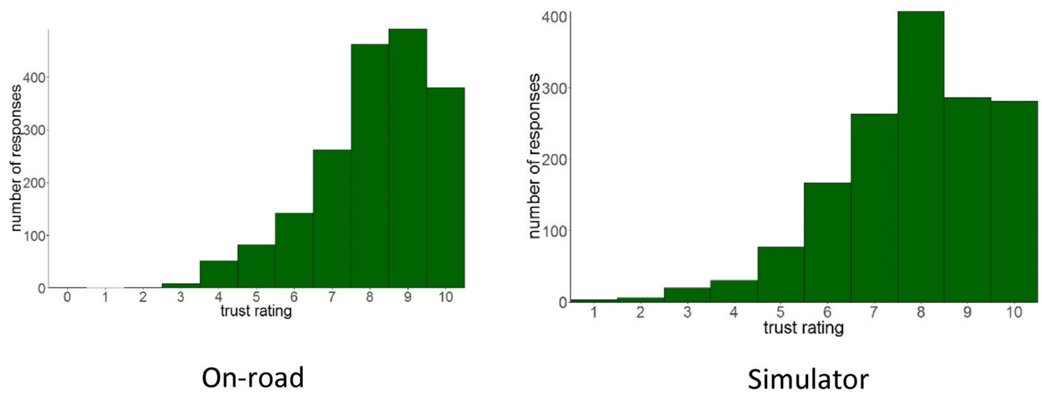


Figure 2. Frequency distribution of trust ratings on the road (n = 95) and in the simulator (n = 110).
Key: *0 is 'no trust' and 10 is 'complete trust'.*

this experiment. The vehicle detects and responds to the presence of other road users, but other than flashing yellow light indicators for turning movements, did not otherwise communicate with other road users.

The on-road trials were conducted on University of the West of England, Bristol campus roads which were temporarily closed to the public. The campus roads had adjacent footways and the cyclist rode within the carriageway. An experimenter acted as the cyclist and rode a Specialized Crosstrail bicycle towing a child trailer (dummy) on-road. The study team member acting as a pedestrian pushed a pushchair containing a young child (dummy) on-road. In the Simulator, the cyclist and pedestrian taking part in the encounters were represented by avatars.

The Simulator was programmed to generate the images and mimic the Wildcat scenarios using SCANeR II® software (OKTAL Sydac, France, Simulation in Motion). The set-up included three large projector screens to provide 180° front and side views, and side-mirrors with back left and right screens projected, and a windscreen mounted rearview mirror with the rear view projected via a large monitor. The simulator was controlled by five Hewlett Packard 8 Core 3.70 GHz Intel Xeon v3 PCs. It used the same autonomous decision management system as the Wildcat, run on a separate PC of the same specification. The experimenter control station had five 21" Iiyama Prolite E2480HS monitors.

Procedure

A researcher accompanied the cyclist (pushing their cycles) and pedestrian participants on a pre-specified walking route which allowed observation of all events from adjacent footways. The AV moved continuously, and the time for the participants to move to the next vantage point was less than the time it took the AV to travel there. The participants attending in their capacity as a driver sat in the front right-hand seat of the AV, which was a left-hand drive vehicle with a safety driver, able to retake control if required. The safety driver was required as part of the risk assessment. The presence of the safety driver was not emphasized to the participants and they performed an operational and facilitative role with the participants, for example in relation to seat belts, and explaining what do if the participant wanted the trial to stop.

To obtain the full effect of the simulator experience, all participants sat in the simulator vehicle in sets of three, taking specific seats according to role. Driver participants sat in the 'driver's' seat within the right-hand drive cabin layout of the simulator; cyclist participants sat in the front left-hand seat, with therefore a view of the carriageway more similar to riding a cycle than would be the case in a rear seat; the pedestrian sat in the rear left-hand side seat. The researchers helped reduce the impact of potential nausea by limiting the simulated journey to two runs, offering water to drink, amending fan settings, opening the car doors between trials.

Analysis

Statistical analyses were undertaken using IBM SPSS Version 25 (IBM SPSS Statistics 2019 Armonk, NY, USA). Paired samples t-tests were used to compare the trust scores at the zebra crossing (presence versus absence of a pedestrian) and the parked car (presence versus absence of cyclist), and repeated measures analysis of variance (ANOVA) was used for the side road junction (cyclist present, pedestrian present, no other road user present). Two-factor mixed-design ANOVA was used for comparisons by participant role and between platforms. Effect sizes for paired comparisons are presented as Cohen's d and calculations and their interpretation were based on Lenhard and Lenhard (2016).

Results

Overview

The analysis presented includes data from all participants who completed at least two full circuits of the trial (n = 95 for the AV and n = 110 for the simulator, and with 76 participants completing both AV and simulator runs). Non-completions resulted from weather issues, participant availability, and technical issues – quite typical of AV studies involving road trials. Figure 2 shows the frequency distribution of trust ratings for data pooled across all events, for all

Table 2. Summary of mean trust ratings (scale 0–10; n = number of respondents).

Location of event	Encounter type	All respondents Mean	All respondents St. Dev.	Cyclists Mean	Cyclists St. Dev.	Pedestrians Mean	Pedestrians St. Dev.	Drivers Mean	Drivers St. Dev.
On-road		n = 95		n = 33		n = 27		n = 35	
Zebra crossing	No other road user	8.4	1.35	8.2	1.12	8.5	1.62	8.6	1.33
	Pedestrian	8.1	1.52	8.2	1.35	8.2	1.40	7.9	1.76
Parked car	No other road user	7.7	1.52	7.5	1.52	7.6	1.38	8.0	1.61
	Cyclist	8.2	1.40	8.1	1.47	8.2	1.34	8.3	1.42
Junction	No other road users	8.1	1.31	8.0	1.18	8.2	1.41	8.1	1.38
	Pedestrian	8.0	1.42	7.7	1.42	8.3	1.44	8.0	1.40
	Cyclist	8.2	1.32	8.2	1.17	8.2	1.42	8.3	1.39
Simulator		**n = 110**		**n = 37**		**n = 32**		**n = 41**	
Zebra crossing	No other road user	7.3	1.84	6.9	2.06	7.7	1.75	7.4	1.66
	Pedestrian	8.1	1.43	7.8	1.47	8.3	1.27	8.2	1.52
Parked car	No other road user	7.9	1.51	7.6	1.35	8.0	1.34	8.0	1.75
	Cyclist	7.8	1.54	7.7	1.36	8.2	1.34	7.7	1.82
Junction	No other road user	7.8	1.64	7.5	1.47	8.0	1.60	7.8	1.81
	Pedestrian	7.9	1.47	7.5	1.52	8.1	1.37	8.0	1.48
	Cyclist	8.1	1.38	7.8	1.34	8.3	1.22	8.2	1.50

Note: Cyclists and pedestrians observed in the on-road situation from outside the automated vehicle, and in the simulator, from inside the simulation vehicle.

circuits, and for all participants who completed two or more circuits for each platform.

There are no significant correlations between trust scores and age, the time period a driving license has been held, or the number of miles driven per year. The only significant difference by gender in the on-road trial was the trust score for stopping for a pedestrian at a zebra crossing. By contrast all but two of the simulator events (overtaking a parked car, and stopping for a pedestrian at a zebra crossing) were significant. In every case the effect size was small, and we conclude there are no major differences in perceptions of trust between men and women.

Three on-road trials were affected by technical difficulties, but removal of the data did not change the mean score across all events, and were therefore not removed. In the Simulator trials, the pedestrian avatar behaved erratically on four occasions and these events were removed from the analysis. Table 2 presents the mean trust ratings for each event. Two-tailed p-values were considered significant if $p < 0.05$.

Aggregating for all respondents, the lowest mean trust rating in the on-road trials was for overtaking a parked car (7.7) and the highest was for crossing a zebra crossing with no pedestrian on the zebra crossing (8.4). In the Simulator, crossing a zebra crossing without a pedestrian on the crossing was given the lowest trust ratings on average (7.3). Participants were always presented with this event first, and it was shortly after the start of the simulation. Researchers' observations of participants in the simulator suggest that respondents were slightly taken aback by the initial acceleration and associated noise with setting off from stationary in automated mode. A paired t-test showed a statistically significant increase in participants' trust scores for this event in their second simulator trial compared to their first simulator trial ($t(109) = 4.79$, $p < 0.001$), although this event still received the lowest score per event, on average, when considering all participants' second simulator run data combined.

We now present analyses of differences in trust scores in the following order: by encounter type (Table 3, Research Question 1); by participant role (Table 4, Research Question 2); by platform and encounter types (Table 5 and 6, Research Question 3).

Effect of maneuver type and presence of other road users on trust score

Table 3 presents results of the tests of difference in trust scores by platform (on-road versus simulator), location (zebra crossing, parked car and side road junction) and encounter type (presence or absence of pedestrians and cyclists). The baseline is taken as being no encounter with a pedestrian or cyclist; hence a positive difference indicates a lower trust score with an encounter.

For the zebra, the on-road results show a statistically significant reduction in trust score with the presence of a pedestrian ($t(94) = -2.51$, $p = 0.01$, $d = 0.26$). The statistically significant difference in the Simulator between presence and absence of the crossing pedestrian ($t(109) = 6.03$, $p < 0.001$, $d = 0.58$) is likely to be due to the trial start effect described above.

For the overtake of a parked car, the on-road results show a statistically significant increase in trust score with the presence of a cyclist ($t(94) = 4.52$, $p < 0.001$, $d = 0.46$). This significant difference is not replicated in the simulator ($t(109) = -0.29$, $p = 0.77$, $d = -0.03$).

For the right turn into the side road, there is no statistically significant difference in trust ratings depending on whether no other road user was present, or a pedestrian or cyclist was present ($F(1.8, 171.5) = 2.80$, $p = 0.07$). The repeated measures ANOVA for the on-road data required a Greenhouse-Geisser adjustment due to the violation of the sphericity assumption. However, there was a statistically significant difference in simulation ($F(2, 218) = 10.41$, $p < 0.001$). Bonferroni post-hoc analyses were applied to control for multiple comparisons and revealed no difference for the event where no road user was present compared to a pedestrian being present. However, the trust rating when a cyclist was crossing the side road was higher and statistically

Table 3. Test of difference in trust scores by encounter type.

Platform	Location of event	Sample mean of differences (no encounter – encounter)	t-value	Cohen's d	*p*-value
On-road	Zebra crossing	−0.32	−2.51	−0.26	0.014
On-road	Parked car	0.46	4.52	0.46	< 0.001
Simulator	Zebra crossing	0.77	6.03	−0.58	< 0.001
Simulator	Parked car	−0.03	−0.29	−0.03	0.773
		Degrees of freedom conditions/error	**F-statistic**	**η^2**	***p*-value**
On-road	Side road junction	1.8/171.5	2.80	0.03	0.069
Simulator	Side road junction	2/218	10.41	0.09	<0.001

Note: positive mean differences represent lower trust ratings when an encounter is experienced during the event.

Table 4. ANOVA of trust scores by participant role.

Location of event	Encounter type	F-statistics	Degrees of freedom (conditions)	Degrees of freedom (error)	η^2	*p*-value
On-road						
Zebra	No other road user	0.56	2	92	0.01	0.57
	Pedestrian	0.31	2	92	0.01	0.74
Parked car	No other road user	1.15	2	92	0.02	0.32
	Cyclist	0.23	2	92	0.01	0.80
Junction	No other road user	0.13	2	92	<0.01	0.88
	Pedestrian	1.14	2	92	0.02	0.32
	Cyclist	0.09	2	92	<0.01	0.92
Simulator						
Zebra	No other road user	1.79	2	107	0.03	0.17
	Pedestrian	0.85	2	107	0.02	0.43
Parked car	No other road user	0.89	2	107	0.02	0.41
	Cyclist	1.10	2	107	0.02	0.34
Junction	No other road user	0.95	2	107	0.02	0.39
	Pedestrian	1.81	2	107	0.03	0.17
	Cyclist	1.36	2	107	0.03	0.26

Table 5. Summary of mean trust ratings for participants exposed to both platforms (n = 76).

		On-road		Simulator	
Location of event	Encounter type	Mean	St. Dev.	Mean	St. Dev.
Zebra	No other road user	8.5	1.29	7.5	1.60
	Pedestrian	8.1	1.52	8.2	1.36
Parked car	No other road user	7.8	1.51	7.9	1.41
	Cyclist	8.3	1.35	7.9	1.36
Junction	No other road user	8.1	1.27	7.9	1.49
	Pedestrian	8.0	1.42	8.0	1.33
	Cyclist	8.2	1.33	8.2	1.32

significantly different from the event with no other road user ($p = 0.001$), and the event with a pedestrian being present ($p = 0.007$).

Effect of road user type on trust score

Table 4 presents ANOVA findings of trust scores by participant role, calculated separately for each event on each platform. None of the events received trust scores that were statistically significantly different according to participant role and the corresponding effect sizes were small.

In addition, a two-factor mixed-design ANOVA 2 (participant role: driver, cyclist, pedestrian) × 3 (encounter type: none, pedestrian, cyclist) was also used to compare the trust ratings between paired events and the set of three events according to participant role. We found none of the interaction terms to be statistically significant on either platform (the AV or the Simulator), and therefore the participant role does not have a significant effect on the relative trust ratings between events with and without an encounter with another road user.

Effect of platform on trust score

We are able to compare trust ratings within subject between the on-road and the Simulator trials for the 76 participants who completed two full circuits in the Simulator and at least two on-road circuits. Table 5 presents the mean trust scores for these matched samples.

Overall, the trust ratings were slightly higher on-road than in the Simulator but there is no consistent pattern of differences. Matched pairs t-tests identified a statistically significant difference in the Simulator trust scores relative to the on-road scores for only two of the events: zebra with no pedestrian ($t(75) = 4.68$, $p < 0.001$, $d = 0.54$) and overtaking a parked vehicle with an on-coming cyclist ($t(75) = 2.17$, $p = 0.03$, $d = 0.25$), representing medium and small effects. The significant difference for the zebra crossing emanates from the trial start effect in the Simulator described above.

Table 6 presents results from a 2 (platform: on-road and Simulator) × 2 (encounter: none, pedestrian, cyclist) factorial repeated measures ANOVA for the zebra crossing and the parked car events, and 2 (platform: on-road and Simulator) × 3 (encounter: none, pedestrian, cyclist) factorial repeated measure ANOVA for the side road junction events.

The significance of the effect of the platform for the zebra ($F(1,75) = 7.29$, $p = 0.009$) again emanates from the issues connected with the start of the simulator trial. The interaction term is statistically significant ($F(1,75) = 15.55$, $p < 0.001$) for overtaking a parked car (but with a large effect size, $\eta^2 = 0.172$). This indicates that the relationship between the two overtaking events (with and without an encounter with an on-coming cyclist) is not the same for each platform.

Table 6. ANOVA of trust scores by platform and encounter type (n = 76).

Location of event	Effect	F-statistic	Degrees of freedom 1	Degrees of freedom 2	Mean square error	η^2	*p*-value
Zebra	Platform	7.29	1	75	15.285	0.089	0.009
	Encounter	1.47	1	75	1.616	0.019	0.230
	Interaction term	33.87	1	75	17.932	0.311	<0.001
Parked car	Platform	0.46	1	75	0.878	0.006	0.502
	Encounter	7.24	1	75	4.185	0.088	0.009
	Interaction term	15.55	1	75	5.440	0.172	<0.001
Junction	Platform	0.36	1	75	1.246	0.005	0.550
	Encounter*	5.47	1.75	130.95	2.476	0.171	0.007
	Interaction term	1.56	2	150	0.605	0.039	0.213

*Corrected (Greenhouse-Geisser) degrees of freedom are included where sphericity assumptions were not met.

For the junction, there is a statistically significant main effect of the encounter ($F(1.75,130.95) = 5.47$, $p = 0.007$), but the main effect of the platform ($F(1,75) = 0.36$, $p = 0.550$) and the interaction term ($F(2,150) = 1.56$, $p = 0.213$) were not statistically significant. For the junction test, the Mauchly test for sphericity indicated that Greenhouse-Geisser corrections for departure from sphericity were required. This suggests that the scores for the on-road and the Simulator platforms are consistent for the right turn into a side road.

The final cross-platform effect of interest relates to the impact the different platforms have on people in the different participant roles, namely cyclist, driver or pedestrian. A two-way 2 (platform: on-road and Simulator) × 3 (participant role: cyclist, driver and pedestrian) mixed-design ANOVA was undertaken for the trust ratings for each event separately, considering the platform and the participant role as the two factors. We found that none of the interaction terms are statistically significant, and so a person's participant role did not differentially influence trust ratings for the different platforms.

Discussion

The research aimed to understand how road user trust in AVs varies depending on the maneuver being undertaken, the type of road user, and the platform. We thought that trust would be higher after encounters with pedestrians or cyclists because participants would perceive how the AV behaves and have their confidence increased. For example, they could observe that the AV gave way and was not a risk to cyclists or pedestrians. We anticipated differences between different road users and as a result of their level of experience, and that trust would be higher in the simulator because it is a fixed platform and not operating in the real world where there are many uncontrolled events and situations. We discuss each finding in turn.

Maneuver type and presence of other road users

We found that trust ratings in the AV on-road and in the Simulator were generally in the range 7.3 to 8.4 out of 10. The mean ratings are similar across all events and are at the higher end of the Likert Scale. Slightly lower trust scores with an average approaching 7/10 were found by Zoellick et al. (2019) in a study with 125 participants that involved a campus AV ride which therefore has similarities to ours. Paddeu et al. (2020) found trust scores in the range 6.6 to 8.3 with more greater exposure creating higher scores. The scores from this experiment are broadly at the same level. No statistically significant correlations were identified between age and the trust scores given for each event, and this contradicts the, admittedly marginally non-significant, finding of Gold et al. (2015) in the hand-over context. No statistically significant correlations were identified between driving experience and the trust ratings given for each event, contradicting our hypothesis.

Our results have demonstrated a high level of trust in the AV in the simulator and real world. Trust, and perceived benefit, have been identified as key determinants of acceptance of automated driving (Liu et al., 2019), whilst safety concerns and distrust in technology reduce willingness to ride in public automated vehicles (Kassens-Noor et al., 2020). In contrast to our results, being older has been associated with being more risk averse and with a reduced likelihood of adopting AVs (Wang & Zhao, 2019).

It was unexpected that in the on-road trial we found a reduction in trust score (8.4 to 8.1) at a zebra crossing with a pedestrian present, but conversely an increase in trust with an on-coming cyclist when overtaking a parked car (7.7 to 8.2). This confounds our hypothesis that there would be higher trust scores in the presence of both of these types of road user.

By way of possible explanation of this unexpected finding, there are many differences between pedestrians and cyclists: pedestrians travel broadly four times slower (4 km/hr) than cyclists (up to 20 km/hr); and cyclists (at least without suitable segregated provision) are generally users of the carriageway rather than the footway. Some participants also reported the behavior around cyclists to be cautious; for example, "did stop very early before the cyclist/pedestrians" and "As a cyclist, I appreciated its overly cautious approach".

Considering the issue in more detail, the presence of a pedestrian at the zebra crossing could be acting as a reminder of the risk involved in the scenarios presented, and that this effect is different from seeing a cyclist within the carriageway. This could therefore explain the lower level of trust. The higher trust in the overtaking maneuver with an on-coming cyclist is similar to previous results where the on-coming vehicle was a car (Morgan et al., 2018). Overtaking a parked vehicle is a challenging maneuver that requires acknowledgement of an on-coming vehicle's presence, and the prediction of its trajectory relative to the desired path of the overtaking vehicle. It is surmised that the presence of the on-coming vehicle causing the AV to give way, confirms its safe behavior, and hence leads to higher trust. This finding is supported by Riaz et al. (2018), who suggest that more understanding is required in relation to intentions.

These zebra and overtaking findings from the on-road trial were not replicated in the Simulator, and this is likely to be for the reasons created by the simulator starting effect, as noted in the results section. In contrast, for the three events at the priority junction, statistically significant differences for the presence of pedestrians and cyclists were found only in the Simulator, which was not the case for the on-road trial. The average trust rating was lowest for the side road with no other road user present (7.8), slightly higher when a pedestrian was crossing the side road (7.9), and highest with an on-coming cyclist (8.1). The statistically higher trust scores when a cyclist was present compared with the other two scenarios is similar to the findings in the on-road trial that the presence of the cyclist for the overtaking maneuver increased trust. This again may reflect the fact that the behavior of the AV has been confirmed as being safe by the participant.

Road user type

Overall, the cyclist participants gave slightly lower trust ratings than the pedestrian and driver participants, but the differences are not statistically significant and the pattern of responses was not consistent across all events. This does not support our hypothesis that we were likely to find differences as a result of their use of predominantly different parts of the highway. These results suggest that neither the usual transport mode of the observer, nor their viewpoint (either within the vehicle, or as observers on the footway) had an impact on their trust in the AV. This points to little difference in the perspective of different road users concerning AVs. Trust ratings are the higher end of the Likert scale indicate that there is little that would need to be done in relation to explaining AVs to road users, and that they are likely to be fairly well accepted, at least from the point of view of trust in their operational characteristics.

On-road versus simulator trials

The differences in scores between the real-world and simulation is small, suggesting little meaningful difference between the two platforms. However, the on-road trial found differences relating to presence and absence of a cyclist during the overtaking maneuver which the simulation did not find, and, by contrast, the simulation found significant differences between the presence of a cyclist at the junction and the other two events at the junction, which the on-road trial did not find. It is notable that these both involve the presence or absence of the cyclist, and deductions about their trajectory along the road, which hence makes them more complex maneuvers than the relatively straightforward priority of the zebra. Note that the difference at the zebra without a pedestrian present is likely to result from the simulator starting effect. The results do not support our hypothesis that simulator scores will be higher across the board. However, they do point to the fact that had this study been undertaken only in simulation, different conclusions may have been drawn. Our work has also drawn attention to the significant challenges of replicating the real-world on simulation, discussed below.

Limitations

The findings should be considered in the context of the practical limitations affecting the research. For example, it would have been preferable to have the pedestrian and cyclist interacting with the AV themselves in the on-road trials but for safety and insurance reasons this was not possible. However, perspective taking and vicarious experience are key human attributes (Duffy, 2019) and research in other domains including 'empathy for pain' and vicarious somatosensory experience has demonstrated the strong impact it may have (Fitzgibbon et al., 2010; Vandenbroucke et al., 2015). These diverse areas of research, combined with comments of our participants supporting their immersive experience during the study, suggest that despite some differences in perspective-taking across the two platforms, effective rendering of experience was achieved for participants within the study. For instance, no participant mentioned the difference between the real-world cycle having a trailer and the pedestrian a buggy, and the simulation not having those. While the experimental design allowed statistical analysis of the trust scores, it also meant that there was a disconnect in terms of 'real-world' driving experiences because participants were only ever expecting to see seven events.

Practical limitations precluded counterbalancing the order of events which may have impacted trust scores. There was little time after the simulation started before the first event took place and this seemed to adversely affect trust scores for the first event. Also, due to a range of weather, technical and availability constraints, a number of the on-road trials did not take place. Overall these issues reduced the sample size we achieved. We selected participants based on their predominant mode use. We could have, perhaps slightly more extremely, selected participants that were only ever pedestrians or drivers or cyclists. This might have created greater differences in trust scores, but would not necessarily have reflected the population of road users.

Conclusions

This research investigated trust in AVs using participants who predominantly either cycle, walk, or, for comparison, drive. The participants observed a series of seven events that involved the AV potentially needing to give way, and actually needing to give way, to a cyclist and a pedestrian on the road, and in a Simulator.

We found that overall trust ratings in an AV on-road and in a Simulator were in the range 7.3 to 8.4 out of 10 reflecting levels of trust at the higher end of the trust rating scale. For the on-road situation, trust was higher when the AV needed to give way to an oncoming cyclist when overtaking a parked car. In simulation, trust was similarly higher when a cyclist was crossing a side road and the AV had to give way turning right into the side road. These findings suggest that trust in AVs could be affected by the presence of other road users. We conclude that there are possibly two effects playing out here. One is related to reassurance that the AV will give way when other road users are present, hence making the behaviors of the AV very clear in such complex situations. The second is based on some respondents' comments concerning the apparent general cautiousness of the AV. In reality, of course, AVs will have to remain cautious in circumstances such as these. This cautiousness reflects the need for both AVs and other road users to clearly communicate intentions, and have those intentions acknowledged (Ezzati Amini et al., 2021; Löcken et al., 2019; Palmeiro et al., 2018).

We did not find that trust ratings were different between the respondents who were predominantly pedestrians, cyclists or drivers, and this is despite the difference in risk to which they would be exposed when in proximity to an AV. We also found no variation in trust by age or driving experience. We conclude that messaging to road users about the impacts of automated vehicles on their daily road use does not need to be different for different types of road user.

We found little evidence of difference in trust between the real-world and the simulator. However, for the more complex maneuver of ceding priority to an on-coming cyclist, either at a parked car or a junction, there were significant differences with and without an encounter with the cyclist in only one of the two platforms (in the real world for the parked car, and in simulation for the junction). This may point to the limits of the simulation, and therefore indicate that caution is needed when generalizing results solely from simulation.

Acknowledgements

The research described above was undertaken with a grant funded by Innovate UK reference 49478-358173. We acknowledge the overall academic leadership of the project by Professor Tony Pipe of the joint University of Bristol/UWE Bristol Robotics Laboratory which provided the technology integration and the partners on the project: Atkins (Project Management), BAE Systems (Wildcat), Williams (Simulator), Fusion Processing (detection), AXA (insurance), Burges Salmon (regulation), First Bus, Bristol City Council, South Gloucestershire Council.

Disclosure statement

The authors have no interests to declare.

ORCID

John Parkin http://orcid.org/0000-0002-6084-4569
Fiona Crawford http://orcid.org/0000-0002-0500-169X

References

Abe, G., Sato, K., & Itoh, M. (2016). *Driver's trust in automated driving when passing other traffic objects* [Paper presentation].Systems, Man, and Cybernetics (SMC), 2015 IEEE International Conference, In: 897—902.

Abraham, H., Lee, C., Brady, S., Fitzgerald, C., Mehler, B., Reimer, B., & Coughlin, J. F. (2017). Autonomous vehicles and alternatives to driving: Trust, preferences, and effects of age. In *Proceedings of the Transportation Research Board 96th Annual Meeting (TRB'17).*

AlAdawy, D., Glazer, M., Terwilliger, J., Schmidt, H., Domeyer, J., Mehler, B., Reimer, B., & Fridman, L. (2019). *Eye contact between pedestrians and drivers*. Cornell University. https://arxiv.org/abs/1904.04188.

Blau, M., Akar, G., & Nasar, J. (2018). Driverless vehicles' potential influence on bicyclist facility preferences. *International Journal of Sustainable Transportation*, *12*(9), 665–674. https://doi.org/10.1080/15568318.2018.1425781

Camara, F., Giles, O., Madigan, R., Rothmuller, M., Rasmussen, P. H., Vendelbo-Larsen, S. A., Markkula, G., Lee, Y. M., Garach, L., Merat, N., & Fox, C. W. (2018). Predicting pedestrian road-crossing assertiveness for autonomous vehicle control. IEEE, pp. 2098.

Deb, S., Strawderman, L., Carruth, D. W., DuBien, J., Smith, B., & Garrison, T. M. (2017). Development and validation of a questionnaire to assess pedestrian receptivity toward fully autonomous vehicles. *Transportation Research. Part C, Emerging Technologies*, *84*, 178–195. https://doi.org/10.1016/j.trc.2017.08.029

Duffy, J. (2019). The power of perspective taking. Psychology Today, June 2 2019. Available at https://www.psychologytoday.com/gb/blog/the-power-personal-narrative/201906/the-power-perspective-taking. Accessed 2/1/2022

Endsley, M. R. (2017). From here to autonomy: Lessons learned from human–automation re-search. *Human Factors*, *59*(1), 5–27. https://doi.org/10.1177/0018720816681350

Ezzati Amini, R., Katrakazas, C., Riener, A., & Antoniou, C. (2021). Interaction of automated driving systems with pedestrians: Challenges, current solutions, and recommendations for eHMIs. *Transport Reviews*, *41*(6), 788–813. https://doi.org/10.1080/01441647.2021.1914771

Fairley, P. (2017). Self-driving cars have a bicycle problem [News]. *IEEE Spectrum*, [Online], *54*(3), 12–13.

Fitzgibbon, B. M., Giummarra, M. J., Georgiou-Karistianis, N., Enticott, P. G., & Bradshaw, J. L. (2010). Shared pain: From empathy to synaesthesia. *Neuroscience & Biobehavioral Reviews*, *34*(4), 500–512. https://doi.org/10.1016/j.neubiorev.2009.10.007

Fox, C. W., Camara, F., Markkula, G., Romano, R. A., Madigan, R., & Merat, N. (2018). When Should the Chicken Cross the Road?-Game Theory for Autonomous Vehicle-Human Interactions. *Proceedings of the 4th International Conference on Vehicle Technology and Intelligent Transport Systems*, 1, pp. 431–439.

Gold, C., Körber, M., Hohenberger, C., Lechner, D., & Bengler, K. (2015). Trust in automation–before and after the experience of take-over scenarios in a highly automated vehicle. *Procedia Manufacturing*, *3*, 3025–3032. https://doi.org/10.1016/j.promfg.2015.07.847

Grembek, O., Kurzhanskiy, A., Medury, A., Varaiya, P., & Yu, M. (2018). Making intersections safer with I2V communication. arXiv: 1803.00471v2

Hagenzieker, M. P., van der Kint, S., Vissers, L., van Schagen, Ingrid, N. L. G., de Bruin, J., van Gent, P., & Commandeur, J. J. F. (2020). Interactions between cyclists and automated vehicles: Results of a photo experiment. *Journal of Transportation Safety & Security*, *12*(1), 94–115. https://doi.org/10.1080/19439962.2019.1591556

Hakimi, H., Kamalrudin, M., Sidek, S., & Akmal, S. (2018). Trust Requirements Model for Developing Acceptable Autonomous Car. *Journal of Electrical and Electronic Engineering*, *6*(2), 59–74. https://doi.org/10.11648/j.jeee.20180602.14

Henschke, A. (2020). Trust and resilient autonomous driving systems. *Ethics and Information Technology*, *22*(1), 81–92. https://doi.org/10.1007/s10676-019-09517-y

Jian, J., Bisantz, A. M., & Drury, C. G. (2000). Foundations for an empirically determined scale of trust in automated systems. *International Journal of Cognitive Ergonomics*, *4*(1), 53–71. https://doi.org/10.1207/S15327566IJCE0401_04

Kassens-Noor, E., Kotval-Karamchandani, Z., & Cai, M. (2020). Willingness to ride and perceptions of autonomous public transit. *Transportation Research Part A: Policy and Practice*, *138*, 92–104. https://doi.org/10.1016/j.tra.2020.05.010

Körber, M., Baseler, E., & Bengler, K. (2018). Introduction matters: Manipulating trust in automation and reliance in automated driving. *Applied Ergonomics*, *66*, 18–31.

Kyriakidis, M., Happee, R., & de Winter, J. C. F. (2015). Public opinion on automated driving: Results of an international questionnaire among 5000 respondents. *Transportation Research Part F: Traffic Psychology and Behaviour*, *32*, 127–140. https://doi.org/10.1016/j.trf.2015.04.014

Lenhard, W., & Lenhard, A. (2016). Calculation of effect sizes. https://www.psychometrica.de/effect_size.html. Dettelbach (Germany): Psychometrica. DOI: 10.13140/RG.2.2.17823.92329 (Accessed April 2020).

Liu, P., Yang, R., & Xu, Z. (2019). Public acceptance of automated vehicles. *Risk Analysis: An Official Publication of the Society for Risk Analysis*, *39*(2), 326–341. https://doi.org/10.1111/risa.13143

Löcken, A., Wintersberger, P., Frison, A., & Riener, A. (2019). *Investigating User Requirements for Communication Between Automated Vehicles and Vulnerable Road Users* [Paper presentation].2019 IEEE Intelligent Vehicles Symposium (IV), (pp. 879–884). https://doi.org/10.1109/IVS.2019.8814027

Madigan, R., Nordhoff, S., Fox, C., Ezzati Amini, R., Louw, T., Wilbrink, M., Schieben, A., & Merat, N. (2019). Understanding interactions between Automated Road Transport Systems and other road users: A video analysis. *Transportation Research Part F: Traffic Psychology and Behaviour*, *66*, 196–213. https://doi.org/10.1016/j.trf.2019.09.006

Mahadevan, K., Sanoubari, E., Somanath, S., Young, J. E., & Sharlin, E. (2019). *AV-Pedestrian Interaction Design Using a Pedestrian Mixed Traffic Simulator* [Paper presentation].DIS '19: Proceedings of the 2019 on Designing Interactive Systems Conference, June 2019. Pp 475–486. https://doi.org/10.1145/3322276.3322328

Mahadevan, K., Somanath, S., & Sharlin, E. (2018). *Communicating Awareness and Intent in Autonomous Vehicle-Pedestrian Interaction* [Paper presentation].CHI '18: Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems, paper 429.

Mannion, P. (2019). Vulnerable road user detection: State-of-the-art and open challenges. arXiv:1902.03601v1

Medina-Tapia, M., & Robusté, F. (2019). Implementation of connected and autonomous vehicles in cities could have neutral effects on the total travel time costs: Modeling and analysis for a circular city. *Sustainability*, *11*(2), 482. https://doi.org/10.3390/su11020482

Merat, N., Louw, T., Madigan, R., Wilbrink, M., & Schieben, A. (2018). What externally presented information do VRUs require when interacting with fully automated road transport systems in shared space? *Accident Analysis & Prevention*, *118*, 244–252. https://doi.org/10.1016/j.aap.2018.03.018

Morgan, P. L., Alford, C., Williams, C., Parkhurst, G., & Pipe, A. G. (2017). Manual takeover and handover of a simulated fully autonomous vehicle within urban and extra urban settings. In: Stanton, N. A., ed. Advances in Human Aspects of Transportation. In Proceedings of the AHFE 2017 International Conference on Human Factors in Transportation (597). Springer. 760–771.

Morgan, P. L., Williams, C., Flower, J., Alford, C., & Parkin, J. (2018). Trust in an autonomously driven simulator and vehicle performing maneuvers at a T-Junction with and without other vehicles. In *Proceedings of the AHFE 2018 International Conference on Human Factors in Transportation*, 21–25 July 2018.

Nisenson, L. (2017). The pace of change: Why do walking and biking still matter in an autonomous future? *ITE Journal (Institute of Transportation Engineers)*, *87*(10), 21–23.

Nuñez Velasco, J. P., Farah, H., van Arem, B., & Hagenzieker, M. P. (2019). Studying pedestrians' crossing behavior when interacting with automated vehicles using virtual reality. *Transportation Research Part F: Traffic Psychology and Behaviour*, *66*, 1–14. https://doi.org/10.1016/j.trf.2019.08.015

Nordhoff, S., Stapel, J., van Arem, B., & Happee, R. (2020). Passenger opinions of the perceived safety and interaction with automated shuttles: A test ride study with 'hidden' safety steward. *Transportation Research Part A: Policy and Practice*, *138*, 508–524. https://doi.org/10.1016/j.tra.2020.05.009

Paddeu, D., Parkhurst, G., & Shergold, I. (2020). Passenger comfort and trust on first-time use of a shared autonomous shuttle vehicle. *Transportation Research Part C: Emerging Technologies*, *115*, 102604. https://doi.org/10.1016/j.trc.2020.02.026

Palmeiro, A. R., van der Kint, S., Vissers, L., Farah, H., de Winter, J. C., & Hagenzieker, M. (2018). Interaction between pedestrians and automated vehicles: A Wizard of Oz experiment. *Transportation Research Part F: Traffic Psychology and Behaviour*, *58*, 1005–1020. https://doi.org/10.1016/j.trf.2018.07.020

Pammer, K., Gauld, C., McKerral, A., & Reeves, C. (2021). They have to be better than human drivers!" Motorcyclists' and cyclists' perceptions of autonomous vehicles. *Transportation Research Part F: Traffic Psychology and Behaviour*, *78*, 246–258. https://doi.org/10.1016/j.trf.2021.02.009

Parkin, J., Clark, B., Clayton, W., Ricci, M., & Parkhurst, G. (2018). Interactions involving autonomous vehicles in the urban street environment: A research agenda. *Proceedings of the Institution of Civil Engineers - Municipal Engineer*, *171*(1), 15–25. https://doi.org/10.1680/jmuen.16.00062

Rad, S. R., de Almeida Correia, G. H., & Hagenzieker, M. (2020). Pedestrians' road crossing behaviour in front of automated vehicles: Results from a pedestrian simulation experiment using agent-based modelling. *Transportation Research Part F: Traffic Psychology and Behaviour*, *69*, 101–119.

Rasouli, A., & Tsotsos, J. K. (2018). Autonomous Vehicles that Interact with Pedestrians: A Survey of Theory and Practice. arXiv:1805.11773v1.

Reinhard, R., Rutrecht, H. M., Hengstenberg, P., Tutulmaz, E., Geissler, B., Hecht, H., & Muttray, A. (2017). The best way to assess visually induced motion sickness in a fixed-base driving simulator. *Transportation Research Part F: Traffic Psychology and Behaviour*, *48*, 74–88. https://doi.org/10.1016/j.trf.2017.05.005

Riaz, F., & Niazi, M. A. (2017). Towards social autonomous vehicles: Efficient collision avoidance scheme using Richardson's arms race model. *PLoS One*, *12*(10), e0186103.

Riaz, F., Jabbar, S., Sajid, M., Ahmad, M., Naseer, K., & Ali, N. (2018). A collision avoidance scheme for autonomous vehicles inspired by human social norms. *Computers & Electrical Engineering*, *69*, 690–704. https://doi.org/10.1016/j.compeleceng.2018.02.011

Rödel, C., Stadler, S., Meschtscherjakov, A., & Tscheligi, M. (2014) Towards Autonomous Cars: The Effect of Autonomy Levels on Acceptance and User Experience. *AutomotiveUI '14 Proceedings of the 6th International Conference on Automotive User Interfaces and Interactive Vehicular Applications Pages 1-8*. Seattle, WA, USA—September 17 - 19, 2014

Saleh, K., Hossny, M., & Nahavandi, S. (2017). Towards trusted autonomous vehicles from vulnerable road users perspective. IEEE, pp. 1.

Schaefer, K. E., Chen, J. Y. C., Szalma, J. L., & Hancock, P. A. (2016). A meta-analysis of factors influencing the development of trust in automation: Implications for understanding autonomy in future systems. *Human Factors*, *58*(3), 377–400.

Schneemann, F., & Gohl, I. (2016). *Analyzing driver-pedestrian interaction at crosswalks: A contribution to autonomous driving in urban environments* [Paper presentation]. 2016 IEEE Intelligent Vehicles Symposium (IV), (pp. 38–43). https://doi.org/10.1109/IVS.2016.7535361

Society of Automotive Engineers ((2018). *Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles* [Paper presentation]. J3016^{TM}. Available at https://www.sae.org/standards/content/j3016_201806/ (accessed March 29, 2018).

Stanciu, S. C., Eby, D. W., Molnar, L. J., St. Louis, R. M., Zanier, N., & Kostyniuk, L. P. (2018). Pedestrians/bicyclists and autonomous vehicles: How will they communicate? *Transportation Research*

Record: Journal of the Transportation Research Board, *2672*(22), 58–66. https://doi.org/10.1177/0361198118777091

Tabone, W., de Winter, J., Ackermann, C., Bärgman, J., Baumann, M., Deb, S., Emmenegger, C., Habibovic, A., Hagenzieker, M., Hancock, P. A., Happee, R., Krems, J., Lee, J. D., Martens, M., Merat, N., Norman, D., Sheridan, T. B., & Stanton, N. A. (2021). Vulnerable road users and the coming wave of automated vehicles: Expert perspectives. *Transportation Research Interdisciplinary Perspectives*, *9*, 100293. https://doi.org/10.1016/j.trip.2020.100293

Vandenbroucke, S., Crombez, G., Loeys, T., & Goubert, L. (2015). Vicarious experiences and detection accuracy while observing pain and touch: The effect of perspective taking. *Attention, Perception & Psychophysics*, *77*(5), 1781–1793. https://doi.org/10.3758/s13414-015-0889-2

Vlakveld, W., van der Kint, S., & Hagenzieker, M. P. (2020). Cyclists' intentions to yield for automated cars at intersections when they have right of way: Results of an experiment using high-quality video animations. *Transportation Research Part F: Traffic Psychology and Behaviour*, *71*, 288–307. https://doi.org/10.1016/j.trf.2020.04.012

Wang, S., & Zhao, J. (2019). Risk preference and adoption of autonomous vehicles. *Transportation Research Part A: Policy and Practice*, *126*, 215–229. https://doi.org/10.1016/j.tra.2019.06.007

WHO (2018). *Global status report on road safety 2018: Summary*. World Health Organization. 2018 (WHO/NMH/NVI/18.20). Licence: CC BY-NC-SA 3.0 IGO).

Zoellick, J. C., Kuhlmey, A., Schenk, L., Schindel, D., & Blüher, S. (2019). Amused, accepted, and used? Attitudes and emotions towards automated vehicles, their relationships, and predictive value for usage intention. *Transportation Research Part F: Traffic Psychology and Behaviour*, *65*, 68–78. https://doi.org/10.1016/j.trf.2019.07.009