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Driver responses to encountering automated vehicles in an urban environment

TRL

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Executive summary

Background

The GATEway (Greenwich Automated Transport Environment) project aims to understand and identify ways to overcome the technical, legal and societal barriers of implementing automated vehicles in an urban environment. One potential issue for such implementation is a lack of a priori knowledge of the ways human drivers might respond to the presence of automated vehicles (AVs) in the driving environment. If human drivers know that AVs are designed to be risk-averse and compliant with traffic rules, they may adapt their behaviour in response to AVs in a way that may impact upon on road safety and traffic flows. Such impacts may vary depending on the proportion of AVs in the driven environment and the extent to which drivers can recognise vehicles as AVs.

To address this issue, a simulator trial was conducted to investigate driver behaviour and perceptions when encountering AVs in an urban environment.

Method

Sixty participants undertook ten simulator drives, comprising two distinct driving tasks:

1. Crossing a 'give way' junction (four drives)
2. Overtaking a slow-moving vehicle on an urban dual carriageway (six drives)

In the junction task, the proportion of AVs in the passing traffic was varied (80% or 20%) and the recognisability of the AVs was varied (high or low). In the overtaking task, the type of vehicle approaching in the overtaking lane was varied (AV or Human Driven Vehicle (HDV)) and the recognisability of the AV was varied (high or low).

Data collected during the trial included participant driving performance (via the simulator), subjective impressions (via post-drive questionnaires) and qualitative data on decision-making and experiences and opinions of AVs (via post-trial interviews and questionnaires).

Findings

In the junction task, participants pulled into smaller gaps between vehicles when there were more AVs in the traffic. However, there was no significant difference in gap size acceptance when participants intercepted AVs versus HDVs.

In the overtaking task, participants typically chose to wait until the approaching vehicle had passed in all instances, regardless of whether the vehicle was an AV or HDV. This may have been due in part to over-representation of patient and cautious driving styles in the sample.

Participants' subjective impressions of each drive did not significantly vary according to the vehicle type encountered, the recognisability of the AVs, or the proportion of AVs in the traffic. Post-trial comments suggest that a few participants felt more confident about pulling out in front of the AV at the junction. However in most cases, participants' decisions on when to undertake a manoeuvre were based on gap size assessments and judgements of safety.

Conclusion

Given the exploratory, pilot nature of this study its conclusions are necessarily tentative. As on-road exposure to AVs is currently extremely limited, drivers typically do not feel sufficiently knowledgeable about AV behaviour to treat them any differently than they would an HDV. As AVs become more prevalent, some human drivers may adapt their driving behaviour when interacting with them in urban environments. Future research should seek to understand how drivers will behave when they have had greater exposure to AVs and how drivers might interact with AVs when under time pressure.

1 Introduction

1.1 Project aims

GATEway (Greenwich Automated Transport Environment) is an £8 million project funded by industry and Innovate UK, and led by TRL. Centred in the Royal Borough of Greenwich in London, it aims to understand and overcome the technical, legal and societal challenges of implementing AVs in an urban environment.

The project has six key objectives:

Demonstrate the safe and efficient integration of sophisticated automated transport systems into complex real world smart city environments.	**Understand** the technical, cultural, societal and legal challenges and barriers to adoption surrounding automated vehicles.
Inspire industry, public bodies and the wider public to engage with autonomous transport technology.	**Generate** valuable, exploitable knowledge of the systems required for the effective validation, deployment, management and integration of automated transport within a smart city environment.
Create a validated test bed in the heart of London for the evaluation of next generation automated transport systems, including the detailed testing protocols and benchmark data for independent verification of automated systems.	**Position** UK PLC at the forefront of the global connected and autonomous vehicle marketplace, encouraging inward investment and job creation.

1.2 This report

A potential issue for the implementation of AVs in urban environments is a lack of a priori knowledge of human driver responses to the presence of AVs in the driving environment. This relatively under-researched topic was explored in a pilot study. A simulator trial was conducted to investigate driver behaviour and perceptions when encountering AVs on urban roads. This report presents the findings of the simulator trial.

2 Background

2.1 Vehicle automation

Vehicle systems can perform at varying levels of automation. The Society of Automotive Engineers (SAE) standard J3016 classifies automated driving systems according to the degree of automation versus human control (Figure 1; SAE International, 2014). At level 4 (high automation) or level 5 (full automation), the vehicle's automated driving system monitors the driving environment and performs all aspects of the driving task either in specific driving modes (level 4) or under all conditions (5). Vehicles operating at these levels are the focus of the GATEway project's investigations.

SAE level	Name	Narrative Definition	Execution of Steering and Acceleration/ Deceleration	*Monitoring* of Driving Environment	Fallback Performance of *Dynamic Driving Task*	System Capability *(Driving Modes)*
Human driver **monitors the driving environment**						
0	No Automation	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	Driver Assistance	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes
2	Partial Automation	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/ deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes
Automated driving system **("system") monitors the driving environment**						
3	Conditional Automation	the *driving mode*-specific performance by an *automated driving system* of all aspects of the dynamic driving task with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes
4	High Automation	the *driving mode*-specific performance by an automated driving system of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes
5	Full Automation	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**

Figure 1: SAE levels of automation (SAE International, 2014)

Accordingly, this simulator study sought to investigate driver behaviour and perceptions in relation to highly or fully automated vehicles.

2.2 Expected prevalence of AVs

As AVs are introduced on to public roads, they will initially seldom be encountered by human drivers. However, if the introduction is successful, the proportion of AVs will increase, and might eventually reach 100 per cent. It is plausible that the duration of any period of transition to universal AV prevalence will be at least 20 years, given the lifespan of current production models of cars (approximately 14 years) (SMMT, 2016). Human drivers will encounter and interact with AVs in increasing proportions during this transition period.

2.3 Behaviour of AVs

The potential of automated systems to improve safety and traffic flows is dependent on several factors, including how AVs and HDVs will interact during the transitional phase. Safety and traffic flow evaluations of AVs are based on the assumption of high levels of AV prevalence, and very little research has been conducted on the impacts of AVs in this transitional phase (Thomas, 2014).

Human drivers display a wide range of driving styles, from cautious and patient to risk-taking and angry (Taubmann Ben-Ari, Mikulincer, & Gillath, 2004). Conversely, AV behaviour is by design compliant (with traffic laws and speed limits) and conservative (i.e. risk-averse) (Parkin, Clark, Clayton, Ricci, & Parkhurst, 2016). Humans may adapt their behaviour in relation to AVs upon recognising them as such. A key question that remains unanswered is whether human drivers will take more risks knowing that an AV has a range of safety systems (Thomas, 2014).

A report on attitudes to automated vehicles found that vulnerability to abuse is a concern for the public, with an expectation that 'pranksters' may exploit the fact that AVs are programmed to stop and constantly jump out in front of them (Sciencewise, 2014). Similarly, it is possible that drivers of other vehicles could take advantage of this aspect of AV behaviour. A recent qualitative study of public attitudes towards AVs found that while many were optimistic about safety and quality of life improvements resulting from the introduction of AVs, some saw AVs as a potential nuisance and envisaged opportunities to take advantage of or 'bully' them (Tennant, Howard, Franks, Bauer, & Stares, 2016). If such adaptation to AVs were widespread, there might be significant adverse impacts on road safety and traffic flows. Such impacts may vary depending on:

- The proportion of AVs to HDVs in the general traffic environment
- The extent to which human drivers can recognise other vehicles as AVs (and therefore exhibit AV-adapted behaviours in relation to them)

Driver behaviour adaptations to AVs could have particularly significant consequences in urban environments given the the more complex nature of interactions between road users. For example, at priority junctions drivers are required to make decisions about when to cross or join a traffic stream. According to a literature review on urban traffic interactions, drivers seek and accept gaps in the traffic that are sufficiently long (in terms of time and distance) for them to conduct the manoeuvre without causing conflict and while providing a margin of safety (Parkin et al., 2016). Evidence suggests that a driver typically rejects many gaps before accepting a gap (Salter & Hounsell, 1996). This review identified a need to investigate how human drivers will behave towards AVs that are seeking to join or cross their stream of traffic (Parkin et al, 2016). However, given the aforementioned potential for the abuse of AV stopping behaviour, it is also necessary to understand how human drivers will interact with AVs when the AV has priority and the human driver is required to make a gap size judgement.

Very little research has been carried out to investigate whether these adaptations in driver behaviour are likely to occur. If human drivers do indeed adapt their behaviour towards AVs, urban transport authorities might need to introduce specific measures and interventions to manage and mitigate the adverse impacts of some interaction styles.

2.4 Research questions

This exploratory study aimed to address these issues by focussing on two specific types of vehicle interaction in an urban environment: a human driver giving way at a junction, and a human driver changing lanes to overtake on an urban section of multi-lane road. In both of these situations, that driver's behaviour could potentially differ depending on whether other vehicles involved in the interaction are AVs or other HDVs. The study aimed to investigate drivers' response to AVs versus HDVs on the basis that they were recognisable as such (not on the basis that they performed as such). Specifically, the study focussed on the following key questions:

1. When required to give way at a junction:
    a. Are drivers more likely to intercept an HDV or AV? (Hypothesis H1: Drivers will intercept AVs more frequently than HDVs.)
    b. Is there a difference in drivers' gap size acceptance or acceleration based on whether the vehicle they intercept is an HDV or AV? *(Hypothesis H2: Drivers will accept smaller gaps and/oraccelerate less hard when intercepting AVs compared with HDVs.)*
        i. To what extent are these differences influenced by the proportion of AVs to HDVs in the general traffic environment? (Hypothesis H3: Drivers will on average accept smaller gaps, and/or accelerate less hard when there is a greater proportion of AVs to HDVs.)
        ii. To what extent are these differences influenced by the recognisability of AVs? (Hypothesis H4: Drivers will accept smaller gaps, and/or accelerate less hard when the recognisability of AVs is higher.)
    c. Do drivers' perceptions of safety, comfort, frustration or difficulty differ according to the:
        i. Proportion of AVs to HDVs in the general traffic environment (Hypothesis H5: Drivers will perceive their safety and comfort to be higher and frustration and difficulty to be lower when there is a larger proportion of AVs to HDVs.)
        ii. Recognisability of the AVs (Hypothesis H6: Drivers will perceive their safety and comfort to be higher and frustration and difficulty to be lower when the recognisability of AVs is higher.)
2. When required to overtake a slow-moving vehicle on a dual carriageway:
    a. Are drivers more likely to intercept an approaching HDV or AV? (Hypothesis H7: Drivers will intercept AVs more frequently than HDVs)
    b. Do drivers' perceptions of safety, comfort, frustration or difficulty differ according to the:
        i. Approach vehicle type (Hypothesis H8: Drivers will perceive their safety and comfort to be higher and frustration and difficulty to be lower when the approach vehicle is an AV)

ii. Recognisability of the AVs (Hypothesis H9: Drivers will perceive their safety and comfort to be higher and frustration and difficulty to be lower when the recognisability of AVs is higher.)

3. How do drivers express their experiences, perceptions and understanding of AVs after completing the test drives?[1]

[1] This question was addressed using qualitative research methods. Qualitative research seeks to generate rather than test hypotheses.

3 Method

3.1 Overview

Sixty participants took part in a driving simulator trial in TRL's DigiCar (see 0). During the trial, participants were provided with information on AV behaviour and appearance, and then undertook 10 short urban drives. Driving performance data were recorded by the driving simulator. Subjective impressions were recorded after each drive and at the end of the trial. Open-ended questions, via questionnaires and interviews, explored participants' experiences, perceptions and decisions.

3.2 Participants

Sixty participants were recruited to take part in the simulator trial. All were recruited from TRL's participant database of approximately 3,000 road users living local to TRL's Crowthorne offices.

Participants were required to meet the following inclusion criteria:

- Maximum age of 70
- Have a valid UK driving licence
- At least 5 years driving experience
- Drive at least 3,000 miles per year

Participants were paid £25 in compensation.

3.3 Experimental design

3.3.1 Procedure

Participants completed 10 drives. Each drive was followed by a short questionnaire. All participants completed a post-trial questionnaire, and one-third of the sample was also interviewed. Participation lasted approximately 90 minutes.

3.3.1.1 Familiarisation drive

Participants were introduced to the vehicle, which was operated with a manual gearbox and controls similar to any normal car. Participants undertook a familiarisation drive in the simulator so as to provide opportunity for them to get used to the vehicle controls and the simulation experience. The familiarisation drive lasted approximately seven minutes and took place on an empty motorway. To ensure they were adequately prepared for the trial drives, participants practiced changing lanes, bringing the vehicle to a complete stop and proceeding to drive again. During the drive, and all drives in the actual test, participants were instructed to drive as they normally would in a real car.

3.3.1.2 AV briefing

Following the familiarisation drive, participants were presented with an information sheet on ‘self-driving vehicles’ (see 0). The information sheet described how AVs behave, and contained images depicting how the AVs in the trial differed visually from the HDVs.

3.3.1.3 Trial drives

Participants undertook 10 trial drives. The junction task was completed four times (see section 3.3.2.1) and the overtaking task was completed six times (see section 3.3.2.2). Half of participants completed the overtaking drives first and the other half completed the junction tasks first. Within each task, participants completed the drives in a randomly assigned order to control for order effects.

Each drive took approximately 1-2 minutes to complete. Details of the driving tasks are provided in sections 3.4.3.1 and 3.4.4.1.

After each drive, a short questionnaire was administered (see section 3.5.2.1), with participants providing verbal responses to the researcher.

3.3.1.4 Post-trial questions

After the trial drives, participants completed a questionnaire which recorded demographic information, driving behaviour ratings, and information about participants’ experiences during the trial.

One-third of participants took part in a post-trial interview. Participants were asked open-ended questions about their perceptions and experiences of AVs during the trial and generally, with the researcher probing particularly interesting or relevant responses. Written notes were made during the interview by the researcher as well as an audio recording using a digital voice recorder.

3.3.2 Experimental conditions

3.3.2.1 Junction

Table 1 shows the four conditions completed in the junction trial drives.

Table 1. Junction conditions

Condition	Proportion of AVs in traffic	Recognisability of AVs
1	20%	High
2	20%	Low
3	80%	High
4	80%	Low

The factors below were varied between conditions.

Proportion of AVs in driven environment

The proportion of AVs to HDVs was varied so that AVs comprised either 80% or 20% of the traffic.

Recognisability of AVs

The AVs in the traffic were presented as either high-recognisability AVs or low-recognisability AVs (see section 3.4.2).

3.3.2.2 Overtake

Table 2 shows the six conditions completed in the overtake trial drives.

Table 2. Overtake conditions

Condition	Task attempt	Approach vehicle type	Recognisability of AVs
1A	1	HDV	N/A
2A	1	AV	High
3A	1	AV	Low
1B	2	HDV	N/A
2B	2	AV	High
3B	2	AV	Low

The factors below were varied between conditions.

Approach vehicle type

The vehicle approaching in the overtaking lane was either an HDV or an AV.

Recognisability of AVs

When the approaching vehicle was an AV, it was presented as either a high-recognisability AV or a low-recognisability AV.

Task attempt

Participants completed each vehicle type/recognisability condition twice to investigate whether participants behaved differently on the first attempt versus the second attempt. First and second attempts were completed in consecutive blocks.

3.4 Driving simulator scenarios

3.4.1 Visual database

A photorealistic 3D model of the Greenwich peninsula was used in the trial. The trial utilised short sections of the model to examine the manoeuvre decisions under investigation and to minimise the risk of simulator sickness.

3.4.2 Vehicle models

Some AVs are fitted with light detection and ranging (LiDAR) sensors. As such, the vehicles representing AVs were modelled with LiDAR units on their roofs. The designs were based on recent trends in sensor shape, size and positioning.

The recognisability of AVs was varied in the trial. On the high-recognisability AVs, the LiDAR unit was mounted on a rack. On the low-recognisability AVs, the LiDAR unit was positioned directly on the roof of the vehicle (see images in 0).

In the junction scenarios, AVs were presented in three different colours so that participants could not identify the vehicle type simply by its colour.

3.4.3 Give way junction

3.4.3.1 Driving task

Each drive started with the participant vehicle positioned behind the give way line on the minor road of a crossroads. Participants were instructed to cross the junction. They were asked to try to pull into one of the gaps in the traffic if they felt it was safe to do so (see Figure 2). Participants were also instructed to wait for the first vehicle to pass them before attempting to cross the junction.

After completing the cross, participants were asked to stop the vehicle.

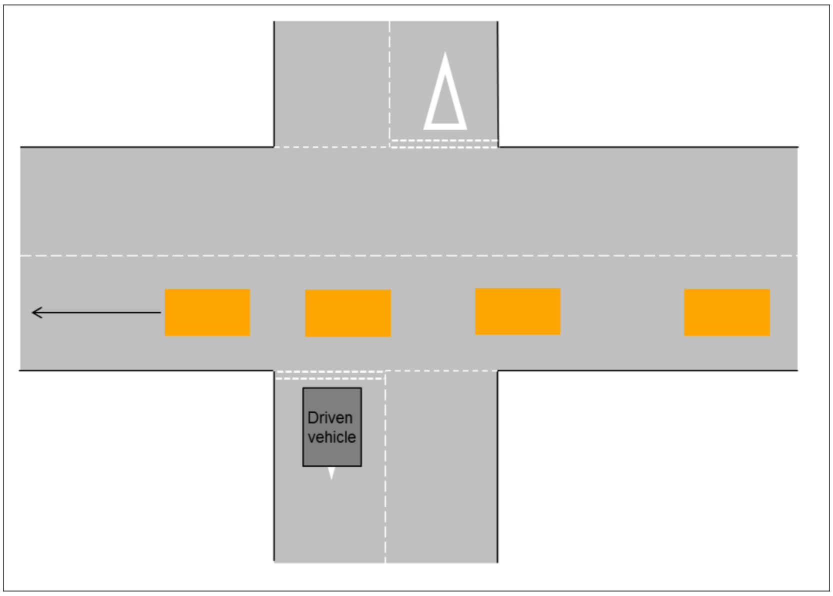

Figure 2: Road layout and traffic flow in junction task (not to scale)

3.4.3.2 Traffic modelling

Vehicles were programmed to travel at a constant speed of 20 mph on the major road from right to left. There were 20 vehicles in the traffic. The gaps between the vehicles gradually increased in time headway from 0.5s to 6.5s (see 0). No traffic was present in the other lane of the major road and participants were informed that they did not need to look left to check for vehicles.

The initial gaps of 0.5s were designed to be unambiguously too small to pull into to induce mild frustration in participants. It was assumed that a time headway of 6.5s provided a sufficiently large gap for most drivers to cross the junction comfortably, and that other drivers may simply wait for all of the vehicles to pass even if presented with larger gaps. This was confirmed during piloting.

All vehicles were programmed to behave in the same way, regardless of whether they appeared as AVs or HDVs.

Participants' views of the road scene are shown in Figure 3 and Figure 4.

Figure 3: Side view of approaching traffic in the junction task

Figure 4: Front view of junction

3.4.4 *Overtaking on a dual carriageway*

3.4.4.1 Driving task

Each drive started with the participant vehicle positioned in the left lane of an urban dual carriageway behind a lead vehicle. Participants were instructed to overtake the vehicle in front when they felt it was safe to do so. An example is shown in Figure 5.

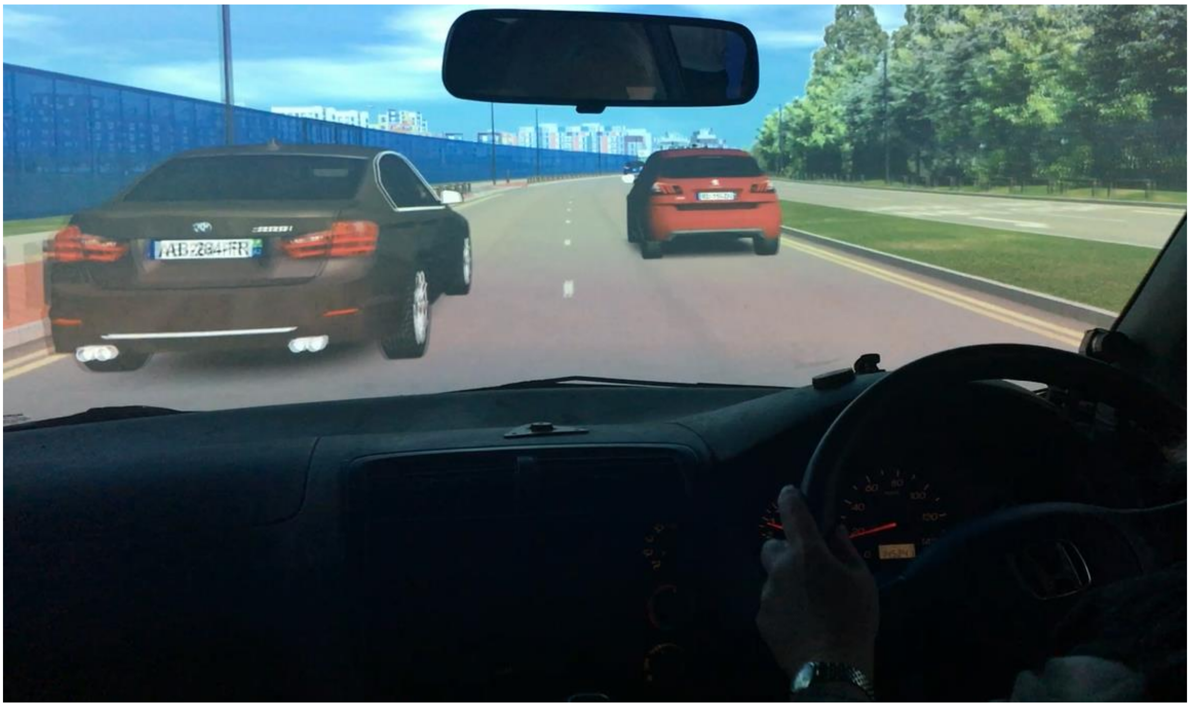

Figure 5: Example of an overtaking manoeuvre in the low-recognisability AV condition

3.4.4.2 Route

The route was a 0.6 mile stretch of urban dual carriageway with curves and one side junction. If participants did not overtake the lead vehicle before the end of the route, the drive was repeated.

3.4.4.3 Vehicle behaviour modelling

The lead vehicle travelled at a speed of 25mph.

Two vehicles were present in the overtaking lane. To induce mild frustration, the first vehicle initially mirrored the speed of the participant vehicle and prevented participants from being able to overtake.

The second vehicle was one of three vehicles: an HDV; a high-recognisability AV, or a low-recognisability AV. This vehicle maintained a headway of 24m with the first vehicle (approximately 5.5 car lengths based on a small hatchback). Piloting with several drivers determined that this headway presented participants with a gap that was sufficiently large to pull into without causing a collision, but not so large that it felt like an ‘easy’ manoeuvre.

Halfway into the route, providing the participant vehicle was within 30m of the lead vehicle the ‘mirror vehicle’ accelerated to 56 mph over 5s to disinhibit the other vehicles (see Figure 6). The second vehicle accelerated to 40 mph.

All vehicles were programmed to behave in the same way, regardless of whether they appeared as AVs or HDVs.

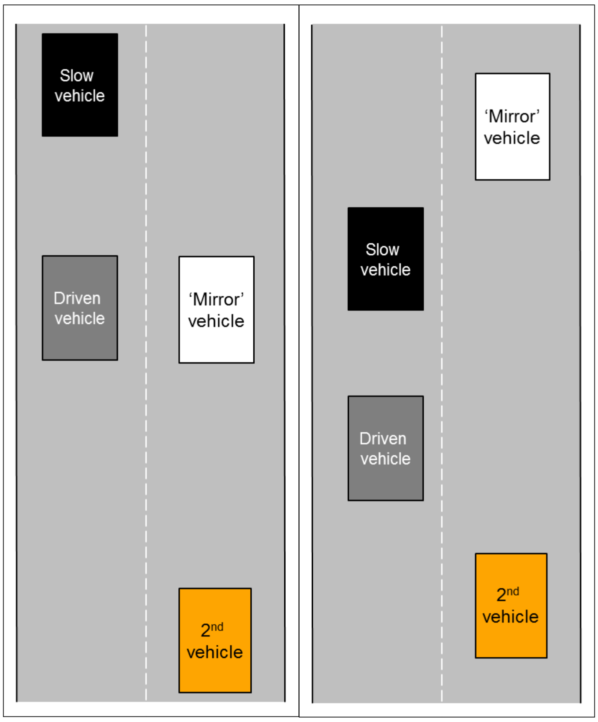

Figure 6: Relative positions of vehicles before (left) and after (right) overtaking was possible (not to scale)

3.5 Materials

3.5.1 AV briefing

An information sheet was created to provide participants with information on AVs (see 0).

To investigate their responses to AVs, it was necessary for participants to be able to distinguish them from HDVs. Images of a high-recognisability and low-recognisability AV were presented alongside that of an HDV.

Ideally participants would have learned about AV behaviour naturally through continual exposure to them in the driven environment. The time constraints of the trial did not allow for a learning period of an adequate duration, so participants were provided with some basic information on the performance of AVs; that is, that they are programmed to be risk averse and abide by traffic laws.

3.5.2 Questionnaires

3.5.2.1 Post-drive

After each drive, participants responded to rating scale items designed to probe their subjective impressions of safety, comfort, frustration and difficulty in each scenario (see 0). Ratings were provided verbally by participants and recorded by the researcher.

After the overtaking drives, participants were also asked to identify whether the vehicle behind the mirror vehicle was an AV or HDV to assist with interpreting these subjective data (see Appendix 0).

3.5.2.2 Post-trial

At the end of the trial, participants completed a questionnaire (see 0) with the following components:

Demographic information

Participants were asked to report their age, gender, annual mileage, and the number of years they had had a driving licence.

Multidimensional Driving Style Inventory

The Multidimensional Driving Style Inventory (MDSI; Taubman-Ben-Ari, Mikulincer, & Gillath, 2004) is a 44-item measure designed to assess eight domains of driving behaviour. Descriptions of these constructs, as offered by Taubman-Ben-Ari and colleagues (2004) are presented in 0.

Participants provided responses on a 6-point Likert scale with the following anchors: 0 (not at all), 1 (very little), 2 (little), 3 (moderate), 4 (much), 5 (very much).

Ease with which AVs were recognised

Participants were asked to rate how easy or difficult it was to identify the self-driving vehicles.

Experiences of the trial

For participants who did not take part in an interview, the post-trial questionnaire included a series of open-ended questions. These questions probed participants' expectations and perceptions of AVs during the trial, decision-making during the driving tasks, and general thoughts on AVs.

3.5.3 Interview topic guide

In order to gain an in-depth insight into participants' decisions, experiences and perceptions, post-trial interviews were conducted with the first 20 participants (i.e. one-third of the sample). To avoid duplication, participants who took part in an interview did not provide responses to the open-ended post-trial questions.

An interview topic guide using open, non-leading questions was developed to capture data in a consistent and non-biased way (0). Interviewers probed particularly relevant or interesting topics that emerged when appropriate opportunities arose during the interview.

3.6 Data Collection and Analysis

3.6.1 Driving performance

3.6.1.1 Junction task

As presented in Section 3.3.2, participants completed four junction drives under different conditions. These conditions covered all the possible combinations of two independent variables, each with two levels:

1. Proportion of AVs (20%/80%)
2. Recognisability of AVs (High/Low)

Independent variables are defined as those which have been manipulated as they are expected to influence the outcome measures in some way.

Data related to the outcome measures of interest (i.e. dependent variables) in the junction task were collected. The list of dependent variables, along with how they were derived, is in presented in Table 3.

Table 3: List and descriptions of dependent variables

Dependent variable	Operational definition
Vehicle intercepted (AV/HDV)	The type of vehicle that the driver pulled out in front of as they crossed the junction
Gap acceptance (2.5s to 6.5s in 0.5s intervals)	The time in seconds between consecutive vehicles travelling through the junction (see 0)
Maximum vehicular acceleration (m/s^2)	The maximum acceleration of the driver's vehicle from the point at which they began pressing the accelerator to the point at which they intercepted the other vehicle
False starts (count)	A count of the number of instances in which a force greater than 0.2N was applied to the accelerator pedal but that did not result in a successful junction crossing
Number of collisions (count)	A count of the number of drives in which the driver's vehicle contacted one of the vehicles travelling through the junction

The method and results from this analysis will be presented in Section 4.

3.6.1.2 Overtaking task

As presented in Table 2 in Section 3.3.2, participants completed six overtaking drives under three different conditions (with each condition attempted twice). The independent variables on which the conditions were based were:

1) Type of approaching vehicle (HDV for drive 1 and AV for drives 2 and 3)
2) Recognisability of AV (N/A for drive 1, high for drive 2 and low for drive 3)

Data were recorded on whether or not the participants pulled out in front of the vehicle approaching in the overtaking lane (mid-platoon overtake[2]). Additionally, data on a number of dependent variables were collected, including speed, sternway, vehicular acceleration, force placed on accelerator and decision time[3].

The method and results from this analysis will be presented in Section 4.

3.6.2 *Subjective impressions*

The subjective data were analysed to determine:

- Overall ease of AV recognition
- Differences in perceptions of safety, comfort, frustration and difficulty between experimental conditions
- Differences in ability to differentiate AVs and HDVs between experimental conditions (in the overtake task)

3.6.3 *Interview and post-trial comments*

The interview notes and post-trial comments were entered into a spreadsheet and a workshop was undertaken with all of the interviewers. The content of this workshop was structured so that the interviewers consolidated the key emerging themes from the interviews. Interviewers also liaised with each other while the interviews were being undertaken to share emerging themes.

The key themes identified from the interviews and post-trial comments are presented in section 4.5.

[2] The term 'mid-platoon overtake' will be used to describe the event in which the participants pulled out in front of the approaching HDV or AV and did not wait until both the mirror vehicle and that vehicle had passed before changing lanes.

[3] Values that are recorded for these variables are only meaningful in cases when the driver performed a mid-platoon overtake.

4 Results

4.1 Participants

Sixty participants took part in the trial. There were 33 males and 27 females. Participants were aged between 23 and 69, with a mean age of 47.9 years. On average, participants had held a driving licence for 28.8 years (SD = 13.1) and drove 12,284 miles per year (SD = 13016).

4.1.1 Driving styles

Participants' mean scores for the MDSI driving behaviour domains are shown in Figure 7. In general, the sample had high scores on the 'patient' and 'careful' domains and low scores on the 'risky' and 'dissociative' domains.

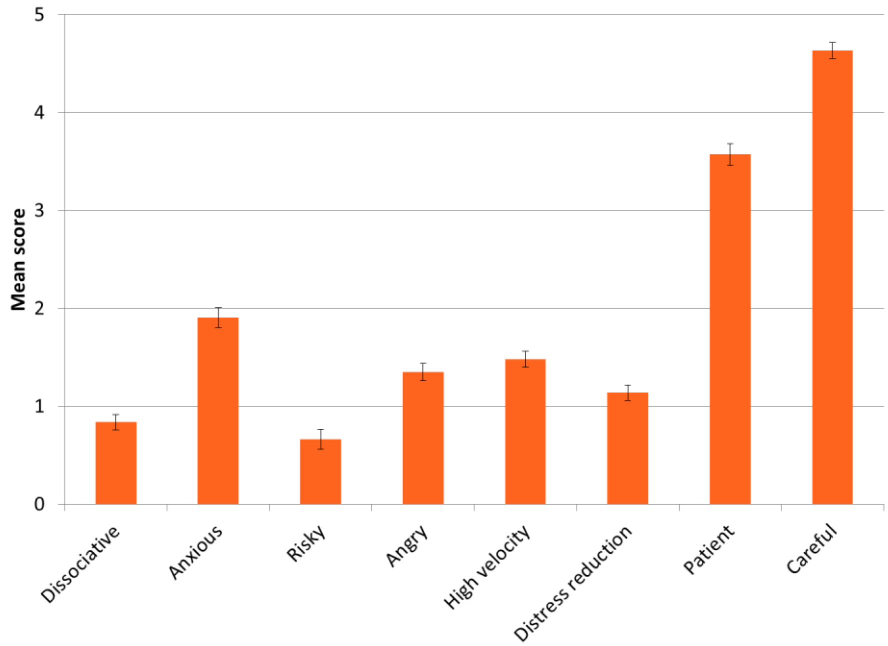

Figure 7: Mean (with standard error) scores on the MDSI driving behaviour domains

4.2 Ease of AV recognition

Participants were asked to indicate how easy or difficult it was to identify the self-driving vehicles. Responses were made on a 5-point scale from 'very difficult' (1) to 'very easy' (5) with a mid-point of 'neither easy nor difficult' (3). Participants' responses are displayed in Figure 8. The data indicate that the majority of participants found it easy to identify AVs in the trial.

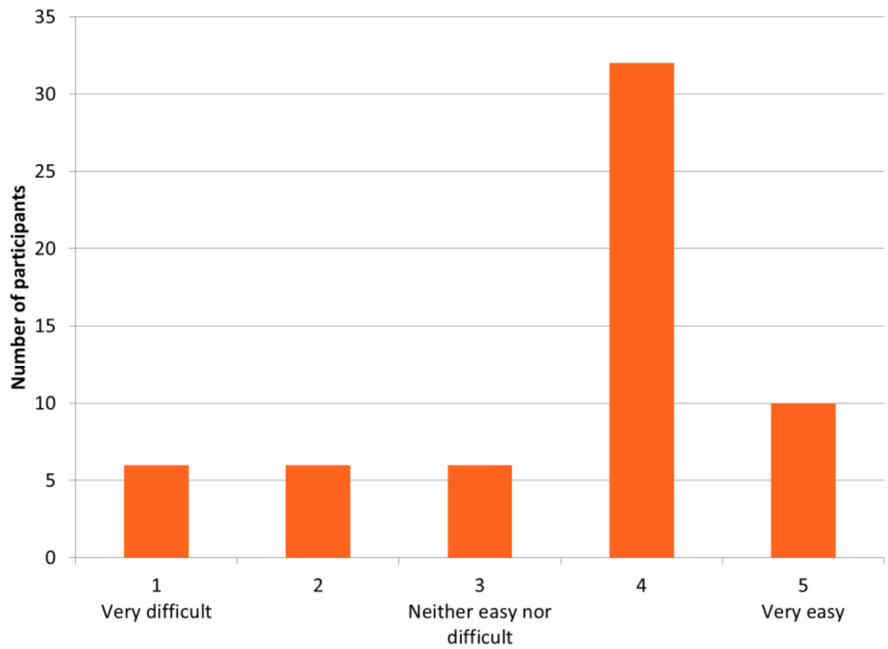

Figure 8: Participants' ratings of how easy or difficult it was to identify the AVs

4.3 Junction task

One participant collided with the approaching vehicle on the first drive for this task (condition 4). The participant reported that he had forgotten to release the handbrake before pulling out. As this incident was most likely explained by unfamiliarity with the simulator environment rather than a specific response to the experimental condition, these data were discarded and the drive was repeated. There was no indication that the participant approached the subsequent drives differently as a result of the collision.

4.3.1 Driving performance

This section presents the results from the analysis of the factors described in Section 3.6.1.1 relating to type of vehicle intercepted, gap acceptance, maximum vehicle acceleration and accelerator force as well as the number of false starts. A summary of the key findings can be found in Section 4.3.1.5.

4.3.1.1 Type of vehicle intercepted

The type of vehicle in front of which participants pulled out was recorded. As the traffic was composed of both AVs and HDVs and participants could choose which vehicle they intercepted, this allowed us to assess whether there were differences in the proportion of drivers that pulled out in front of an AV instead of an HDV between conditions.

The distribution of interceptions by vehicle type and condition is presented in tabular format in Table 4 and visually in Figure 9.

Table 4: Distribution of interceptions by vehicle type and condition

Condition (AV%, Recognisability)	Total number of interceptions	Number of AV interceptions	Proportion of interceptions that were AV
1 (20%, High)	54	11	20.4%
2 (20%, Low)	55	9	16.4%
3 (80%, High)	54	44	81.5%
4 (80%, Low)	54	45	83.3%
Overall	207	109	50.2%

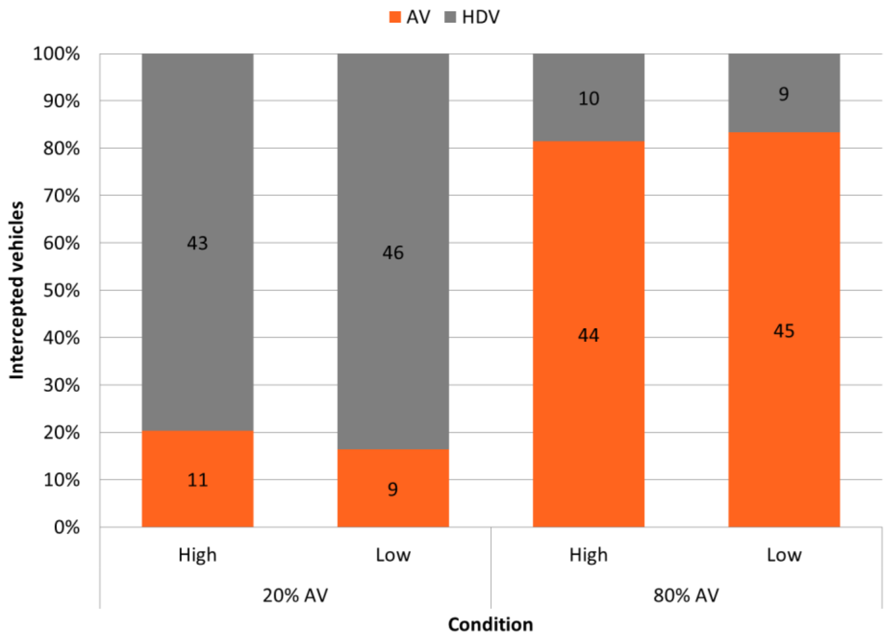

Figure 9: Distribution of vehicle interceptions by type and condition

A Cochran Q test was conducted using data from the 48 participants that accomplished the manoeuvre under all four conditions. There was a statistically significant difference in the proportion of intercepted vehicles that were AVs between conditions ($p < 0.01$[4]). Although this shows that the proportion of AV interceptions was not the same for all four conditions, the Cochran Q test does not allow pairwise comparisons to be made.

Although it seems evident from Figure 9 that the difference in the proportion of AV interceptions was likely due in large part to the proportion of AVs in the traffic, separate McNemar tests were conducted in order to confirm this[5]. Table 5 presents the level of statistical significance for each of these tests.

[4] Throughout this section we use the convention from the behavioural sciences in reporting p-values (the chance of a given effect having arisen purely due to random fluctuations in the data) as statistically significant if they are below 0.05 (5%).

[5] The sample sizes for the individual McNemar tests were larger than that of the Cochran Q because participants were able to be included on a condition-by-condition basis in the McNemar scenario whereas they had to complete all four interceptions to be included in the Cochran Q scenario.

Table 5: Level of significance of the effect of the proportion and recognisability of AVs on vehicle intercepted for the individual McNemar tests (* = significant)

Comparison	Description	p-value
Drive 2 vs. 4	Effect of the proportion of AVs when recognisability is LOW	< 0.01*
Drive 1 vs. 3	Effect of the proportion of AVs when recognisability is HIGH	< 0.01*
Drive 1 vs. 2	Effect of recognisability when the proportion of AVs is LOW	0.58
Drive 3 vs. 4	Effect of recognisability when the proportion of AVs is HIGH	1.00

As expected, the effect of the proportion of AVs in the traffic on the type of vehicle that was intercepted is significant. In other words, the more AVs there were in the traffic, the higher the number of AVs intercepted. There was no statistically significant effect of the recognisability of AVs on the proportion of AV interceptions.

4.3.1.2 Gap acceptance

Built into the hypothesis that participants were expected to behave differently in the presence of AVs is the hypothesis that they were willing to accept smaller gaps between vehicles (in seconds) in which they would be able to pull out. The distribution of gap acceptance by condition is presented in Figure 10.

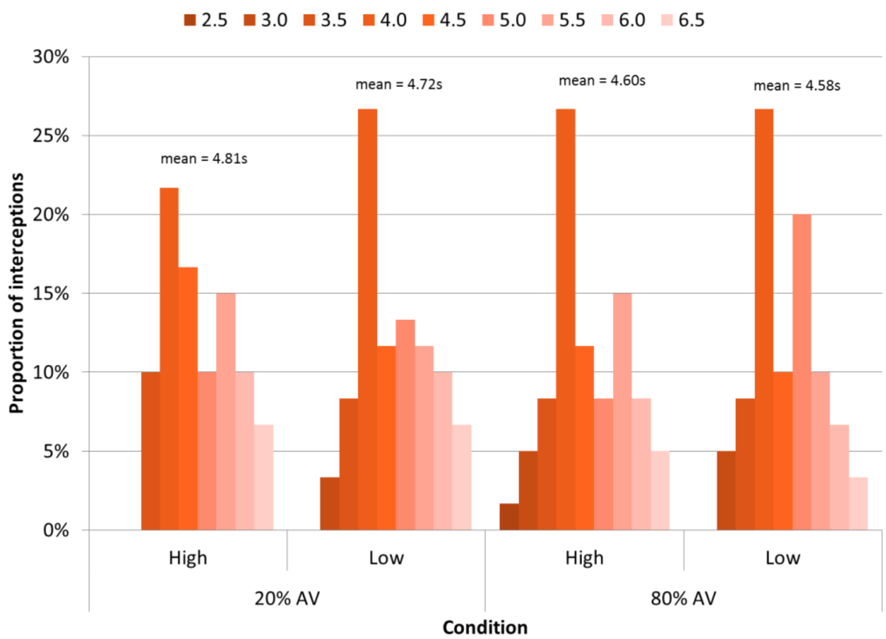

Figure 10: Distribution of vehicle interceptions by gap acceptance (seconds) and condition

A two-way repeated-measures ANOVA was used to investigate the relationship between gap acceptance, the proportion of AVs in the traffic and their level of recognisability. Only the main effect of the proportion of AVs was statistically significant ($p = 0.04$) with a moderate to high effect size (partial eta-squared = 0.09[6]). Participants allowed for slightly

[6] Cohen (1988) suggests that partial eta-squared values of 0.01, 0.06 and 0.14 should be interpreted as small, moderate and large effect sizes respectively.

smaller gaps when there were more AVs in the traffic. On average, the mean gap acceptance was 4.62 seconds when 20% of traffic was made up of AVs whereas they allowed 4.42 seconds when the proportion of traffic was 80%. This slight difference can be seen by comparing the distribution of the two left-most groupings with the two right-most groupings of gap acceptance in Figure 10.

There was no statistically significant effect of the recognisability of AVs on gap acceptance.

It is important to note that the preceding analysis of gap acceptance was not able to account for the type of vehicle that was intercepted. Independent samples t-tests[7] were conducted for each condition to determine whether there was a significant difference in gap acceptance between participants that intercepted a HDV and those that intercepted an AV. Due to the imbalance in the number of participants in each group (see Figure 9), the direction and significance of the effects that were detected using t-tests were verified using non-parametric tests.

There were no statistically significant differences in mean gap acceptance between participants that intercepted HDVs as opposed to AVs for all conditions (all $p > 0.05$).

4.3.1.3 Vehicular acceleration and accelerator force

The maximum vehicular acceleration (m/s^2) was recorded for each participant. A similar approach to that used to analyse gap acceptance was utilised to analyse the acceleration data: the first step being to investigate the relationship between acceleration and the proportion and recognisability of AVs and the second being to determine if there was a significant difference in acceleration depending on the type of vehicle that was intercepted. Figure 11 presents the mean (maximum) acceleration metrics by condition.

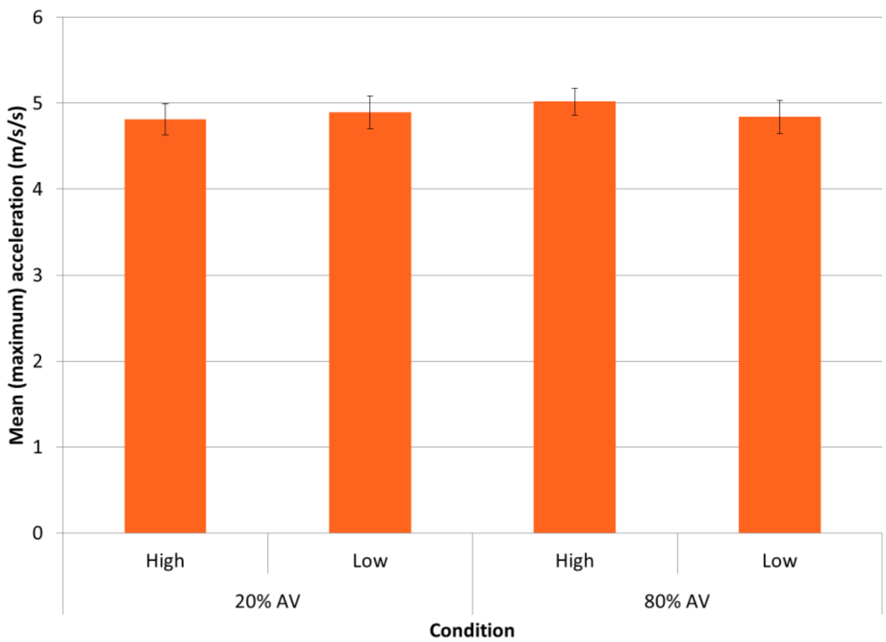

Figure 11: Mean acceleration and standard error by condition

[7] Independent samples t-tests are used to determine the significance of differences between the means of independent groups.

Friedman tests[8] showed that there was no significant difference in vehicular acceleration between conditions ($p = 0.20$). In other words, there was insufficient evidence to show that the proportion and recognisability of AVs influenced maximum vehicular acceleration.

Mann-Whitney tests[9] were then utilised to investigate the relationship between acceleration and the type of vehicle intercepted. Again, there were no statistically significant differences in vehicular acceleration force between participants that pulled out in front of AVs and those that pulled out of HDVs, regardless of which conditions are considered.

4.3.1.4 *Number of false starts*

The number of false starts was recorded for each condition (see Table 3 for the description of what was classified as a false start). It is important to note that false starts did not depend on whether or not the participant accomplished the manoeuvre. In other words, false starts could have been recorded for those who eventually intercepted a vehicle as well as for those pulled out at the end of the traffic stream. The distribution of false starts can be found in Figure 12.

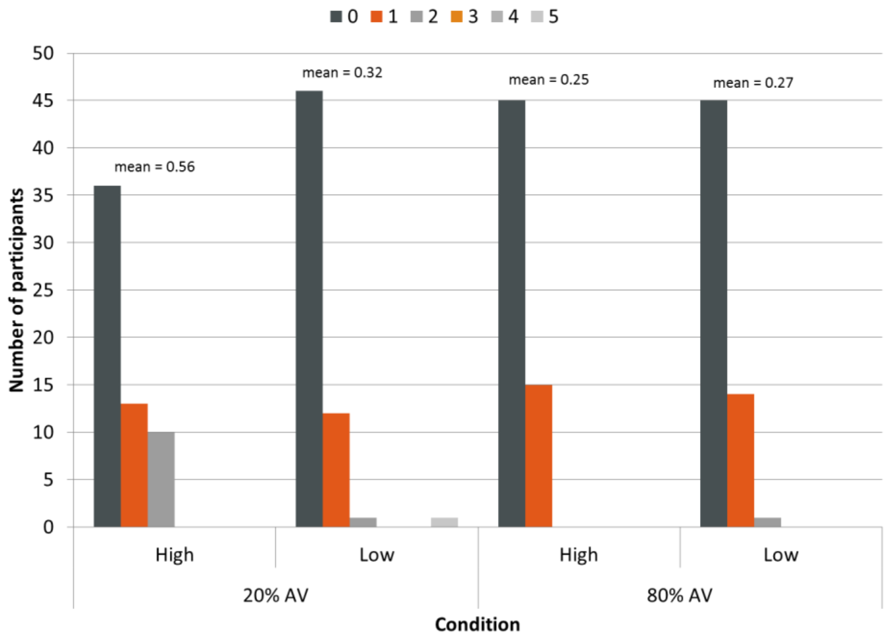

Figure 12: Number of participants by number of false starts and condition

The Friedman test that was conducted determined there to be significant differences in the number of false starts between conditions ($p = 0.04$). A high-level look at the mean ranks defined within the Friedman test indicates that there were significantly more false starts in condition A1 (20%, HIGH).

[8] Friedman tests are the non-parametric equivalents of repeated measures ANOVA. Friedman tests were preferred over ANOVA in this case as the assumptions that are required for ANOVA were not met.

[9] Mann-Whitney tests were used instead of independent samples t-tests as the assumptions required for the latter were not met.

To investigate these relationships in greater detail, Wilcoxon signed-rank tests were performed, the results of which are presented in Table 6.

Table 6: Level of significance of the effect of the proportion and recognisability of AVs on the number of false starts for the individual Wilcoxon signed-rank tests (* = significant)

Comparison	Description	p-value
Drive A2 vs. A4	Effect of the proportion of AVs when recognisability is LOW	0.806
Drive A1 vs. A3	Effect of the proportion of AVs when recognisability is HIGH	0.005*
Drive A1 vs. A2	Effect of recognisability when the proportion of AVs is LOW	0.031*
Drive A3 vs. A4	Effect of recognisability when the proportion of AVs is HIGH	0.835

The effect of the proportion of AVs at HIGH levels of AV recognisability (A1 vs. A3) as well as the effect of recognisability when the proportion of AVs in the traffic is low (A1 vs. A2) were statistically significant (p-values of 0.005 and 0.031 respectively). There were significantly more false starts when fewer AVs were present compared with more, when AVs were highly recognisable. Additionally, in the scenarios in which 20% of the traffic consisted of AVs, there were more false starts when AVs were highly recognisable compared with when they were less recognisable.

Comparing the number of false starts by the type of vehicle intercepted was meaningless due to the sequence in which these events take place. In other words, by definition, false starts can only occur before a vehicle is intercepted; therefore the number of false starts was only analysed with respect to proportion and recognisability of AVs.

4.3.1.5 Summary

The key findings related to the junction tasks are summarised in Table 7.

Table 7: Junction task key findings

Outcome measure	Key finding(s)
Proportion of AV interceptions	The larger the proportion of AVs in the traffic, the larger the number of AV interceptions The recognisability of AVs had no effect on the proportion of AV interceptions
Gap acceptance	Participants accepted smaller gaps when there were more AVs present There was no significant effect of the recognisability of AVs on gap acceptance There was no difference in gap acceptance based on what type of vehicle was intercepted
Maximum vehicular acceleration	There were no differences in maximum vehicular acceleration by condition nor by type of vehicle intercepted
Number of false starts	When AVs were highly recognisable, there were more false starts when there were fewer AVs present in the traffic (20%) When there were fewer AVs in the traffic (20%), there were more false starts when AVs were more recognisable

4.3.2 Subjective impressions

Participants were asked to how safe, comfortable and frustrated they felt during the drive, and how difficult they found the drive. Responses were made on a 10-point scale ranging from 'not at all safe / comfortable / frustrated / difficult' (1) to 'extremely safe / comfortable / frustrated / difficult' (10).

Figure 13 shows participants' mean ratings for each of the junction drives. Generally, ratings of safety and comfort were relatively high. Frustration was overall moderate and the difficulty of the drive was deemed to be relatively low. Judgements appeared to be very similar between the AV proportion and AV recognisability variants.

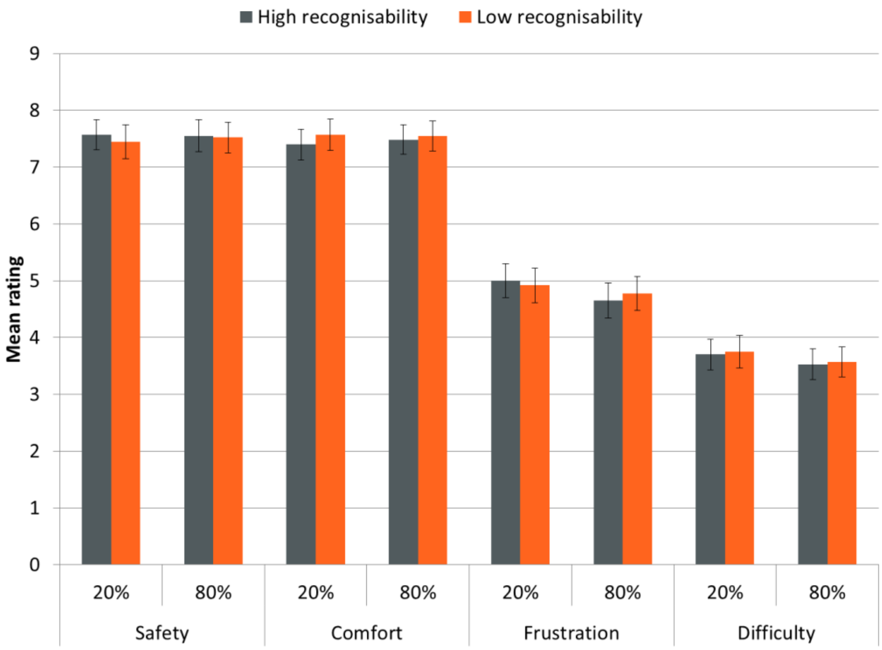

Figure 13: Mean (with standard error) ratings on subjective measures after the junction conditions

Friedman tests revealed that there were no significant differences between the four conditions on any of the subjective measures (all *p*s > 0.05). This suggests that participants' perceived workload did not differ based on the proportion of AVs in the traffic or on the recognisability of the AVs.

4.4 Overtaking task

4.4.1 Driving performance

Out of the total of 360 drives made by the 60 participants (60 participants driving under six conditions), participants only pulled into the middle of the two-vehicle platoon 45 times (12.5% of drives). In the other drives, participants changed lanes after both the mirror vehicle and the approaching AV/HDV had passed. Due to the resulting small sample sizes, it was not possible to conduct any robust statistical analysis similar to that found in Section 4.3 to investigate the influence of the approach vehicle type and level of AV recognisability on the outcome measures (dependent variables). Despite this, an exploratory task was undertaken to investigate any interesting trend that may be present.

Table 8 presents the number of mid-platoon overtakes by condition.

Table 8: Number of mid-platoon overtakes by condition

Drive (vehicle type, recognisability)	Number of mid-platoon overtakes	Proportion of all drives
1A (HDV, N/A)	4	7%
1B (HDV, N/A)	5	8%
2A (AV, High)	12	20%
2B (AV, High)	9	15%
3A (AV, Low)	8	13%
3B (AV, Low)	7	12%
Total	45	12.5%

The data indicate that the two conditions with the highest number of mid-platoon overtakes were attempts 1 and 2 of the high-recognisability AV condition, respectively. Participants completed a similar but marginally higher number of these manoeuvres on the second attempts (n = 24) than the first attempts (n = 21).

The number of mid-platoon overtakes per participant is summarised in Figure 14 and shows that the majority of participants either always overtook after both vehicles had passed or only pulled out in between the vehicles once.

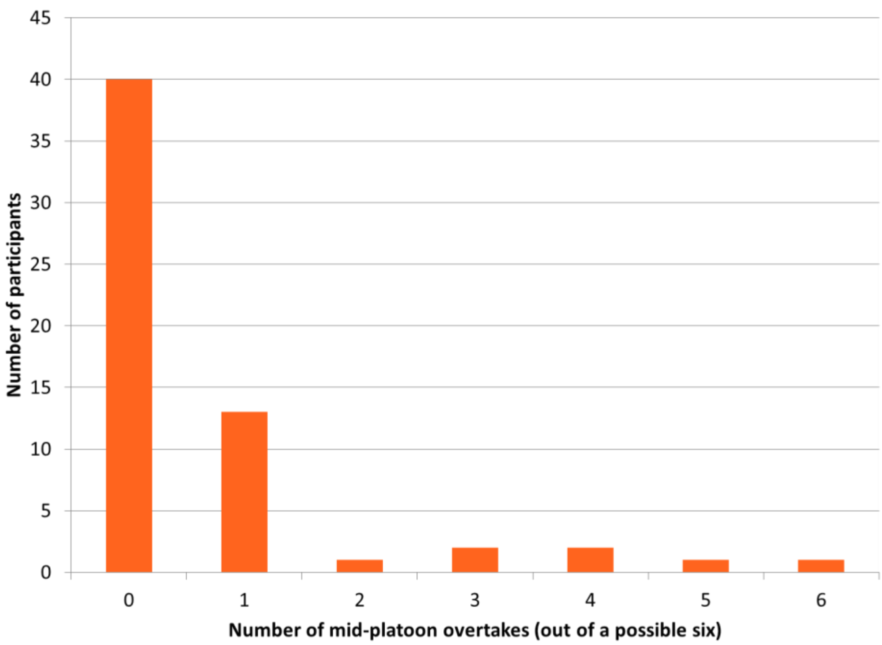

Figure 14: Distribution of participants by the number of mid-platoon overtakes (out of 6)

Although a large number of participants performed zero or one mid-platoon overtakes, there was a subset of participants that did so in at least four of the six drives. These participants will be discussed as case studies in section 4.4.2.

4.4.2 Case studies

Nearly half of the mid-platoon overtakes were made by four of the 60 drivers. These four participants (labelled a-d) overtook mid-platoon on at least four of the six drives (Table 9). The behaviours of participants a and c were consistent with the hypothesis that participants would be more likely to pull out in front of an AV than a HDV.

Table 9: Participants who performed four or more mid-platoon overtakes

Participant	HDV		AV (high)		AV (low)	
	Attempt 1	Attempt 2	Attempt 1	Attempt 2	Attempt 1	Attempt 2
a	×	✓	✓	✓	✓	✓
b	✓	✓	✓	✓	✓	✓
c	×	×	✓	✓	✓	✓
d	✓	✓	✓	×	×	✓

Participants' scores on the MDSI were explored for patterns in driving style (Figure 15). All four participants scored highest on the 'careful' domain, followed by the 'patient' domain except for participant b whose second highest score was on the 'risky' domain. This suggests that these participants typically display controlled driving behaviour and tend to be polite towards other drivers. Participants a and b, who undertook the most mid-platoon overtake, scored noticeably higher on the 'risky' domain than the sample mean.

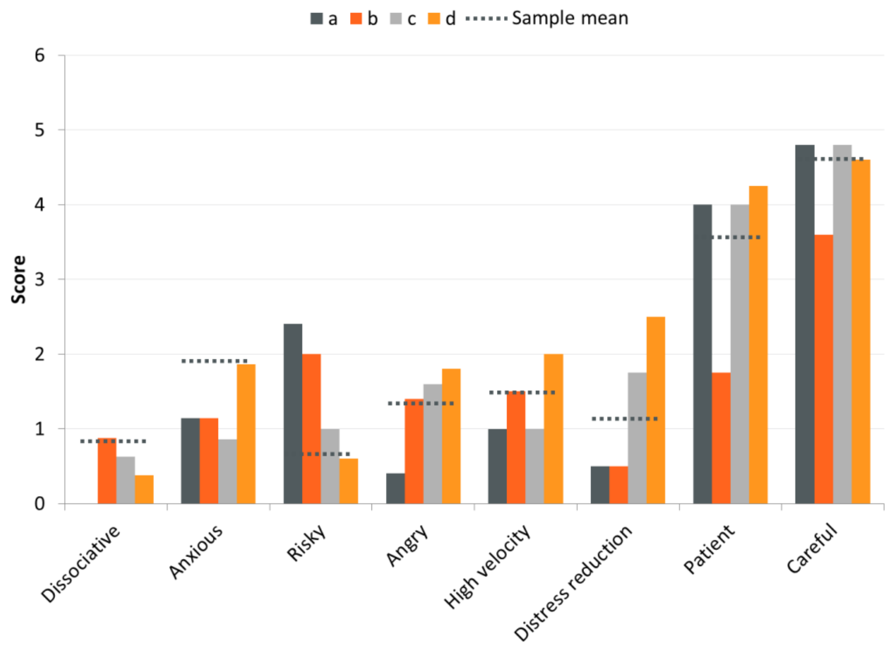

Figure 15: MDSI scores of participants who performed four or more mid-platoon overtakes

These four participants' post-trial comments were examined to explore the reasons behind these decisions. A commentary on each participant is provided below.

4.4.2.1 *Case study 1*

Participant a overtook mid-platoon in all of the AV drives and on the second attempt of the HDV drive. This participant said he decided to overtake "as soon as" the blue car (i.e. the mirror vehicle) was in front, and that his decision did not differ based on whether the approaching vehicle was an AV or HDV.

4.4.2.2 *Case study 2*

Participant b overtook mid-platoon in all six drives. The participant reported observing "no noticeable difference" between the behaviour of AV and HDVs. He said that he decided to overtake "when there was a space in the right hand lane", and that his decision did not "at all" differ based on the type of vehicle that was approaching.

4.4.2.3 *Case study 3*

Participant c overtook mid-platoon in all of the AV drives but neither of the HDV drives. He said he noticed that AVs "dropped back when you pull out"[10]. After the mirror vehicle had passed, he "checked the speed of the car behind" before performing the manoeuvre. The participant said that his decision differed according to the approaching vehicle type "a little bit" as the AVs "seemed easier to pull out in front of".

4.4.2.4 *Case study 4*

Participant d overtook mid-platoon in both of the HDV drives, attempt 1 of the high-recognisability AV drive and attempt 2 of the low-recognisability AV drive. She decided to overtake "as soon as the vehicle on my right had passed me, and the car coming up behind was not too fast". The vehicle type did not affect her decision because she "couldn't tell" at a glance whether it was an AV or not.

In summary, one participant performed mid-platoon overtakes whenever the approaching vehicle was an AV but not when it was a HDV. This was because he perceived the AV to be more responsive and easier to pull out in front of. The other participants who performed several mid-platoon overtakes based their decisions on the space available and the speed of the vehicle behind. Much like the wider trial sample, all four participants reported having careful and patient driving styles. Two participants had a driving style that was more risky than the sample mean.

4.4.3 *Questionnaire data*

Descriptive analysis of the questionnaire data revealed that the data did not comply with parametric assumptions. As such, non-parametric statistics (Friedman and Wilcoxon matched-pairs) were used for analysis.

[10] In reality, both AVs and HDVs were programmed to decelerate if a vehicle pulled out in front of them.

4.4.3.1 Identification of vehicle type

Participants were asked to state what type of vehicle the second car in the overtaking lane was. The vehicle was referred to by its colour rather than its position for ease of description and to avoid drawing attention to the significance of the vehicle's location. Participants were only asked to state the vehicle type if they first reported noticing the vehicle.

Figure 16 shows the percentage of participants who correctly identified the vehicle type present in each condition, compared to the percentages of participants who stated the wrong vehicle type or said they did not know what type of vehicle it was. In all conditions, the majority of participants correctly identified whether the vehicle was an AV or HDV. On both attempts, the low recognisability AV was correctly identified by fewer participants than the high recognisability AV or the HDV.

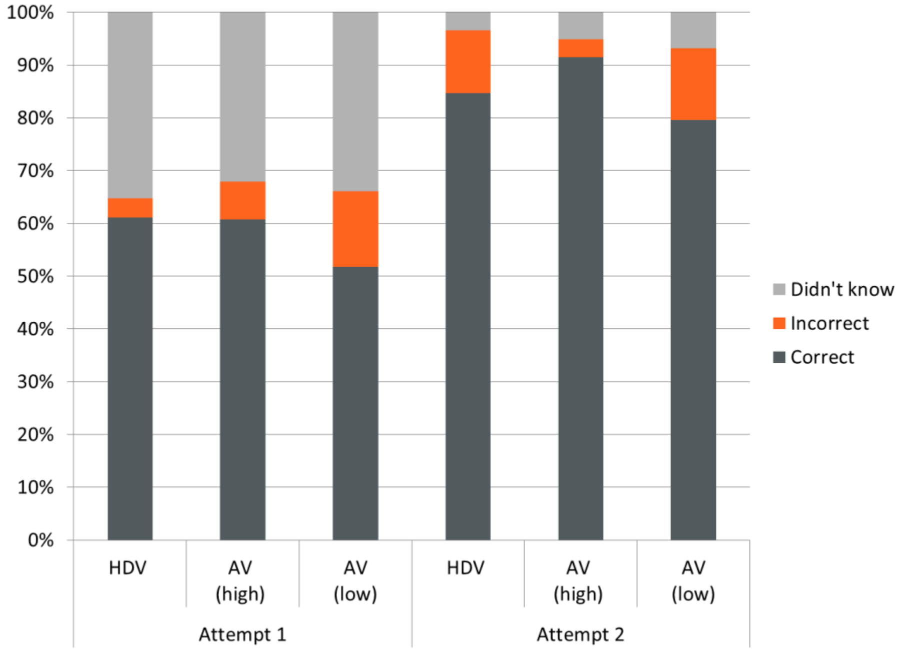

Figure 16: Percentage of participants who correctly or incorrectly identified the vehicle type present in the overtaking conditions (recognisability of the AV in parentheses)

Main effect of vehicle type

In order to conduct statistical tests on these data, participants' responses were coded as 'correct' or 'incorrect'; the latter included both incorrect identifications and 'don't know' responses. Comparisons were made between participants' abilities to correctly identify the vehicle type on the first attempts (1A vs 2A vs 3A) and on the second attempts (1B vs 2B vs 3B) of each vehicle condition.

Cochran's Q tests revealed no significant differences in the proportion of correct vehicle identifications on the first attempts ($p = 0.59$) and on the second attempts ($p = 0.16$) based on the vehicle type present. This suggests that there were no significant differences in participants' abilities to recognise HDVs and AVs, including after a second exposure to each vehicle type.

Learning effects

The data in Figure 16 also suggest that overall, participants were better at identifying the vehicle type on the second attempts of all conditions. Comparisons were made between Attempt 1 and Attempt 2 for each of the vehicle conditions.

An exact McNemar's test determined that there was a statistically significant difference in the proportion of correctly identified vehicles between Attempt 1 and Attempt 2 across all of the vehicle conditions (all *p*s < 0.01), suggesting a practice effect. It is also possible that being prompted to identify the vehicle type made participants more observant in the latter drives.

4.4.3.2 Subjective impressions

Figure 17 shows participants' mean ratings of safety, comfort, frustration and difficulty in each of the overtaking drives. Generally, ratings of safety and comfort were relatively high and ratings of frustration and difficulty were relatively low. Mean ratings were similar between the three vehicle conditions. Figure 17 indicates a slight trend towards greater safety and comfort and lower frustration and difficulty on the second attempts.

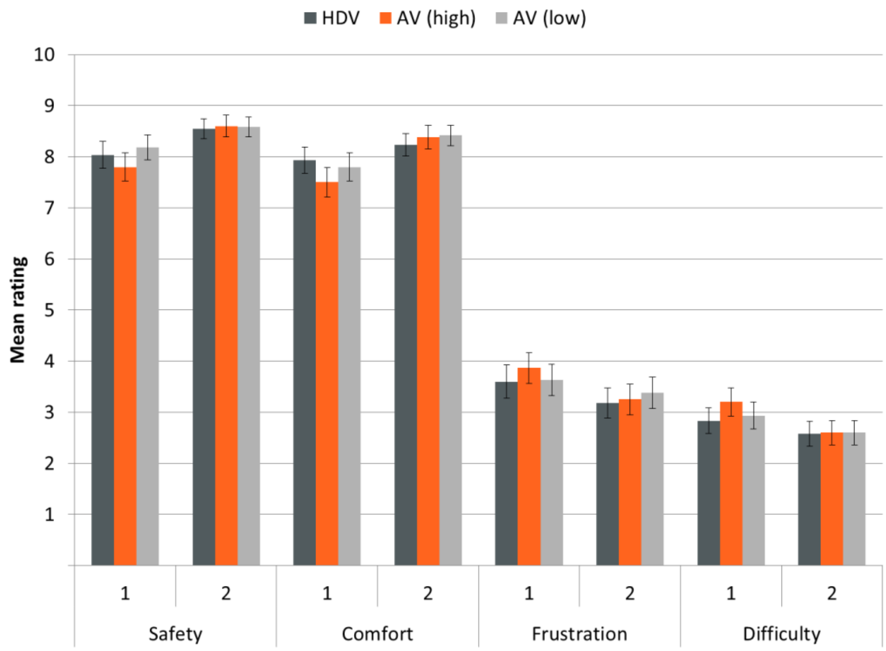

Figure 17: Mean (with standard error) ratings on subjective measures after the overtaking conditions (attempts 1 and 2)

For each item and attempt, participants' ratings for the two AV conditions were aggregated into one mean rating. This allowed a comparison of participants' judgements of interacting with HDVs versus AVs, irrespective of AV recognisability. Wilcoxon matched-pairs tests determined that there were no significant differences in participants' judgements of safety, comfort, frustration or difficulty based on whether the approaching vehicle was a HDV or AV (see Table 10).

Table 10. Mean subjective ratings for HDV and aggregated AV conditions

	Attempt 1			Attempt 2		
	HDV	AV	Sig. (p)	HDV	AV	Sig. (p)
Safety	8.03	7.99	0.29	8.55	8.59	0.53
Comfort	7.93	7.65	0.06	8.23	8.40	0.11
Frustration	3.60	3.75	0.08	3.18	3.32	0.37
Difficulty	2.83	3.07	0.10	2.58	2.60	0.83

Key findings from the overtaking task:

- Participants typically overtook the lead vehicle after both vehicles in the platoon had passed; participants only manoeuvred in between the vehicles on 12.5% of all drives.
- The majority of participants who pulled out in between the vehicles did so in only one drive.
- Four participants pulled out in between the vehicles on more than three drives. Only one of these participants reported behaving differently based on whether the second vehicle was an AV or HDV.
- The majority of participants were able to recognise whether the vehicle was an AV or HDV. There were no significant differences in recognition based on the vehicle type or AV recognisability.
- There were no significant differences in perceptions of safety, comfort, frustration or difficulty according to vehicle type or AV recognisability.

4.5 Qualitative analysis of drivers' judgements and perceptions

The following section discusses participants' comments in the post-trial interview and open-ended questions section of the questionnaire. A commentary on the key themes is presented below. Verbatim quotes are provided where particularly relevant or insightful comments were made.

4.5.1 *Decisions on manoeuvres*

In this section, participants' decisions on when to pull out into the junction and when to overtake are discussed.

4.5.1.1 Key factors

Participants described several factors as key in deciding when to overtake or pull into the junction:

- Judging when it was safe to perform the manoeuvre
- Judging whether the gap size between vehicles was sufficient, which included distance-based and time-based assessments
- Using road features and street furniture (e.g. roundabouts, lampposts) as distance markers
- Assessing the speed of approaching vehicles
- Avoiding causing another vehicle to slow down or brake

Female, 29

I was trying to judge whether they were a car length apart or closer, just like I would on a normal road…it's just how I've been taught when I was learning to drive.

Because I know roughly how big my car is or how small it is – if I can get my car in the gap with some extra room, I'd consider that to be safe. If however I decided to go in and the car was near my back end, and I went in to force them to brake, then I don't classify that as safe.

Female, 27

4.5.1.2 Relevance of vehicle type

Vehicle type as a factor

On the junction task, a small number of participants described feeling more confident about pulling out in front of an AV than an HDV, and pulling into a smaller gap when an AV was approaching. Some participants described actively searching for AVs. The following reasons were given:

- Greater confidence in AVs than HDVs
- AVs would react quicker than HDVs

- AVs avoid collisions
- The speed of AVs is more consistent, allowing the driver to pull out more sharply
- AVs appeared to be moving slower
- Human drivers would be more aggressive or irritated in response to vehicles pulling out in front of them

> At the give way junction, which I found more frustrating, I was actively looking for self-driving vehicles as I felt I could pull out in a smaller gap than normal in front of them.

Female, 29

> I felt that I would prefer to pull out in front of a self-driven car for the safety advantage that I assume it would react more quickly than a human-driven if necessary…I feel I would be more inclined to take risks.

Female, 54

Other references to the vehicle type were also made:

- One participant reported trusting HDVs more than AVs in the junction task
- A few participants said they did not respond to AVs any differently from HDVs during the trial but they would pull out in front of an AV if they were under time pressure

> I trusted the human-driven vehicle more. I know that's completely wrong but it's probably something I will have to change as the self-driven cars are supposed to be safer?

Female, 42

> In hindsight, if I was in a rush and I had to pull out in front of somebody, I'd rather have done it in front of an automated one rather than a human one…I imagine it would have taken avoiding action better than a human can.

Male, 35

Vehicle type as irrelevant

Most participants said that their decisions on performing the two manoeuvres did not differ based on whether the vehicle they encountered was an AV or HDV. There were several reasons for this:

- The vehicle type was not identified
  - The second vehicle was only recognised as an AV or HDV after it had passed the participant vehicle (overtaking task)
  - Focus was on the driving task so the vehicle type was not noticed (junction task)

- Judgements were based on safety or gap size when the vehicle type was identified
    - Participants waited for both vehicles to pass irrespective of whether the second vehicle was an AV or HDV (overtaking task)
    - Participants were only concerned with identifying an acceptable gap (junction task)
- AV behaviour and HDV behaviour were not perceived as different
- AVs were treated as HDVs due to cautiousness about them

> I didn't notice so much that they were human-driven or self-driven until I'd kind of pulled out…and hadn't really thought about it. I just kind of took it that they were a normal car…I think you've got some much going on when you're trying to pull out of a junction, you're trying to see whether I can pull out quick enough, you're trying to not hit the car that's about to go past first.

Female, 32

> I didn't pay any particular attention to what type of car was approaching, only the speed as regardless, I would not want to overtake unless it was safe to do so.

Female, 54

> I wasn't looking to see which ones were self-driving and which ones weren't…it'd be like asking whether I'd based my decision on a female driving or a man driving, an old person or a young person…it's still the same gap.

Male, 45

> I did what I would do in the real world. I see a couple of Teslas but I don't come across self-driving cars so I wouldn't know how to react. But equally, if they started on the road and I knew I could pull out and their brakes would stop automatically, then I would just pull out, if I was in a hurry."

Male, 32

4.5.2 Humans vs. computers

Many participants discussed the relative advantages and disadvantages of AVs and human drivers as well as the implications of AVs and human drivers interacting on roads.

4.5.2.1 Advantages and disadvantages of AVs

Numerous participants felt that removing the human element from driving would be positive. The following advantages of AVs were discussed:

- Greater consistency in performance
- Greater predictability of vehicle behaviour
- Enhanced ability to avoid collisions
- Removal of human error (e.g. caused by distraction or fatigue)
- Closer and more uniform following (improving traffic flow and fuel efficiency)

> I think they're a very good idea, they'd increase occupant safety…they take the human factor out of [the] ability to take risk or go beyond limits such as speed limit…on a motorway they'd leave a more reasonable stopping distance and not stop and start sharply…and reduce issues such as tiredness from driving.

Male, 23

The following disadvantages of AVs were also described:

- Susceptibility to software faults
- Lack of intelligence and experience to cope with unforeseen events
- Enjoyment of driving is removed
- Not yet proven to be safe

Male, 60

> I can see them being an asset provided the technology is thoroughly tried and tested. My concern would be the carnage that could ensue on a busy motorway if a system fails on a self-driven vehicle.

4.5.2.2 AV-HDV interactions

Several participants thought that while AVs could be beneficial if they constituted all of the vehicles on the road, a mix of AVs and human road users would be problematic. The following issues were foreseen:

- AVs would have to cope with different types of road users (e.g. pedestrians, cyclists, mobility scooter users)
- AVs would have to integrate with different driving styles
- Human driver behaviour may be too erratic and unpredictable for AVs to respond safely
- AVs do not use informal methods of interaction with human drivers (e.g. flashing their headlights to let a driver out of a junction)
- AVs would be regularly cut up because drivers would believe the AV would avoid a collision, causing frustration to the AV occupant(s)
- Adherence to speed limits by AVs may frustrate other road users
- AVs might alter driver perceptions of how to drive and make driver behaviour worse

- Human drivers would attempt to ‘race’ with AVs
- HGV platoons on motorways would block drivers from joining the carriageway

> If a pedestrian is crossing the road a self-driving car might not know it’s there until it picks it up with sensors, and cyclists can be erratic, as can other cars.

Male, 46

Male, 63

> It could be frustrating owning such a vehicle, if other drivers can immediately identify them. I think you would be continuously cut up because other drivers would feel you cannot crash into them.

Some participants felt that AVs needed to be more recognisable to human drivers. The following suggestions were made, all relating to the vehicle body:

- All AVs should be a certain colour
- All AVs should be bright or luminous shades
- All AVs should have a distinctive pattern on the bodywork

4.5.2.3 Control of the vehicle

Many participants also discussed the implications of the driver not being in control of the vehicle. The following issues about transferring control to the vehicle were raised:

- Not being in control of the vehicle might not feel safe or comfortable (i.e. a lack of trust in AVs)
- Being in control is enjoyable
- Sitting in a vehicle and not doing anything would not be enjoyable
- The driver would want and/or need to take control in situations that cannot been foreseen or programmed (as drivers have the experience to cope with them)
- Drivers could become less alert and more complacent

> I'd be happy with it being on autopilot, but then if I saw something or the computer system went down or something, that there would be a back-up system that I'd be able to then take over and kind of drive the car and everything and stop it getting into a collision or whatever, I don't really know. I just know that I'd want to be able to have *some* control over the vehicle.

Female, 27

> I don't think it's a replacement for a driver though, I think you'd still need to have a driver in it. I don't think I'd like to see vehicles without steering wheels and pedals and you don't have to be a licenced driver to operate it…it's a bit like an aeroplane where they have autopilot. You still need a pilot to be able to deal with situations which you can't actually programme into something…just ones that you don't foresee happening but if you've been driving, if you've got experience then you're able to cope with these unforeseen things.

Male, 58

However a number of opportunities afforded by transferring control to the vehicle were also anticipated:

- Drivers who do not enjoy driving would no longer need to do so
- Drivers who are fatigued could sleep or relax
- Drivers could drink alcohol in the vehicle (if legal)

> Can't wait to sleep going to work in the morning (not every morning), and if allowed have a beer.

Male, 43

4.5.3 Questions and concerns

Many participants' comments consisted of questions and concerns about AVs. Some participants had ideas about how they thought AVs would behave but were not certain. Several participants described being cautious about the capabilities of AVs until they had been thoroughly tested and their safety had been proven. Participants' comments are summarised below.

4.5.3.1 How do AVs work?

Some participants questioned how AVs function:

- What size of object is detected by the sensors?
- How would they know where to go?
- How would they react to obstacles?

- Would an AV 'think' to slow down on a residential road?

4.5.3.2 What is the user's input?

Participants posed several questions about what would be required of the driver of an AV:

- Would users need to pay attention to the road?
- Would AVs be self-driving all the time?
- Would the user be able to take over control to prevent an impending collision?
- Would users need to have a driving licence?

> So you haven't got to observe anything? The car will do it all for you? You haven't got to take any notice of what's around you? Or you can just sit back and go "off you go"?

Female, 60

4.5.3.3 'What would happen if…?'

Some participants voiced questions and concerns about how AVs would perform in rare and unusual situations:

- How would AVs perform in 'unexpected' situations? (e.g. hardware or software failure, extreme weather, erratic road user behaviour, any situation that has not been accounted for in the AV's design)
- How would AVs perform in 'dilemma' situations? (e.g. when the AV has to choose between two actions with undesirable outcomes)

Female, 54

> I am not yet confident that all aspects of perception in a self-driven car would be accounted for e.g. what if a cat was lying in the road or signs at the roadside told you of a transient problem like flooding in one lane? I would need to engage a lot more before I would be truly confident.

4.5.3.4 Who is responsible?

Several participants raised questions about responsibility for the vehicle's control and liability in the event of a collision:

- Who is responsible for accidents and injuries caused by AVs?
- Are drivers responsible even if the vehicle is automated?
- How will insurance liability work?
- Would there never be human error in an accident?

- Who would decide who is ‘right’ and ‘wrong’?

> I’d love to know as the technology develops how insurance liability goes along hand-in-hand with that. Is there a degree of driver responsibility regardless of the fact they’re self-driven? I mean, for myself personally, I leave my house to drive to work at about half past five in the morning, and it’s like an hour’s drive. So for me, if I had a self-driving car, it’s entirely possible I would fall asleep. If the car then subsequently had an accident while I was asleep at the wheel, would that be my culpability because I wasn’t aware?”

Male, 36

Summary of qualitative analysis:

- Manoeuvre decisions were commonly based on gap size, the speed of approaching vehicles and judgements of safety.
- Some participants reported feeling more confident about pulling out in front of an AV than a HDV.
- Participant often drew comparisons between the capabilities of automated driving systems and human drivers.
- Some participants thought that interactions between AVs and human road users could be problematic, with concerns around drivers’ responses to AVs as well as AVs’ ability to respond adequately to human behaviours.
- Participants discussed the risks and opportunities relating to the lack of human control over a vehicle.
- Many questions and concerns were raised about how AVs function and who is responsible for their control.

5 Discussion

Compared to interacting with HDVs, interacting with AVs on urban roads may result in differences in decision-making and manoeuvring by human drivers. This exploratory driving simulator study examined the effects of interacting with AVs on driver behaviour and subjective impressions. It also examined drivers' experiences and perceptions of sharing urban roads with AVs.

The key findings are summarised below.

5.1 Previous research

Participants' driving performance and explanations of their behaviour were generally consistent with existing evidence that drivers judge and choose gaps in the traffic that allow them to conduct the manoeuvre without causing conflict and while providing a margin of safety (Parkin et al., 2016). In line with the findings of Salter and Hounsell (1996), participants rejected many gaps before crossing the junction. Nevertheless, some participants reported feeling more confident when pulling out in front of AVs and some said that they might try to intercept one if they were in a hurry, which echoes previous evidence on perceived opportunities to take advantage of AVs (Tennant et al., 2016).

5.2 Key findings

5.2.1 Junction task (relating to research questions 1a-1e)

- Participants were more likely to intercept an AV when there were more AVs in the traffic.
- Between participants that intercepted AVs versus HDVs, there was no significant difference in gap size acceptance or maximum vehicular acceleration.
- Participants pulled into smaller gaps between vehicles when there were more AVs in the traffic.
- When AVs were highly recognisable, there were more false starts when there were fewer AVs in the traffic than when there were more.
- When there were fewer AVs in the traffic, there were more false starts when the AVs were more recognisable.
- There were no differences in maximum vehicular acceleration or participants' subjective impressions of the task based on the proportion of AVs or recognisability of AVs.

These findings suggest that when there is a high proportion of AVs in the general traffic environment, human drivers may pull into smaller gaps at a junction than they would in a traffic environment with a low proportion of AVs.

A false start may be an indication that a driver was preparing to pull out into the road but decided not to. The findings suggest that when it is easier to recognise the AVs, drivers may be more likely to abandon the manoeuvre if there are few AVs in the traffic. Similarly, when there are few AVs in the traffic, drivers are more likely to at least *prepare* for the manoeuvre when the AVs are more recognisable.

5.2.2 Overtaking task (relating to research questions 2a-2b)

- In total, participants pulled out into the platoon on 45 out of the 360 drives (12.5%).
- The number of instances of participants pulling out into the platoon were too few to compare the likelihood of pulling out in front of an AV as opposed to a HDV.
- In all other drives, participants pulled out after both vehicles had passed.
- Comments made by participants who pulled out mid-platoon in more than three drives suggest that the vehicle type did not typically factor into the participants' overtaking decisions.
- There were no differences in participants' subjective impressions of the task based on the approach vehicle type.

These findings suggest that when overtaking a slow-moving vehicle, drivers tend to wait for a clear gap behind two vehicles rather pulling into a gap between them regardless of whether the second vehicles is an AV or HDV. Comments on decision-making factors indicate that drivers typically assess the size of the gap and make judgements based on the approaching vehicle's speed, even when they are informed that AVs are designed to avoid collisions.

5.2.3 Post-trial comments (relating to research question 3a)

- Some participants reported feeling more confident about pulling out in front of an AV as opposed to a HDV.
- Most participants based their manoeuvre judgements on gap size and traffic speed.
- Participants foresaw issues in interactions between AVs and HDVs, such as the ability of AVs to respond to unpredictable behaviour and the possibility of human drivers taking advantage of AVs.
- Many questions and concerns were raised about how AVs function and who is responsible for their control, with some participants commenting that their current understanding of AVs is limited.

Despite comments indicating that a few participants behaved more assertively when they interacted with AVs, participants typically reported treating AVs as they would any other vehicle. The questions, issues and concerns discussed by participants suggest that overall, drivers do not feel sufficiently informed in regard to AV performance to be truly confident in them.

5.2.4 Hypotheses

Associated with the research questions presented in Section 2.4 were proposed hypotheses for what types of results were expected. Lists of the hypotheses with an assessment of whether or not they were supported by the results for the junction and overtaking tasks are presented in Table 11 and Table 12 respectively.

Table 11: Junction task hypotheses and associated findings

Hypothesis	Associated findings
H1: Drivers will intercept AVs more frequently than HDVs	The type of vehicle intercepted depended on the split of AV/HDVs in the traffic
H2: Drivers will accept smaller gaps and/or accelerate less hard when intercepting AVs compared with HDVs	There were no significant differences in gap size acceptance or acceleration between AV and HDV interceptions
H3: Drivers will on average accept smaller gaps and/or accelerate less hard when there is a greater proportion of AVs to HDVs	Drivers accepted significantly smaller gaps when more AVs were present There was no significant difference in acceleration according to the proportion of AVs to HDVs
H4: Drivers will accept smaller gaps and/or accelerate less hard when the recognisability of AVs is higher	There were no significant differences in gap size acceptance or acceleration between different levels of AV recognisability
H5: Drivers will perceive their safety and comfort to be higher and frustration and difficulty to be lower when there is a larger proportion of AVs to HDVs	There were no significant differences in perceptions of safety, comfort, frustration or difficulty based on the proportion of AVs to HDVs
H6: Drivers will perceive their safety and comfort to be higher and frustration and difficulty to be lower when the recognisability of AVs is higher	There were no significant differences in perceptions of safety, comfort, frustration or difficulty between different levels of AV recognisability

Table 12: Overtaking task hypotheses and associated findings

Hypothesis	Associated findings
H7: Drivers will intercept AVs more frequently than HDVs	Although statistical comparisons were not possible due to the small number of mid-platoon overtakes, this exploratory analysis seemed to support this hypothesis
H8: Drivers will perceive their safety and comfort to be higher and frustration and difficulty to be lower when the approach vehicle is an AV	There were no significant differences in perceptions of safety, comfort, frustration or difficulty based on the approach vehicle type
H9: Drivers will perceive their safety and comfort to be higher and frustration and difficulty to be lower when the recognisability of AVs is higher	There were no significant differences in perceptions of safety, comfort, frustration or difficulty between different levels of AV recognisability

5.3 Methodological considerations

A key strength of this exploratory study was the use of qualitative interviewing to probe participants' experiences of the trial drives and their post-hoc explanations for their behaviour in the trial. This insight into participants' perceptions and decision-making processes is valuable in interpreting the quantitative findings and aids in the formulation of relevant questions for future investigations.

The TRL DigiCar simulates the driving experience to a high level of fidelity, but simulator studies can never perfectly mimic real-world driving conditions. Biases associated with driving in an artificial road environment and being observed in a research setting can impact the ecological validity of studies of this kind. Nevertheless, the study provided a rigorous and repeatable procedure to robustly investigate specific conditions whilst controlling for the effect of extraneous variables such as traffic flow, road geometry and third-party driver behaviour. While the short trial drives may have been limited in providing an immersive experience, they were effective at maximising participant wellbeing in a driven environment that typically presents a higher risk of simulator sickness.

AVs and HDVs were programmed to behave in the same way in the trial, so participants may have experienced the vehicles performing in ways that were not consistent with the pre-trial information. However, this equivalence in performance between AVs and HDVs enabled a robust assessment of differences in perceptions and expectations of each vehicle type.

With respect to the overtaking task, although the statistical analysis was not possible due to small sample sizes, the exploratory analysis provided some indication that preliminary results are generally in line with those presented as hypotheses, e.g. that drivers are more likely to pull out in front of an AV than a HDV (see Table 8). It is important to note that participants may have recognised the vehicle type after it passed them, and in fact, post-trial comments indicate that this was the case for some individuals. Participants' identification of the AVs versus HDVs in this task should be treated with caution, as they may have recognised the vehicle after the point at which they would have decided whether or not to pull out in front of it. In any case, participants' qualitative comments on the influence of the approach vehicle type on their overtaking decisions were more detailed and more illuminating than their post-drive questionnaire responses.

Participants' only learning about AVs within this trial was via the pre-trial information sheet. The study did not include a direct learning phase where participants experienced AVs and became aware of their behaviour for themselves. Participants therefore had limited knowledge of AVs to draw upon during the trial drives, which may explain some of the non-significant findings. It is also important to note that some participants may have known more about AVs than others due to media coverage, although we can assume that none had any direct experience of interacting with AVs. Subsequent studies could investigate how drivers behave following a period of exposure to and implicit learning about AVs.

Mean scores on the MDSI domains (as well as the mean age of participants) suggest that patient and cautious drivers may have been overrepresented in the trial sample, which may account for some of the non-significant findings. Drivers with a more risky and/or high-velocity driving style may be more likely to exhibit the hypothesised behaviours. Future trials could pre-screen and group drivers by dominant driving style (based on normative data) and investigate whether there are differences in how these groups of drivers interact with AVs. Further information about MDSI scores of the population would provide some context for the sample means within the study. For instance, instead of presenting the sample means as in Figure 7, standardised means (in relation to the population) could be provided which would indicate the extent to which the sample means deviate from the population means.

Improvements to the design of experiments similar to this one may enable a set of different hypotheses to be tested. In the junction task, both the proportion and recognisability of AVs were manipulated; however, participants were not instructed to pull out in front of a specific type of vehicle and were therefore able to choose which vehicle they intercepted. In future studies, manipulating this variable would add statistical power to any comparisons between the types of vehicle that were intercepted. For example, the findings indicate that gap acceptance was smaller when more AVs were present but that participants did not accept significantly smaller gaps when intercepting AVs versus HDVs (H2 and H3 in Table 11). The latter result may be accurate (i.e. a true negative) but it is also possible that the experiment lacked the statistical power necessary to detect a smaller effect. Similarly, for the overtaking task, instructing participants that they have to attempt a mid-platoon overtake would allow for the difference between mid-platoon overtakes between AVs and HDVs to be investigated. Another possible adjustment could be to have a steady stream of traffic in the overtaking lane (as in the junction task) that is composed of both AVs and HDVs.

5.4 Conclusion

This exploratory study provides some tentative evidence that, as AVs become more prevalent, some human drivers may adapt their driving behaviour when interacting with them in urban environments. At junctions, human drivers may pull out into smaller gaps between vehicles when there are more AVs in the traffic, although they do not necessarily intercept AVs more readily than HDVs. Comments from drivers who did not adapt their behaviour towards AVs suggest that they may be motivated to do so in certain circumstances, such as when they are in a hurry. Exposure to high and full automation is currently extremely limited, so drivers typically perceive that they have insufficient information or experience to judge how they would react in situations on-road and thus to treat them any differently from a HDV.

5.5 Future research questions

Analyses of participants' driving behaviour and post-trial comments suggest that human-AV interactions may indeed differ somewhat from human-HDV interactions. Further investigation of this aspect of vehicle automation is therefore required.

Future research could aim to address the following research questions:

- How do drivers interact with AVs under time pressure?
- How do drivers interact with AVs following a period of exposure to them in the driven environment (i.e. when AV behaviour is learned implicitly)?
- How does driving style influence the way in which drivers interact with AVs?
- How far do human drivers interact differently with AVs compared to HDVs in different manoeuvres on urban roads?
- How far do human drivers interact differently with AVs compared to HDVs in different manoeuvres on other types of roads, for instance on extra-urban single-carriageway roads, or on motorways?
- How far do human drivers interact differently with vehicles that could be under either human or automated system control (i.e. at lower levels of automation)?

The question of whether human drivers intercept AVs more readily than HDVs in an overtaking manoeuvre still needs investigation within a suitable study design.

Further qualitative research following simulated experiences of interaction with AVs would also clearly be very valuable.

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Appendix A TRL driving simulator

The TRL driving simulator is the most advanced in the UK. It is housed in the Driving Simulation Centre - a suite of engineering workshops, software development facilities, presentation rooms, impairment testing laboratories, and medical examination quarters. The simulator uses a real full size car with all displays and controls operating as in real life. A sophisticated projection and sound system give a life-sized realistic driving environment, and a vibration and motion base give heave, pitch and roll to the car body, and add to the sense of movement experienced by the subject in the virtual world produced.

The fully interactive simulator can be used for both training and research, and offers the advantages of providing a safe environment to study situations where the risks and costs involved would be preventative on a real road system. Sponsors of recent research have included the UK Highways Agency, the Department of Transport, Environment and the Regions, the European Union, Research Councils and private industry. Topics studied have included evaluations of in-vehicle telematics systems, mobile phone use, highway engineering schemes, and driver impairment studies of alcohol, cannabis and driver fatigue.

Technical Description

The TRL driving simulator is based on a medium sized hatch back – a Honda Civic.

The car is surrounded by three screens to the front providing 210º horizontal × 40º vertical field of view and one similar sized screen to the rear providing a 70º horizontal × 40º vertical field of view, enabling use of all three of the vehicles mirrors.

Images are projected onto the screens at resolutions of 1280 × 1024. The scene is updated at rates between 30 and 60Hz.

From a separate control room the Trials Manager uses another workstation to provide an interface to the experiment. The station provides the operator with a birds-eye view of the road layout and the positions of all vehicles in the driving scenario. This same display provides a continuous representation of the use of the vehicle controls and vehicle speed. Other traffic in the driving scenario are also managed by this workstation and can also be monitored in 'real time'.

The system uses MultiGen databases for the 'driving world', these are created by specialist 3-D modelling experts to TRL specification. The simulation software is called SCANeR II and has been developed by a French Company - OKTAL, who provide advice and maintenance. The SCANeR system provides intelligent vehicles that relate their behaviour to that of the simulator vehicle (within the confines of a described behaviour pattern) or behave as autonomous intelligent vehicles operating collision detection and avoidance.

The car body is mounted on servos which supply motion to simulate the tilt and roll experienced in normal braking, acceleration and cornering. The servos are located in the position of the normal car shock absorbers and provide roll, pitch and heave displacements of ±7º, ±4º and 200mm respectively. Steering force feedback is also provided to the driver.

The car has simulated engine noise and has external noise of passing traffic and road tyre noise.

Surveillance video cameras are mounted in the car and participants can be recorded during their drive. The location of the cameras can be changed to give a facial view or whatever is required. There is also an in-car intercom system so that the experimenter can give the participant instructions, alternatively the in-car colour LCD display can also be used to give instructions or provide other task-related information.

A database of some 1000+ volunteers is maintained to help with selection of the participants.

Capabilities

Traffic: Traffic can be generated which is either 'intelligent' or 'autonomous'. The 'intelligent' traffic behaves like an intelligent driver, obeying road junctions, not crashing and so on. 'Autonomous' traffic can be pre-programmed to do unexpected things, like brake suddenly or hinder the driven vehicle.

Vehicle model: The way that the driven vehicle behaves is defined by a complex mathematical model. The software enables the vehicle to skid and recover. The way it reacts to bumps in the road is also realistic.

Night driving: The software has different levels of night time driving. The driven car has headlights, operated via the dashboard switch. The simulation can also create street lighting, other vehicle headlamps patterns and other artificial light sources (from buildings and so on) to give a compelling night driving experience.

Fog: There are different levels and types of fog, this can be pre-programmed to appear in the simulation or controlled via a menu interface.

Noise: Road noise and traffic noise is generated outside the car, as well as an in-car noise and vibration for the engine.

Traffic lights: Traffics light are definable in terms of sequence, duration and cycle times. The whole junctions can be defined. The 'intelligent' traffic will also obey the signals as expected.

Time of day: The time of day can be set, which gives different lighting levels through daylight, dusk to dark.

Appendix B AV information sheet

Self-driving cars

Self-driving cars have a cautious, patient driving style. They always comply with traffic laws and speed limits. Self-driving vehicles are programmed to avoid risk and to take action to avoid collisions. They are designed to behave consistently and predictably.

In the following drives, some of the vehicles in the traffic will be self-driving vehicles. The images below show how the self-driving vehicles look different from human-driven vehicles.

Self-driving vehicle

Self-driving vehicle

Human-driven vehicle

Appendix C Traffic modelling in junction task

This section describes how the traffic was modelled in the junction task scenario. Each scenario contained a 20-vehicle platoon of traffic. The diagrams below show which vehicles were 'human-driven' (H) and which were 'automated' (A), and the time gap between vehicles (in seconds).

In each scenario, the first three gaps were 0.5 seconds in length to induce mild frustration. Gap sizes will then be increased by 0.5 seconds. Whenever the vehicle type changed, the same gap size was presented twice (once for each vehicle type). The scenarios were designed so that the '20% density' vehicles were encountered at regular intervals.

For each AV proportion condition, there were two versions which were be counterbalanced: one in which the '20% density' vehicle was presented first, and one in which the '80% density' vehicle was presented first. For each condition, half of the participants experienced one version and the other half experienced the alternative version. This ensured that the results were not confounded by vehicle order.

Recognisability of AVs: high

20% AVs

HDVs first

Start	H	0.5	H	0.5	H	0.5	H	1.0	H	1.0	A	1.5	H	2.0	H	2.5	H	2.5	A	3.0

H	3.5	H	4.0	H	4.0	A	4.5	H	5.0	H	5.5	H	5.5	A	6.0	H	6.5	H	End

AVs first

Start	H	0.5	H	0.5	H	0.5	H	1.0	A	1.0	H	1.5	H	2.0	H	2.5	A	2.5	H	3.0

H	3.5	H	4.0	A	4.0	H	4.5	H	5.0	H	5.5	A	5.5	H	6.0	H	6.5	H	End

80% AVs

HDVs first

Start	A	0.5	A	0.5	A	0.5	A	1.0	H	1.0	A	1.5	A	2.0	A	2.5	H	2.5	A	3.0

A	3.5	A	4.0	H	4.0	A	4.5	A	5.0	A	5.5	H	5.5	A	6.0	A	6.5	A	End

AVs first

Start	A	0.5	A	0.5	A	0.5	A	1.0	A	1.0	H	1.5	A	2.0	A	2.5	A	2.5	H	3.0

A	3.5	A	4.0	A	4.0	H	4.5	A	5.0	A	5.5	A	5.5	H	6.0	A	6.5	A	End

Recognisability of AVs: low

20% AVs

HDVs first

Start	H	0.5	H	0.5	H	0.5	H	1.0	H	1.0	A	1.5	H	2.0	H	2.5	H	2.5	A	3.0

H	3.5	H	4.0	H	4.0	A	4.5	H	5.0	H	5.5	H	5.5	A	6.0	H	6.5	H	End

AVs first

Start	H	0.5	H	0.5	H	0.5	H	1.0	A	1.0	H	1.5	H	2.0	H	2.5	A	2.5	H	3.0

H	3.5	H	4.0	A	4.0	H	4.5	H	5.0	H	5.5	A	5.5	H	6.0	H	6.5	H	End

80% AVs

HDVs first

Start	A	0.5	A	0.5	A	0.5	A	1.0	H	1.0	A	1.5	A	2.0	A	2.5	H	2.5	A	3.0

A	3.5	A	4.0	H	4.0	A	4.5	A	5.0	A	5.5	H	5.5	A	6.0	A	6.5	A	End

AVs first

Start	A	0.5	A	0.5	A	0.5	A	1.0	A	1.0	H	1.5	A	2.0	A	2.5	A	2.5	H	3.0

A	3.5	A	4.0	A	4.0	H	4.5	A	5.0	A	5.5	A	5.5	H	6.0	A	6.5	A	End

Appendix D Post-drive questionnaires

Overtake drives

Circle the drive completed: 1 2 3

The questions below will ask you how you felt during the drive you just completed.									
1. On a scale from 1 to 10, how safe did you feel during the drive?									
Not at all safe									Extremely safe
1	2	3	4	5	6	7	8	9	10
2. On a scale from 1 to 10, how comfortable did you feel during the drive?									
Not at all comfortable									Extremely comfortable
1	2	3	4	5	6	7	8	9	10
3. On a scale from 1 to 10, how frustrated did you feel during the drive?									
Not at all frustrated									Extremely frustrated
1	2	3	4	5	6	7	8	9	10
4. On a scale from 1 to 10, how difficult did you find the drive?									
Not at all difficult									Extremely difficult
1	2	3	4	5	6	7	8	9	10

Did you notice the grey/black/red[11] car?

Yes No

(If yes) what type of vehicle was it?

Human-driven Self-driving Don’t know

---

[11] Select the correct colour:

1: grey 2: black 3: red

Junction drives

Circle the drive completed:

4 5 6 7 8 9 10 11

The questions below will ask you how you felt during the drive you just completed.									
1. On a scale from 1 to 10, how safe did you feel during the drive?									
Not at all safe									Extremely safe
1	2	3	4	5	6	7	8	9	10
2. On a scale from 1 to 10, how comfortable did you feel during the drive?									
Not at all comfortable									Extremely comfortable
1	2	3	4	5	6	7	8	9	10
3. On a scale from 1 to 10, how frustrated did you feel during the drive?									
Not at all frustrated									Extremely frustrated
1	2	3	4	5	6	7	8	9	10
4. On a scale from 1 to 10, how difficult did you find the drive?									
Not at all difficult									Extremely difficult
1	2	3	4	5	6	7	8	9	10

Appendix E Post-trial questionnaire

SECTION A. Background information

A1. What was your age at your last birthday?		
A2. Are you male or female? (please tick)	Male	Female
A3. For how many years have you held a driver's licence?		
A4. Approximately how many miles do you drive per year?		

SECTION B. About your driving

The following are a list of statements concerning how people drive. Please read each statement carefully and indicate, on the 6-point scale, to what extent the statement describes you.

	Not at all	Very little	Little	Moderate	Much	Very much
1. I often do relaxing activities while driving	☐	☐	☐	☐	☐	☐
2. I often purposely closely follow other drivers	☐	☐	☐	☐	☐	☐
3. I often beep my horn or 'flash' the car in front as a way of expressing my frustration.	☐	☐	☐	☐	☐	☐
4. I feel I have control over driving	☐	☐	☐	☐	☐	☐
5. I often drive through traffic lights that have just turned red.	☐	☐	☐	☐	☐	☐
6. I usually enjoy the sensation of driving on the limit (dangerously)	☐	☐	☐	☐	☐	☐
7. On a clear motorway, I usually drive at or a little below the speed limit	☐	☐	☐	☐	☐	☐
8. While driving I try to relax myself	☐	☐	☐	☐	☐	☐
9. When I am in a traffic jam and the lane next to mine starts to move, I try to move into that lane as soon as possible	☐	☐	☐	☐	☐	☐

	Not at all	Very little	Little	Moderate	Much	Very much
10. Driving usually makes me feel frustrated	☐	☐	☐	☐	☐	☐
11. I often daydream to pass the time while driving	☐	☐	☐	☐	☐	☐
12. I often swear at other drivers	☐	☐	☐	☐	☐	☐
13. When a traffic light turns green and the car in front of me doesn't get going, I just wait for a while until it moves	☐	☐	☐	☐	☐	☐
14. I drive cautiously	☐	☐	☐	☐	☐	☐
15. Sometimes lost in thought or distracted, I fail to notice someone waiting at a zebra crossing/pedestrian	☐	☐	☐	☐	☐	☐
16. In a traffic jam, I think about ways to get through the traffic faster	☐	☐	☐	☐	☐	☐
17. When a traffic light turns green and the car in front of me doesn't get going immediately, I try to urge the driver to move on	☐	☐	☐	☐	☐	☐
18. At a junction where I have to give right-of-way to oncoming traffic, I simply wait patiently for traffic to pass	☐	☐	☐	☐	☐	☐
19. When someone tries to skirt in front of me on the road I drive in an assertive way in order to prevent it	☐	☐	☐	☐	☐	☐
20. I often fix my hair and/or makeup while driving	☐	☐	☐	☐	☐	☐
21. I am often distracted or preoccupied, and suddenly realise that the vehicle ahead has slowed down, and I have to slam on the brakes to avoid a collision	☐	☐	☐	☐	☐	☐
22. I like to take risks while driving	☐	☐	☐	☐	☐	☐
23. I base my behaviour on the motto "better safe than sorry"	☐	☐	☐	☐	☐	☐
24. I like the thrill of flirting with death and disaster	☐	☐	☐	☐	☐	☐

	Not at all	Very little	Little	Moderate	Much	Very much
25. It worries me when driving in bad weather	☐	☐	☐	☐	☐	☐
26. I often meditate while driving	☐	☐	☐	☐	☐	☐
27. Lost in thoughts I often forget that my lights are on full beam until flashed by another motorist	☐	☐	☐	☐	☐	☐
28. When someone does something on the road that annoys me, I flash them with the full beam	☐	☐	☐	☐	☐	☐
29. I get a thrill out of breaking the law	☐	☐	☐	☐	☐	☐
30. I often misjudge the speed of an oncoming vehicle when overtaking	☐	☐	☐	☐	☐	☐
31. I feel nervous while driving	☐	☐	☐	☐	☐	☐
32. I get impatient during rush hour	☐	☐	☐	☐	☐	☐
33. I feel distressed while driving	☐	☐	☐	☐	☐	☐
34. I often intend to switch on the windscreen wipers, but switch on the lights instead, or vice versa	☐	☐	☐	☐	☐	☐
35. I often attempt to drive away from traffic lights in third gear (or in neutral or park in an automatic car)	☐	☐	☐	☐	☐	☐
36. I often plan my route badly, so that I hit traffic that I could have avoided	☐	☐	☐	☐	☐	☐
37. I often use muscle relaxation techniques while driving	☐	☐	☐	☐	☐	☐
38. I plan long journeys in advance	☐	☐	☐	☐	☐	☐
39. I often nearly (or actually) hit something due to misjudging my gap in a parking lot	☐	☐	☐	☐	☐	☐
40. I feel comfortable while driving	☐	☐	☐	☐	☐	☐
41. I am always ready to react to unexpected manoeuvres by other drivers	☐	☐	☐	☐	☐	☐
42. I tend to drive cautiously	☐	☐	☐	☐	☐	☐

	Not at all	Very little	Little	Moderate	Much	Very much
43. I often beep my horn at others	☐	☐	☐	☐	☐	☐
44. I usually enjoy the excitement of dangerous driving	☐	☐	☐	☐	☐	☐

C1. During the drives you just completed, how easy or difficult was it to identify the self-driving cars?				
Very difficult		Neither easy nor difficult		Very easy
1	2	3	4	5

SECTION D. Your experiences of the trial

D1. Please describe what you experienced during your drives in the trial.
D2. What did you notice about the self-driving vehicles?
D3. Did anything happen that surprised you?

THE FUTURE OF TRANSPORT

GATEway

D4a. At the give way junction, how did you decide when to pull out?
D4b. To what extent did your decision differ based on whether the approaching vehicle was a self-driving vehicle or a human-driven vehicle?
D5a. On the dual carriageway, how did you decide when to overtake?
D5b. To what extent did your decision differ based on whether vehicle approaching from behind was a self-driving vehicle or a human-driven vehicle?
D6. What thoughts do you have on self-driving vehicles?

D7. What other comments do you have?

Appendix F MDSI constructs

Table 13. MDSI constructs and definitions (Taubman-Ben-Ari et al., 2004)

	Construct	Definition
1.	Dissociative	"All these items tap a person's tendency to be easily distracted during driving, to commit driving errors due to this distraction, and to display cognitive gaps and dissociations during driving."
2.	Anxious	"All these items tap a person's tendency to feel distress during driving, to display signs of anxiety due to the driving situation, and to express doubts and lack of confidence about his or her driving skills."
3.	Risky	"All these items tap a person's seeking for stimulation, sensation, and risk during driving and his or her tendency to take risky driving decisions and to engage in risky driving."
4.	Angry	"All the items tap a person's tendency to be hostile towards other drivers as well as behave aggressively and feel intense anger while driving."
5.	High-velocity	"All the items tap a person's tendency to drive fast, to display signs of time pressure while driving, and to be oriented towards high velocity driving".
6.	Distress reduction	"These items tap a person's tendency to engage in relaxing activities during driving aimed at reducing distress while driving."
7.	Patient	"All the items tap a person's tendency to be polite towards other drivers, to feel no time pressure during driving, and to display patience while driving."
8.	Careful	"All the items tap a person's tendency to be careful during driving, to effectively plan his or her driving trajectory, and to adopt a problem-solving attitude towards driving-related problems and obstacles."

Appendix G Interview topic guide

Before the interview

Ensure that the participant's informed consent to the interview and subsequent uses of its outputs has been obtained.

Introduction

We would like to hear from you about your experiences and perceptions of self-driving vehicles, during the trial and generally. There are no right or wrong answers: we want to learn about your own thoughts, in your own words.

Our discussion should last no longer than 15 minutes. I've got a list of questions to go through, so I might have to steer us back to those if we're short for time to make sure they are all covered. I'll be taking notes throughout (the recording is just a back up) so please bear with me while I do that.

---

1. During the drives you just completed, what did you notice about the self-driving vehicles?
2. How did you think they would behave?
3. Did anything happen that surprised you?
4. At the **give way junction**:
    a. How did you decide when to pull out?
    b. To what extent did your decision differ based on whether the approaching vehicle was a self-driving vehicle or a human-driven vehicle?
    c. (if appropriate) What were your reasons for making different decisions based on whether the approaching vehicle was a self-driving vehicle or a human-driven vehicle?
5. On the **dual carriageway**:
    a. How did you decide when to overtake?
    b. To what extent did your decision differ based on whether the vehicle approaching from behind was a self-driving vehicle or a human-driven vehicle?
    c. (if appropriate) What were your reasons for making different decisions based on whether the vehicle approaching from behind was a self-driving vehicle or a human-driven vehicle?
6. What thoughts do you have on self-driving vehicles?
7. Do you have any other comments?

Led by

Supported

Crowthorne House, Nine Mile Ride,
Wokingham, Berkshire, RG40 3GA,
United Kingdom
T: +44 (0) 1344 773131
F: +44 (0) 1344 770356
E: enquiries@trl.co.uk
W: www.trl.co.uk

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