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How will drivers interact with vehicles of the future?

Professor Gary Burnett
Dr David R. Large
Dr Davide Salanitri

July 2019

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About the Author

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Foreword

So much of the debate about automated driving hinges on the question of how we *think* we'll engage with a technology that, as of today, is wholly unfamiliar to the vast majority of us. How we'll actually react in practice is in fact rather uncertain. Despite the imminent arrival of automatic driving that some are predicting, we appear to be some way from being able to test real-world consumer acceptance on the public road.

We were therefore enthusiastic about partnering with the team at the University of Nottingham to see what we could learn from the next-best thing to real-world testing: using a driving simulator, as explained in detail in this report.

What the research brings out is the very real challenge the developers of automated driving face if, as seems most likely, the technology they bring to market allows only for so-called 'conditional' automation, i.e. the vehicle can be set to drive itself in a defined range of circumstances which might not cover all the features involved in making a trip.

For example, the vehicle might be able to control itself on motorways but not on narrow country lanes. Or the technology might operate in most weather conditions but not in snow or through sudden torrential rainfall. And that means the human driver having to re-take control.

As experienced drivers we tend to let slip to the back of our minds how important situational awareness is to driving safely, because it becomes second nature to observe and react accordingly to what is going on around us, in terms of road condition, weather and other traffic. We don't just see how our vehicle is performing by looking at the dashboard, we feel it through our hands being on the steering wheel and our feet being on the pedals.

This research tested what drivers chose to do once released from the driving task and so relieved of the need to maintain situational awareness. And it explored how quickly the required degree of situational awareness could be regained when the need came to retake control. The findings, unsurprisingly, show that retaking control is not something that can be safely handled instantaneously.

If conditionally automated vehicles are to be allowed onto the public road then their designers are going to have to apply their minds to the circumstances where drivers will be invited – or required – to retake control and the very real likelihood that, at best, those drivers will need plenty of warning to set down their papers or close their laptop computer, and, at worst, still more time to wake from slumber.

Simply advising drivers of the need for them to stay awake and alert is unlikely to be a viable, safe option. And that begs the question – *What is?*

Steve Gooding
Director, RAC Foundation

Summary

Automated vehicles are expected to provide the freedom for their drivers to undertake other activities while the vehicle is in control. However, very little empirical data exists regarding the type of activities that drivers may wish, or indeed expect, to undertake in practice, and the potential impact that this choice of activity could have on the manual resumption of the driving task.

In a novel, longitudinal driving simulator study, 49 experienced drivers undertook a 30-minute commute-style journey at the same time on each of five consecutive days, having brought with them their own devices and artefacts to use. The journey involved periods of manual and automated driving, defined at SAE (Society of Automotive Engineers) level 3 (i.e. participants were told that they might be required to resume manual control, given appropriate notice, during periods of automation).

The aims of the study were:

1. to uncover the type of activities that drivers naturally chose to undertake in a vehicle offering SAE level 3 automation, based on empirical evidence;
2. to understand what impact these activities had on the manual resumption of the driving task under both routine and emergency conditions; and
3. to explore possible techniques to help keep drivers 'in the loop' during periods of automation and thereby rebuild their situational awareness prior to the handover of control; and
4. to explore how participants' behaviour changed throughout the course of the week.

Results show that drivers were quick to develop high levels of trust in and acceptance of the automation, and undertook a range of activities while the vehicle was in control – typically with high visual, manual and cognitive demands. The smartphone was the most popular device, used by over 80% of participants. Reading material (books, printed papers etc.) were also popular, with up to 25% of participants engaging in some form of reading activity during the week; in addition, participants commonly used laptops and tablet computers.

While the types of devices used did not change significantly during the week, the proportion of time (as determined by the visual attention directed towards them) increased from approximately 70% on day one to over 80% on day five (i.e. by the end of the week, less than 20% of time was spent directed at the road scene).

Subjective ratings confirmed the high levels of trust and acceptance; moreover, these ratings increased as the week progressed, even after an unexpected, emergency handover on the fourth day, with the highest ratings of acceptance being recorded on day five.

Drivers also indicated high levels of situational awareness, although ratings were lower following the unexpected, day four perturbation – particularly with regard to the demands for and supply of their attentional resources (as revealed by the Situational Awareness Rating Technique).

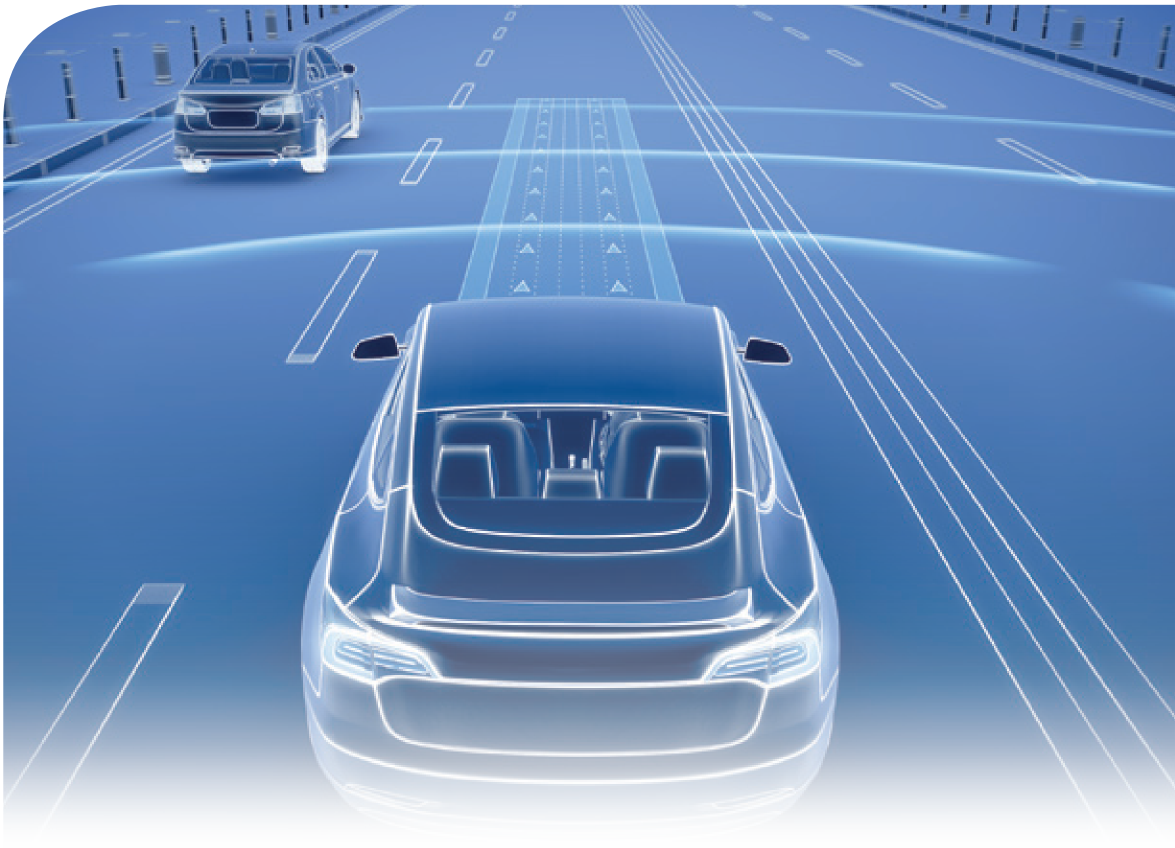
Behavioural indicators suggest an increase in the level of complacency and confidence that drivers held regarding their own ability to take control as the week progressed. For example, drivers showed an increasing tendency as the week progressed to use the 60-second prepare-to-drive notification period (associated with scheduled handovers) to casually dispense with their secondary activities rather than actively preparing to drive.

In practice, initial driving performance after the transfer of control was poor, with high levels of lateral instability and speed variability being manifest during the ten seconds immediately following scheduled handovers. However, driving performance improved significantly with experience throughout the week. Driving performance was also arguably better following the emergency handover – which was suspected to be due to heightened driver arousal associated with the event notification.

Human-machine interface (HMI) design appeared to play an important role in facilitating the efficient resumption of control. For example, providing a feedback HMI – showing the current status of the automated control system – reduced the time to 'driver readiness' (defined as at least one hand being on the steering wheel and a first glance directed towards the road scene) during the emergency handover of control. Additionally, providing a tactical ('top-down') handover HMI – encouraging drivers to check for hazards prior to assuming control – increased mirror checks during the transition, compared to a control ('bottom-up') HMI advising drivers simply to 'take control' – and this difference was evident even during the emergency handover.

Results as a whole indicate a strong need for new driver skills when it comes to future vehicles offering automated functionality, to ensure that drivers efficiently monitor system status displays, and are able to resume control smoothly and safely. The study also provides valuable insights and data for policymakers regarding how people are likely to interact with their future SAE level 3 automated vehicles – and the potential impact that the interaction activities may have on their ability to resume control.

1. Background



Autonomous, that is fully automated, vehicles are expected to offer a number of benefits, including improvements in road safety, increased mobility, enhanced driver comfort and reductions in road congestion [1]. Relinquishing responsibility for vehicle control would also allow drivers to use journey time for non-driving-related tasks, potentially providing a more enjoyable and productive experience during everyday car travel [2].

However, fully automated vehicles are not likely to populate our roads for quite some time [3]. In the meantime, there is an expectation that vehicles offering lower levels of automated control, or those that pose the ability to operate autonomously in certain situations only (e.g. geofenced or 'traffic jam assist'-type technologies), are more likely to be seen.

The Society of Automotive Engineers (SAE) [4] categorises six levels of ascending automation (from levels 0 to 5), that differ in the extent to which the system intervenes in vehicle control, and whether and by how much the human driver needs to monitor the system (in anticipation of potentially taking over control) (Table 1.1). Intermediate, 'level 3' vehicles (also referred to as "conditional automation"), capable of providing functionality such as traffic jam assist and automated highway driving, are expected to be available in the

UK in the next few years [3]. However, at level 3, the human driver is still expected to be responsible for the vehicle's actions, and consequently must be available and prepared to resume manual control in situations that the vehicle cannot handle. It has therefore been suggested that SAE level 3 automated vehicles allow drivers to "become hands and feet free, but not necessarily 'mind free'" [5]. Moreover, the situations in which drivers must regain manual control of automated vehicles may occur unexpectedly and require fast responses, and thus human drivers might find themselves ill-prepared for the transfer of control [1, 5, 6].

Table 1.1: Society of Automotive Engineers (SAE) levels of automation

Level	Name	Description
0	No automation	Human driver completely controls the vehicle.
1	Driver assistance	Individual activities which assist steering or acceleration/deceleration are partially automated.
2	Partial automation	Several, simultaneous activities which assist steering or acceleration/deceleration are partially automated.
3	Conditional automation	In certain driving scenarios, all dynamic, non-strategic, driving activities (e.g. vehicle control but not route choice) are automated but human is expected to intervene when requested.
4	High automation	In certain driving scenarios, all dynamic driving activities are automated and vehicle can cope with human not intervening if and when requested.
5	Full automation	Always and everywhere, all dynamic driving activities are automated with no need for human intervention.

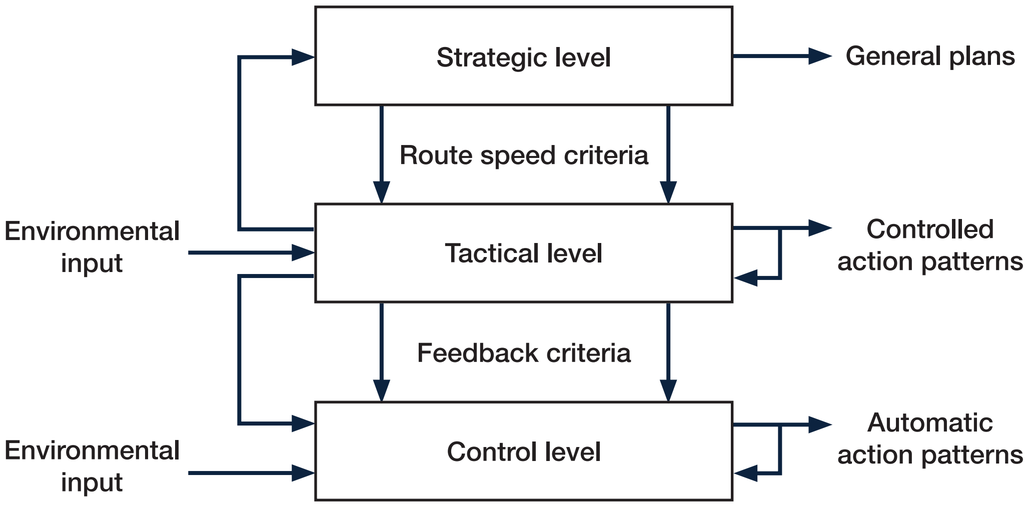
Source: adapted from SAE International (2014), modified

Even in a situation where the takeover request is scheduled and expected to occur, a major concern is that drivers are likely to have become 'out-of-the-loop' (OOTL), i.e. they have not been required to actively monitor, make decisions about or provide physical inputs to the driving task [7]. This reduces their perception and comprehension of elements and events in their environment, and their ability to project the future status of these things – their so-called situational awareness. The driving skills hierarchy [8] (Figure 1.1) identifies situational awareness as a key element at the tactical level of driving. The hierarchy describes the relationship between strategic (planning), tactical (manoeuvring) and control (operational) elements of the driving task in a top-down relationship. The highest, 'strategic' level involves defining the overall journey goals and general plans, including route and mode choice. At the tactical level, drivers negotiate the directly prevailing circumstances in controlled action patterns, involving obstacle avoidance, gap acceptance,[1] turning, overtaking and so on, for which situational awareness is important. The 'control' level (at the bottom of the hierarchy) defines the physical control actions (or automatic action patterns) associated with safe vehicle manoeuvring (steering, braking, mirror checks etc.). To date, proposed takeover requests (issued by the vehicle) typically exist as a 'bottom-up' approach (with respect to Michon's driving skills hierarchy [8]), demanding simply that the driver 'take control' (using

1 'Gap acceptance' is defined as the minimum amount of time (or sometimes space) within which a driver is willing to contemplate undertaking a manoeuvre which involves exploiting a gap between two moving vehicles.

lower-level skills), without attempting to assess or rebuild their situational awareness (using higher-level skills) prior to handing over control.

Figure 1.1: Driving skills hierarchy (after Michon [8])



Source: Adapted from Michon [8]

A further concern is that, given the absence of responsibility for primary control actions during automated driving, human drivers will also be likely to engage in non-driving-related activities, which could in and of themselves contribute to the loss of awareness of the vehicle system state and external driving environment (as drivers become cognitively captivated by their chosen activities). Previous, preliminary work has shown that, given complete freedom to select and engage in activities of their own choosing while the vehicle is in control (even when told that they might have to resume control), drivers selected highly engaging activities – often involving strong visual, manual and cognitive elements – and quickly become absorbed in them, at the expense of their awareness of the external driving situation [2]. In addition, drivers engaged in non-driving-related tasks during automated driving have been found to show greater signs of fatigue and mind-wandering, and to display slower reaction times to takeover requests, as measured by the time taken to look at the road, and place their hands on the steering wheel and their feet on the pedals (typical indicators of readiness to drive) [9].

The aim of the current project was to extend the preliminary investigation conducted by Large et al. [2] by recruiting a larger, representative cohort of drivers, and employ a comprehensive range of quantitative and qualitative measures to determine the types of behaviour prevalent when a level 3 vehicle is notionally 'in control', and the impact that these behaviours have on drivers' ability to resume manual control. It is important to note that, as with the preliminary investigation conducted by Large et al. [2], no restrictions were applied to the nature of activities in which participants could partake while the vehicle was in control – they were simply told to imagine what they might do in such a situation and bring any items they would require to accomplish this (smartphone, laptop, book etc.); they were then free to engage with them. In the context of the current, ongoing reviews of the legal framework for automated vehicles conducted by the UK Law Commission and UNECE (the UN Economic Commission for Europe), the study therefore provides valuable insights and data for policymakers regarding how people are likely to interact with their future level 3 automated vehicles, and the potential impact that these might have on their ability to resume manual control when required to do so.

Furthermore, recognising the fact that drivers' awareness of their surroundings is likely to diminish when they are engaged in secondary activities, and in the light of the driving skills hierarchy, a secondary aim of the study was to explore possible techniques and remediations to help keep drivers 'in the loop' during periods of automation, and to rebuild their situational awareness prior to the handover of control. For example, an HMI (human–machine interface) providing details of the current vehicle status (sensor operability etc.) provided drivers with an indication of the vehicle's ability to maintain control (potentially enabling them to predict an impending transfer of control), and a novel 'top-down' takeover request began by providing tactical-level information to focus the driver's attention (i.e. to increase their situational awareness) prior to the issuing of a request at the control level.

Finally, the conducting of a longitudinal study that required participants to attend on five consecutive days enabled exploration of behavioural adaptations that took place over the week. This approach is highly novel when compared with previous studies (e.g. [1]), which have typically exposed drivers to these future vehicles on one day only (with interactions lasting less than an hour).

The study aims can be summarised as follows:

- to document the types of activities naturally undertaken by drivers during SAE level 3 automation;
- to explore the impact of these activities on drivers' ability to resume manual control;
- to explore possible techniques to help keep drivers 'in the loop' during periods of automation and thereby rebuild their situational awareness prior to the handover of control; and
- to explore behavioural adaptations seen in drivers over an extended time period (a week).

2. Methodology and Approach

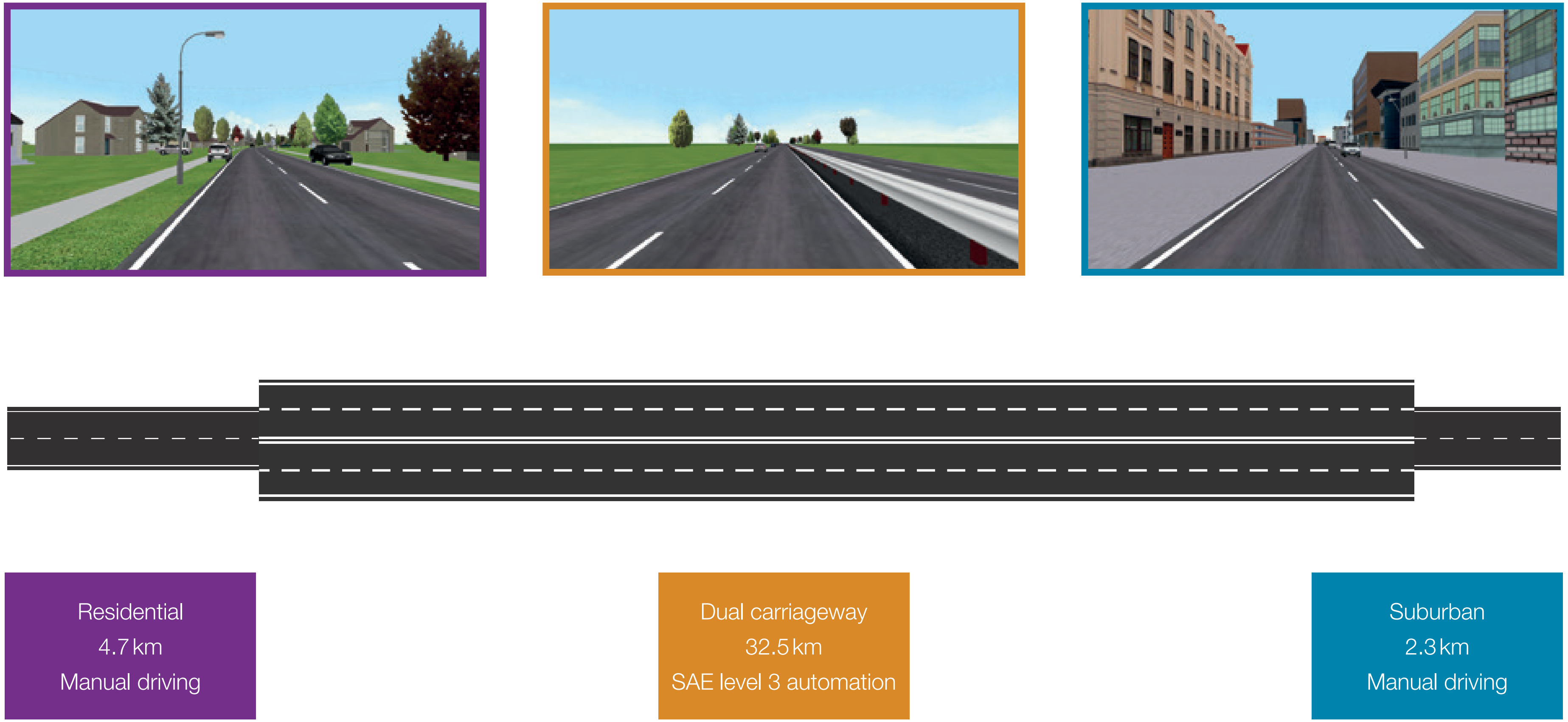
The study took place in a medium-fidelity, fixed-base driving simulator at the University of Nottingham (Figure 2.1). The simulator comprises a right-hand drive Audi TT car positioned within a curved screen, affording a 270-degrees forward and contiguous side image of the driving scene via three overhead high definition projectors, together with rear and side mirror displays. A Thrustmaster T500RS force feedback steering wheel and pedal set are integrated faithfully with the existing Audi primary controls, with the dashboard created using a bespoke application and presented on a 7-inch LCD screen, replacing the original Audi instrument cluster. Four video cameras are strategically located within the vehicle to record participants' behaviour.

The simulated driving environment was created using STISIM Drive software (version 3) (see https://stisimdrive.com), and was designed to replicate a typical commuting journey lasting approximately 30 minutes. Participants began in a residential location (described to them as their home), progressed through a rural setting, joined a UK two-lane dual carriageway (comprising the majority of their journey experience), and finally arrived in an urban/city environment (described as their place of work) (Figure 2.2). All the roads involved were populated with moderate to high levels of traffic (befitting a commute-style journey), authentic road signage, and geotypical roadside artefacts and terrain.

Figure 2.1: University of Nottingham driving simulator, showing external (top) and internal (bottom) views

Source: Authors' own

Figure 2.2: Representation of journey showing residential, dual carriageway and city elements



Source: Authors' own

The simulator was modified to mimic the capabilities of an SAE level 3 automated car, insofar as the driver was able to relinquish the physical primary control actions (steering, accelerating and braking). However, automation was available only on the dual carriageway, replicating a geofenced situation; moreover, there was no lead vehicle ahead of the participants' vehicle. The vehicle's capabilities were described in detail to participants at the start of the study based on the SAE definition of level 3 automated control [4]. Specifically, participants were informed within an information sheet:

> "The vehicle is capable of controlling all aspects of the driving task. However, you may be required to resume manual control given appropriate notice."

Prior to attending, participants were asked to consider what they might like or expect to do on such a journey in an 'automated' vehicle, and bring with them any objects or devices (i.e. their own belongings) to enable these activities. No restrictions were placed on what participants were allowed to do, to avoid pre-empting or influencing their expectations and behaviour.

Participants attended at the same time of day on five consecutive weekdays, with the entire experience framed as a week of daily commutes to work. Adopting a longitudinal approach in this way allowed the exploration of any behavioural adaptations during the week, and increased the ecological validity of the study (defined as the extent to which the findings are generalisable to real-life settings [10]).

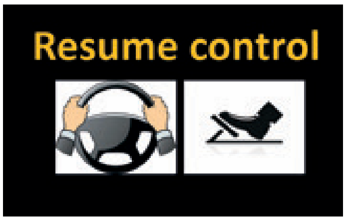
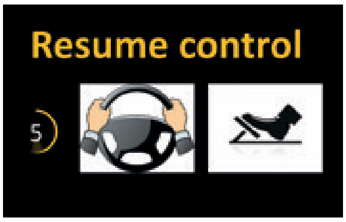
2.1 Human–machine interface

An in-vehicle HMI was installed in the centre console of the vehicle. This provided system feedback throughout the drive, delivered via an interactive PowerPoint presentation controlled remotely by the researcher. Feedback included information such as whether automation was available or not, the current status of the automated control, and guidance during handover requests. Feedback was provided both visually (in the form of text-based messages and images) and audibly (by tones and spoken messages). Participants were alerted to any updates to the information presented using a tone. These differed depending on the nature of the change. For example, a more urgent tone was used to indicate an emergency takeover request. The selection and presentation of the correct feedback (visual and auditory) was controlled remotely by the researcher, without the participant being aware of this human involvement – this is known as a 'Wizard of Oz' approach [11].

As part of the experimental design, the specific nature of the information displayed varied between groups of participants, being presented either as 'top-down' or 'bottom-up' handover advice (see Table 2.1). The 'top-down' approach differed in that participants were provided with animated guidance to check for hazards (highlighting important areas, such as the mirrors, the road ahead etc.), in addition to a count-down timer, during the 10-seconds prior to taking control. In contrast, the 'bottom-up' take-over request simply instructed the driver to "take control". Each participant experienced only one of the handover strategies, and this remained consistent throughout the week.

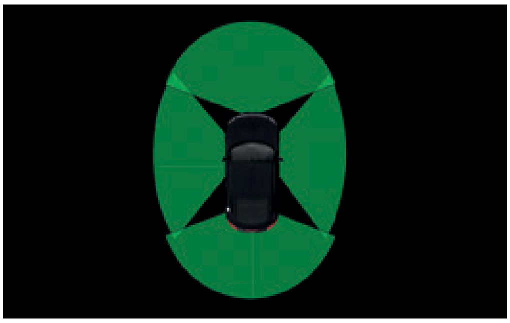
In addition, a feedback HMI showing system 'health' was provided (Table 2.2). This was intended to provide an 'intuitive' overview of the current state of the vehicle's sensors and control system, and therefore an indication of the vehicle's ability to safely provide control. In the real world, factors that could theoretically influence this might include the presence of an external hazard, or a problem with the operational integrity of the sensors or control system, although the system health status feedback HMI was not necessarily intended to replicate a specific real-world system.

Table 2.1: Text-based and pictorial messages for 'top-down' and 'bottom-up' handover advice (changes were accompanied by an appropriate alerting tone and/or voice message)

	Handover advice	
	Top-down (tactical)	**Bottom-up (control)**
Routine takeover request (60 s)		
Routine takeover request (10 s)		 
Emergency takeover request (10 s)		

Source: Authors' own

Table 2.2: Automated system feedback human–machine interface (participants were not explicitly told what each representation meant)

Representation	Status
	**Green**: The sensors are working fine. No action required.
	**Amber**: Warning. The sensors may be faulty or dirty. No immediate action required.
	**Red**: Sensors failure. The driver must immediately take control of the vehicle.

Source: Authors' own

For those participants receiving system health status feedback, the in-vehicle HMI displayed the status of the cars sensors as green, amber or red, indicating increasing levels of severity. Drivers were notified of changes to sensor status (i.e. green to amber) with a non-intrusive tone, and the associated change of colour. This occurred seldom during the week and only for short periods of time (circa 30 seconds), without any accompanying external stimuli in the driving environment.

In practice, the study was conducted as a 2×2 between-subjects design, with four separate conditions to compare differences between HMIs and handover strategies (Table 2.3).

Table 2.3: Experimental design

		System status	
		Feedback	**No feedback**
Handover strategy	Top-down (tactical)	Condition 1	Condition 2
	Bottom-up (control)	Condition 3	Condition 4

Source: Authors' own

As a further novel element of the study design, inclement weather (thick fog) was added to the simulated driving environment part way through the period of automated control on day four. This caused the vehicle's sensors to 'fail' and necessitated the emergency handover of control back to the driver. For participants who received system feedback, this was indicated by the sensor display turning red, accompanied by an urgent alarm and the spoken message: 'fog detected', with manual control provided ten seconds afterwards. Ten seconds was chosen for the duration of transfer of control on the basis of an understanding of current technological capabilities, and corresponds with existing literature and recommendations [12]. For participants who did not receive system feedback, the HMI simply indicated 'autonomous mode' or 'manual driving', throughout, as appropriate. After driving manually for approximately 15 kilometres (which took around eight to ten minutes), the fog cleared and automation became available again. Those participants who chose to re-engage with automated driving were subsequently provided with a routine handover, as on other days, towards the end of the dual carriageway (where the geofenced area ends and manual driving is required).

2.2 Handover and takeover requests

Requests made by the participants to take over and hand over control (as appropriate) were made using a spoken command. Spoken language interfaces are increasingly commonplace in technological applications and can offer a quick, intuitive and increasingly reliable means of interaction. In addition, they do not require users to learn a new HMI or interaction method, but instead typically rely on the use of familiar, 'natural' language. In the current study, participants were required to use an appropriate command, preceded by the keyword "Autocar" (akin to current commercial products, such as Amazon Alexa). For example, "Autocar: start automated driving" requested the handover of control from participant to car.

As far as participants were aware, this automatically initiated the change of state. In practice, it prompted the researcher to make the change manually via the simulator software control portal. Participants were also able to switch between manual and automated driving as and when desired, by using the appropriate command, assuming automation was available. If the change was not possible – typically if the driver requested automated control other than on the dual carriageway or in the midst of heavy fog, or failed to use the keyword "Autocar" – there was no response, and no change took place.

2.3 Participants

Fifty-two participants were recruited to take part in the study. All participants were experienced drivers (with more than two years of driving experience, and driving regularly), and comprised primarily employees and postgraduate students at the University of Nottingham. Unfortunately, three of the participants were unable to complete the study owing to simulator sickness occurring part way through the week, leaving a total of 49 participants (27 male, 22 female; mean age: 32, range: 21–64; mean annual mileage: 5,621) (Table 2.4). Participants were matched as closely as practicable between the four different conditions for age, gender and driving experience. They were recruited by means of advertisements placed around the University of Nottingham campus and sent via email, and were reimbursed with £50 in shopping vouchers as compensation for taking part.

Table 2.4: Participant demographics

Condition	n	Age				Gender		Miles per year
		Min	Max	Mean	Standard deviation	Male	Female	
1	13	21	64	34	13.6	8	5	4,860
2	12	23	56	30	12.0	8	4	4,563
3	14	23	47	30	6.2	6	8	5,579
4	10	23	55	36	11.6	5	5	7,940
All	49	21	64	32	10.7	27	22	5,621

Source: Authors' own

2.4 Procedure

Participants began by driving manually (i.e. they were responsible for all primary control actions). Automated control was made available to drivers only when they joined the dual carriageway, which occurred approximately five minutes into the journey. This was indicated to participants by a text-based message presented on the in-vehicle HMI. The decision to transfer control to the vehicle was entirely at the participants' discretion – they were free to delay the transfer of control, resume manual control part way through, or, indeed, avoid using automated control entirely, if they so desired; no specific instructions were provided.

Participants were told that during periods of automation, they were permitted to engage in their chosen activities as they saw fit – no restrictions were applied other than making drivers aware at the start of the study that they might be required to resume manual control given appropriate notice.

Towards the end of the dual carriageway (which was approximately 20 minutes later), drivers were provided with a scheduled handover. In preparation for this, the in-car HMI provided participants with a "prepare to drive" warning (auditory and visual), delivered 60 seconds prior to takeover. This was followed by a takeover request delivered ten seconds prior to the provision of control.

Takeover requests were devised based on driving skills hierarchy [8]. Half the participants received 'bottom-up' advice, instructing them to 'resume control' (i.e. at the operational/control level) – the assumption is that these drivers subsequently acquire 'tactical' knowledge *after* they resumed physical control (i.e. no further advice was provided as part of the handover). The remaining participants received 'top-down' advice, initially advising them to 'check for hazards' (a 'tactical' action) – by guiding their visual attention towards the road scene, mirrors, and so on – *before* instructing them to resume control; in addition, participants receiving 'top-down' advice were provided with a countdown timer (displayed on the HMI) for each stage of the handover.

Participants always completed the journey by driving manually, for a further five minutes (approximately) after the dual carriageway ended. This was primarily to create an ecologically valid journey experience [10], but also allowed us to determine the immediate effect of the automation on manual driving skills. In addition, it ensured that participants' manual driving skills and exposure were 'recalibrated' before leaving the testing environment, i.e. to prepare participants for potentially driving their own vehicle later that day. Following each drive, participants completed the questionnaire about trust in a specific technology [13], the situational awareness rating technique (SART) scale [14] and the technology acceptance questionnaire [15]. Participants were in attendance for approximately one hour per day.

3. Results and Analysis

3.1 Measures and analysis approach

A large amount of data was generated by this longitudinal study. To provide focus, gaining understanding of three areas in particular was of interest:

1. the type of activities drivers chose to undertake in a vehicle offering SAE level 3 automation;
2. what impact these activities had on the manual resumption of the driving task under both routine and emergency conditions; and
3. how participants' behaviour changed throughout the course of the week.

The study approach, in terms of both measures and analysis, is therefore predicated on understanding and illuminating these three areas of interest. To achieve this, participants provided ratings of trust, technology acceptance and situational awareness using recognised ratings scales. Ratings were provided every day, immediately after each drive, and were subsequently compiled and compared between days.

In addition, split-view videos were captured throughout the entire study to enable an understanding to be gained of the types of activities that were undertaken each day, and how these changed over the course of the week. The videos were also used to extract salient visual indicators (gaze directed towards road situation, mirror checks etc.) during the handover period and immediately thereafter (i.e. during the initial period of manual driving).[2] Videos were coded and analysed on a frame-by-frame basis for the period(s) of interest using the BORIS (Behavioral Observation Research Interactive Software) event-logging software developed by Olivier Friard and Marco Gamba of the University of Turin (http://www.boris.unito.it).

Finally, manual driving performance data was collected using the simulation software. This was interrogated for the first ten seconds of manual driving, immediately after participants took over control, to explore drivers' ability to safely resume control (laterally and longitudinally) after the extended period of automation.

Testing for statistical significance of differences between measures was conducted using SPSS software as and where appropriate, and is elucidated in the appropriate section of the report. Most commonly, an analysis of variance (or ANOVA) test, or a MANOVA, a multivariate extension of ANOVA, was employed to examine whether the means of different groups were equal (including appropriate corrections in situations where multiple comparisons were made, thereby reducing the chance of 'false positive' declarations). In the absence of statistical testing, mean values might appear different, for example, when presented visually on a graph. However, such differences may be due to random variability amongst participants, and might not be generalisable to a wider population.

3.2 Secondary activities

Prior to attending on day one, participants were asked to imagine what they would like to do in a vehicle offering SAE level 3 capabilities (defined to them at the outset) – during a daily commute-style journey – and to bring with them any devices or artefacts that they required to enable these.

It is worth highlighting that while debates are ongoing (particularly amongst the legal community) regarding the types of activities that 'drivers' will be allowed to undertake in such a vehicle during periods of automated control, these are yet to reach fruition. Moreover, there is as yet very little empirical evidence – taken directly from SAE level 3 automated driving – to inform these debates.

Consequently, the study provided drivers with the freedom to exhibit behaviours that were most natural to them – and which may therefore arise whether permitted or not within a vehicle. This also detracted from the experience being seen as a 'controlled' experiment (in which participants were able to select from only a limited range of activities), and avoided pre-empting any legislative control.

Frame-by-frame video coding was undertaken to identify the types of devices and activities undertaken by participants during periods of automation. Behaviours were coded at a 'device' level – that is to say, specifying the primary device used, rather than the specific activity undertaken using the device; for example, 'smartphone' was reported rather than 'accessing emails'. This was to ensure the privacy of participants. To explore any

2 It was not feasible to use eye-tracking techniques owing to ethical and privacy concerns.

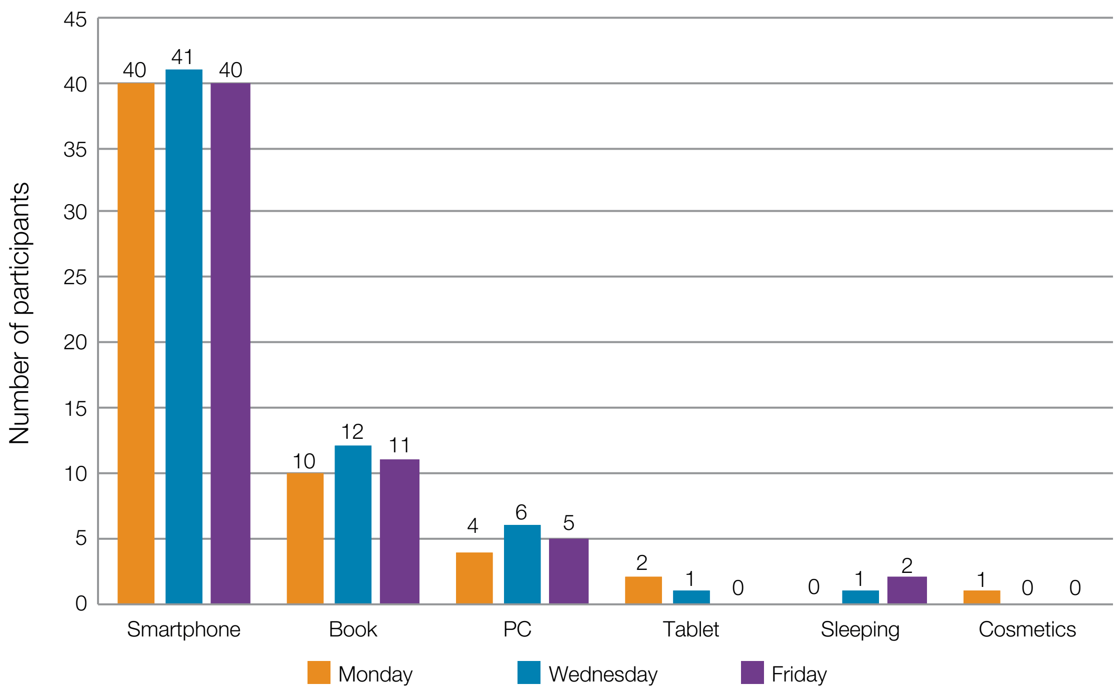
behavioural adaptations across the week's experience, results from day one (Monday), day three (Wednesday) and day five (Friday) are presented here.

3.2.1 Devices used

At an aggregate level, results are perhaps unsurprising. The most common item used by participants, for example, was their smartphone (Figure 3.1). A phone was used by over 80% of participants, and this remained consistent throughout the week.

The next most popular activity was reading a book/magazine or printed papers (identified as 'Book' in Figure 3.1), with up to 25% of participants engaging in some form of reading activity during the week. Again, this remained largely unchanged as the week progressed. Other recorded activities were using a laptop ('PC') or tablet computer, and there was also some incidents of people sleeping, although this was rare – one person did so on Wednesday, and two on Friday.

Figure 3.1: Secondary devices used and activities undertaken during periods of automation



Source: Authors' own

Of note is that most of these activities were highly engaging, generally involving strong visual, cognitive and manual elements. Moreover, participants appeared quite comfortable, even from day one, to engage with these tasks –soon after the opportunity presented itself – despite their ongoing responsibilities towards the vehicle operating at SAE level 3 automation.

Representative examples of device usage are shown in the split-view images in Figure 3.2 to Figure 3.15. It is evident from these that engaging in secondary activities had a marked effect on drivers' apparent readiness to resume control. In particular, issues of visual distraction (e.g. reading a book– Figure 3.5 and Figure 3.6), cognitive distraction (e.g. participant engrossed in a smartphone exchange – Figure 3.2 and Figure 3.4) and manual distraction (e.g. participant using a laptop – Figure 3.10 and Figure 3.11), were evident. Moreover, participants were apparently willing to undertake these activities at the expense of their awareness of the road scene – the participant reading in Figure 3.9, for example, has little hope of seeing the road ahead.

Furthermore, there was evidence that the activities in and of themselves had a marked effect on drivers' state and physical surroundings, with participants repurposing their cabin (lap/steering wheel etc. – Figure 3.6, Figure 3.7 and Figure 3.10), or relaxing their seating position or posture to accommodate secondary task execution. On occasion, drivers had completely repurposed their cabin and were engaged in using multiple items (Figure 3.8, here shown at the point of requested handover).

As a consequence, these drivers were not only required to lay aside their secondary activity prior to resuming control, but also to re-establish appropriate driving posture (by repositioning the seat, sitting upright etc.) (Figure 3.13). For some drivers, secondary activities also necessitated the wearing of reading glasses, and again these needed to be removed and stored prior to taking control (Figure 3.12).

Even so, there was some evidence of drivers remaining vigilant – apparently selecting secondary activities that still enabled them to maintain attention on the road scene, or using items in a manner that enabled quick lay aside. For example, the participant shown in Figure 3.3 is listening to music on his smartphone while watching the road scene ahead. In addition, the driver in Figure 3.11 is holding his laptop to the side, presumably to enable quick placement on the passenger's seat if required, although this might also be necessitated by the presence of the steering wheel, which physically prevented the driver from placing the laptop on his lap (although by doing so, the HMI is notably obscured). There were also some drivers who were apparently comfortable sleeping while the vehicle was in control (Figure 3.14 and Figure 3.15).

Figure 3.2: Example of participant using a smartphone

Source: Authors' own image from driving simulator

Figure 3.3: Example of participant using their smartphone as a music player, while still directing visual attention at the road scene

Source: Authors' own image from driving simulator

Figure 3.4: Example of participant using a smartphone

Source: Authors' own image from driving simulator

Figure 3.5: Example of participant reading a book

Source: Authors' own image from driving simulator

Figure 3.6: Example of participant using the steering wheel to support their book while reading

Source: Authors' own image from driving simulator

Figure 3.7: Example of paperwork obscuring vehicle dashboard/HMI

Source: Authors' own image from driving simulator

Figure 3.8: Example of participant engaged in multiple activities

Source: Authors' own image from driving simulator

Figure 3.9: Example of participant completely obscuring their view of the road scene while reading

Source: Authors' own image from driving simulator

Figure 3.10: Example of participant supporting their laptop against the steering wheel during use

Source: Authors' own image from driving simulator

Figure 3.11: Example of participant holding their laptop to the side, but obstructing their view of the HMI while doing so

Source: Authors' own image from driving simulator

Figure 3.12: Example of participant reading from a tablet computer (note: participant is wearing reading glasses)

Source: Authors' own image from driving simulator

Figure 3.13: Example of participant adjusting seat and posture in preparation for handover

Source: Authors' own image from driving simulator

Figure 3.14: Example of participant sleeping

Source: Authors' own image from driving simulator

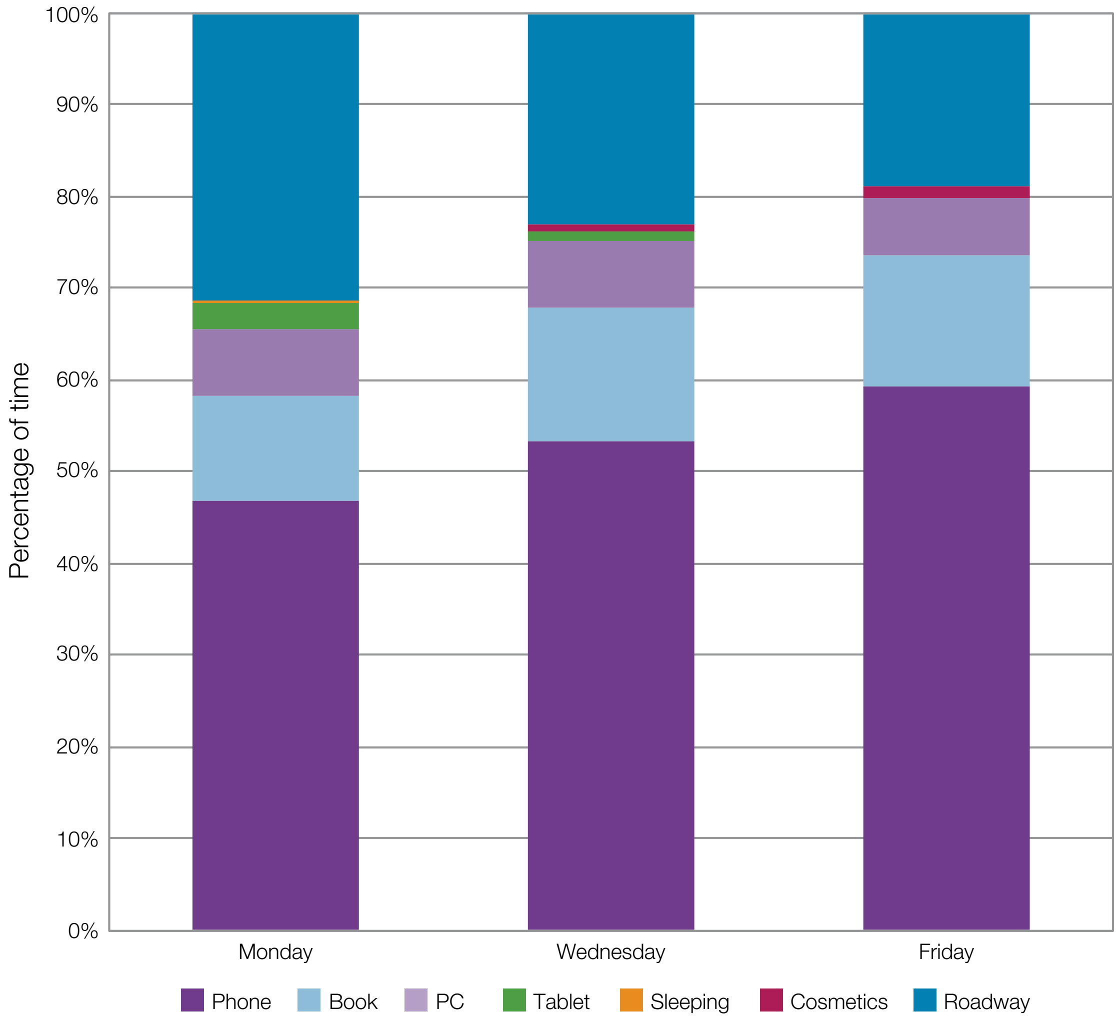
Figure 3.15: Example of participant sleeping

Source: Authors' own image from driving simulator

There was also some evidence that even while participants were engaged in their chosen activities, they still returned their visual attention to the road scene, through occasional glances.

Figure 3.16 shows the mean percentage of time that participants spent engaged in (i.e. directing visual attention towards) their secondary activities, and the percentage directed to the roadway. Of note is that on day one (Monday), almost 70% of participants' visual attention was directed at the secondary activities, with the majority of this directed towards smartphones. Even so, approximately a third of the time was spent looking at the roadway. However, there is a clear pattern as the week progresses, with participants directing less and less visual attention at the road scene, and more at their secondary activity. By day five (Friday), over 80% of visual behaviour is associated with the secondary device/activity, and less than 20% with the road scene. Statistically, the amount of time spent looking out of the vehicle reduced significantly as the week progressed ($F(2,100) = 8.1$, $p = .001$, $\eta_p^2 = .139$).[3]

Figure 3.16: Mean percentage of time spent engaged in secondary activities and looking at roadway during automation



Source: Authors' own

3 The ANOVA family of statistical tests are based on the assumption that the data (specifically, the group means) are similar between groups (i.e. no differences exist). To interpret the results of an ANOVA test, the following values are generally reported:
The *p* value tests the hypothesis that different groups have the same means (in this case, there is no difference in the amount of time spent looking out of the vehicle between days). If *p* is small (typically, less than 0.05), it is unlikely that the differences observed are due to random sampling. Thus, we can conclude that the differences between groups are statistically significant.
The F value is the ratio of two mean square values. Thus, a value of 1.0 indicates no difference, whereas values above 1.0 indicate that the variation among group means is more than would be expected to be seen by chance.
Partial eta-squared (η_p^2) measures the proportion of the total variance ('effect size') that is due to the variable under examination (other variables may also contribute to differences), and is presented as a decimal.

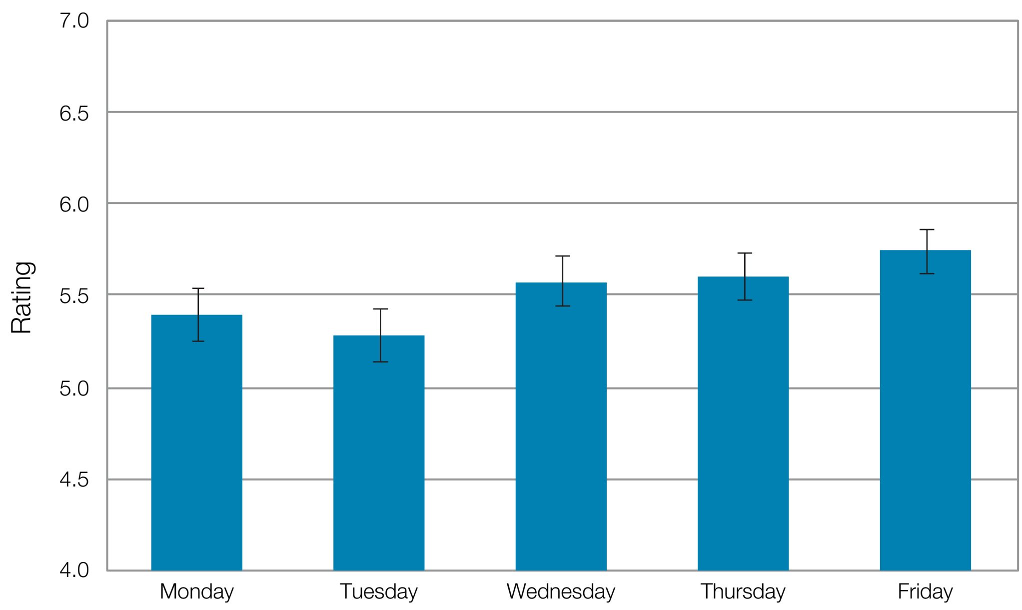
3.3 Trust, technology acceptance and situational awareness

Existing well-established rating scales were utilised to record participants' subjective assessment of their trust in and acceptance of the technology, and their situational awareness, with questionnaires administered immediately after each drive.

3.3.1 Trust

The trust in a specific technology scale [13] is a validated questionnaire that recognises the role that trust plays in technology-related applications (see Appendix A). Responses show that initial trust on day one (Monday) was above the scale median of four (with a rating of 5.4), and thereafter, trust generally increased throughout the week (Figure 3.17). Interestingly, there was no apparent detriment to trust following the emergency handover, either on day four (Thursday) immediately after the experience or indeed, on the following day (Friday). An ANOVA test revealed that differences between daily ratings were significant ($F(4,196) = 6.5$, $p < .001$, $\eta_p^2 = .118$). Pairwise comparisons with Bonferroni corrections for multiple comparisons indicated that ratings on days three, four and five (Wednesday, Thursday and Friday) were significantly higher than those made on day two (Tuesday) ($p < .001$, $p = .047$ and $p = .001$, respectively).

Figure 3.17: Trust in a specific technology ratings with standard error bars, where 1 = "Strongly disagree" (indicating minimum trust) and 7 = "Strongly agree" (indicating maximum trust), with standard error bars



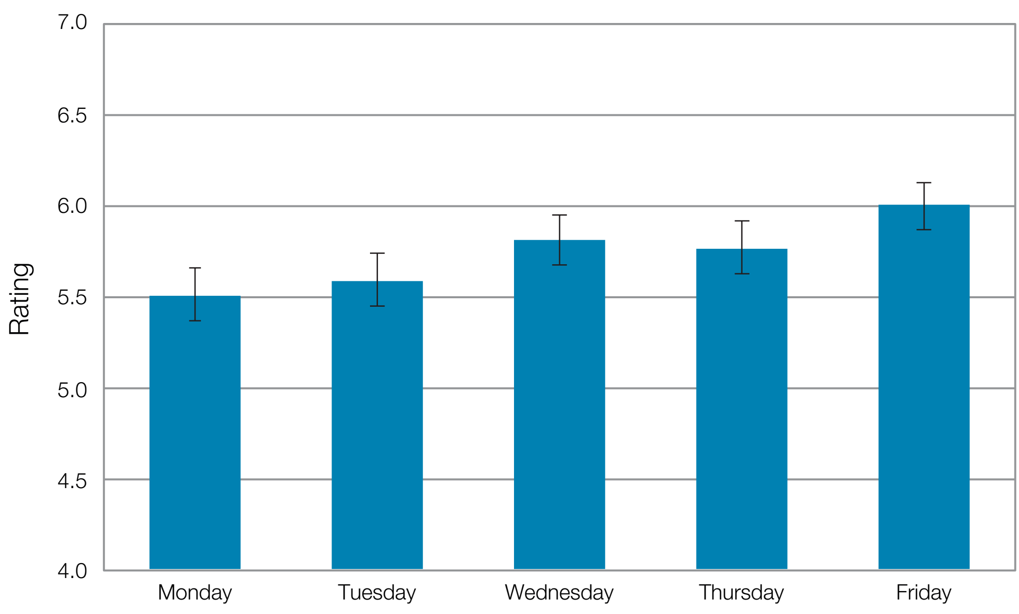
Source: Authors' own

3.3.2 Technology acceptance

The technology acceptance model questionnaire [15] (see Appendix A) was used to measure participants' *acceptance* of the technology, in this case, the automated vehicle. Ratings for technology acceptance indicate that initial acceptance on day one (Monday) was again above the scale median of four (with a rating of 5.5), and generally increased throughout the week (Figure 3.18), although there was an apparent dip in acceptance immediately following the emergency handover experienced on day four (Thursday).

An ANOVA test revealed that differences between daily ratings of acceptance were significant ($F(4,196) = 11.0$, $p < .001$, $\eta_p^2 = .184$). Pairwise comparisons with Bonferroni corrections for multiple comparisons showed that ratings of acceptance on day five (Friday) were higher than those made throughout the rest of the week. In addition, ratings on day three (Wednesday) were higher than those made on days one and two (Monday and Tuesday). This indicates that there was in fact no detriment to acceptance following the emergency handover on day four (Thursday). Moreover, acceptance actually increased the following day.

Figure 3.18: Technology acceptance ratings with standard deviations, where 1 = "Strongly disagree" (indicating minimum acceptance) and 7 = "Strongly agree" (indicating maximum acceptance), with standard error bars



Source: Authors' own

3.3.3 Situational awareness

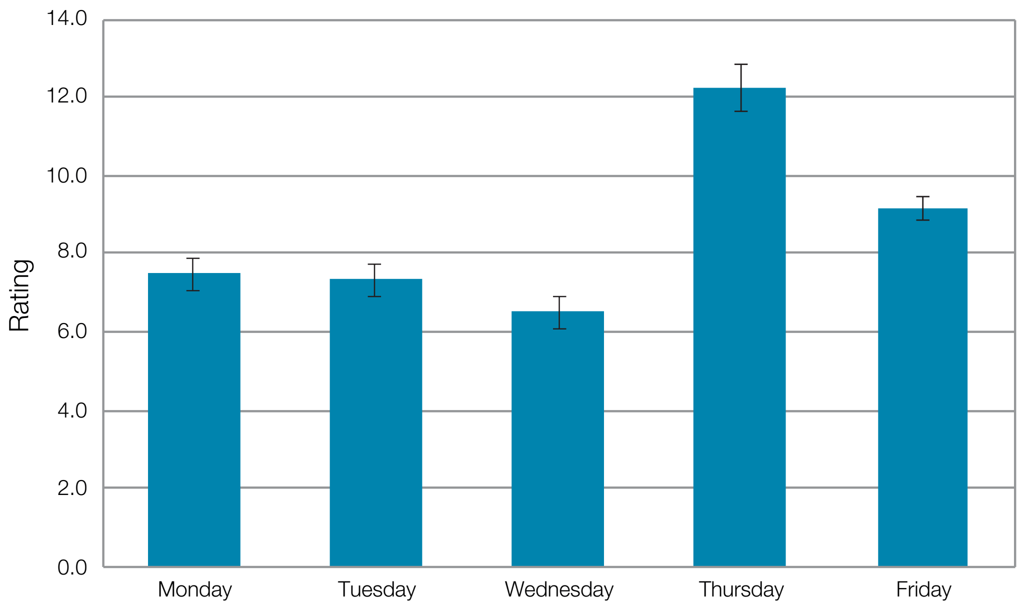
Situational awareness was determined using the SART [14] (see Appendix A). Ratings were combined to elucidate participants' evaluation of:

1. the demands on their attentional resources (complexity, variability, and instability of the situation);
2. the supply of attentional resources (division of attention, arousal, concentration, and spare mental capacity); and
3. their understanding of the situation (information quantity, and information quality).

Demands on attentional resources

Figure 3.19 shows that the demand initially dropped day-on-day as the week progressed (from Monday to Wednesday). However, there was a sharp increase on Thursday (day four) – understandably, given the emergency handover. Although there was a reduction on the following day (Friday – day five), ratings remain higher than they were earlier in the week, suggesting a residual effect of the day four emergency. An ANOVA test revealed that differences between daily ratings of demands on attentional resources were significant ($F(4,196) = 33.5$, $p < .001$, $\eta_p^2 = .406$). Pairwise comparisons, with Bonferroni corrections for multiple comparisons, showed that ratings on day four (Thursday) were significantly higher than on all other days ($p_{max} = .001$), and ratings on day five (Friday) were significantly lower than on day four (Thursday) ($p = .001$), but remained nevertheless significantly higher than on days one, two and three (Monday, Tuesday and Wednesday) ($p = .020$, $p = .003$, $p < .001$, respectively).

Figure 3.19: Demands on attentional resources SART ratings, with standard error bars

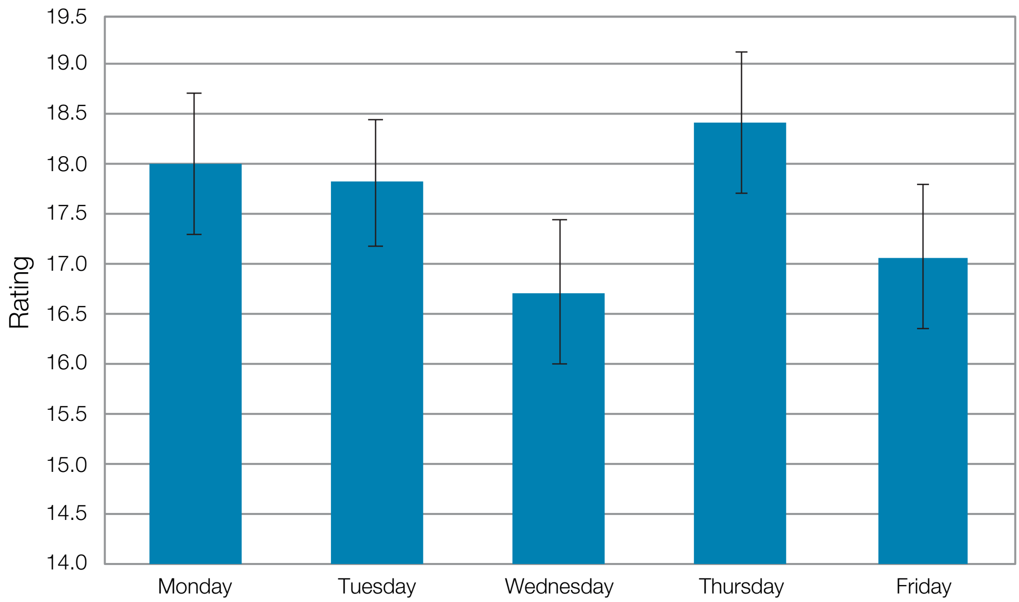


Source: Authors' own

Supply of attentional resources

A similar pattern emerges for the supply of attentional resources, with a decline from day one to day three (Monday to Wednesday), a peak on day four (Thursday) and a subsequent drop on the last day (Friday) (Figure 3.20). However, although a significant effect was revealed ($F(4,196) = 3.4$, $p = .010$, $\eta_p^2 = .065$), differences were significant only between day three (Wednesday) and day four (Thursday) ($p = .020$), indicating a marked effect of the emergency handover on day four.

Figure 3.20: Supply of attentional resources SART ratings, with standard error bars

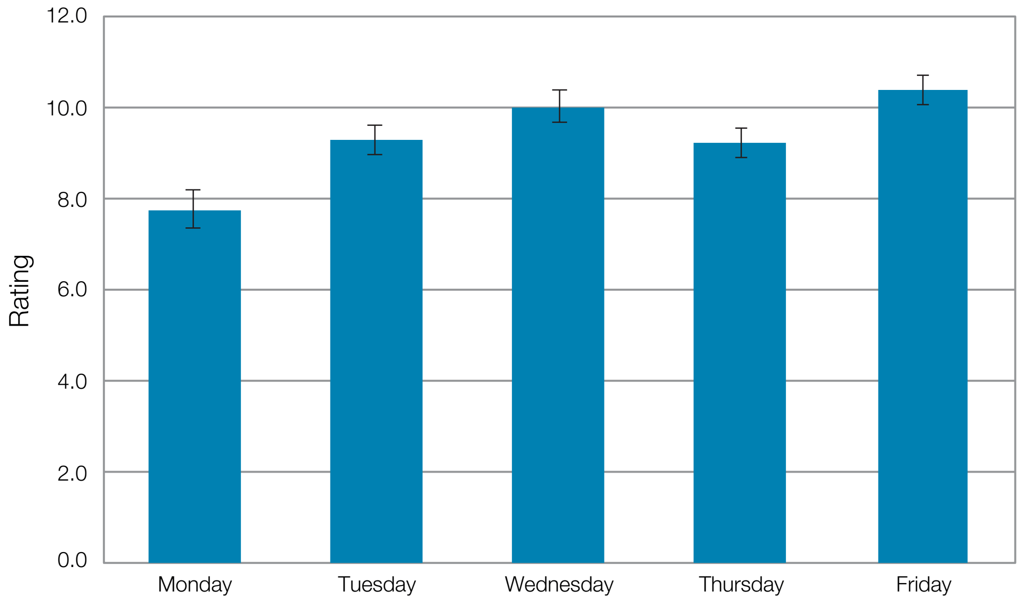


Source: Authors' own

Understanding of the situation

In contrast to other situational awareness measures, participants' understanding of the situation increased as the week progressed (Figure 3.21). There was evidently some 'confusion' on Thursday, indicated by a drop in ratings on day four, although participants' understanding of the situation appeared to increase again the following day. Differences were indeed significant ($F(4,188) = 13.9$, $p < .001$, $\eta_p^2 = .228$), with pairwise comparisons (with Bonferroni corrections for multiple comparisons) indicating that day one ratings were significantly lower than those for the rest of the week ($p_{max} = .018$). In addition, ratings on day five (Friday) were significantly higher than those made on day four (Thursday) ($p = .002$).

Figure 3.21: Understanding of the situation SART ratings, with standard error bars



Source: Authors' own

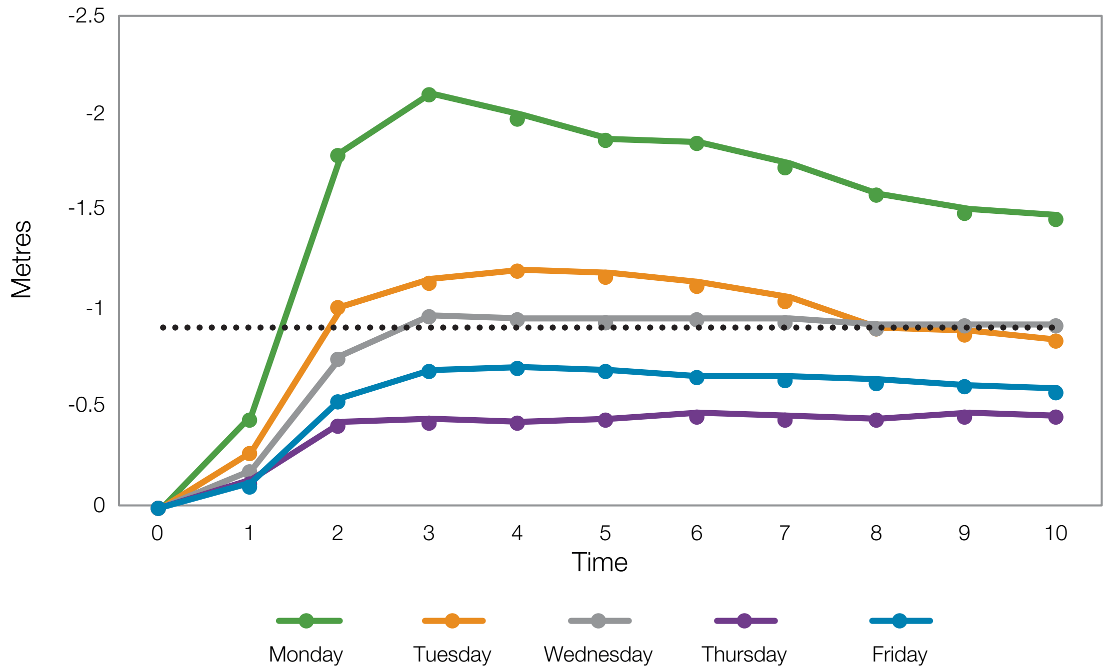
3.4 Manual driving behaviour and performance

In line with previous, similar investigations (e.g. [16]), driving performance during the first ten seconds immediately after resuming manual control was analysed by dividing this into one-second time intervals. Data was captured directly by the simulation software and interrogated to explore variability in lateral behaviour (lane position) and longitudinal behaviour (speed). Additionally, the first control input (accelerator or brake pedal) – after control was handed back – was recorded.

3.4.1 Lane position and lateral instability

The mean lateral lane position from the lane centre immediately following the takeover of control (represented as the position of the centre of vehicle) is shown in Figure 3.22. There is a clear tendency for drivers to move to the left (towards the 'inside' lane) following resumption of control. Driving performance data shows that the lateral movement immediately after resuming control was highly variable. The highest deviation of absolute lane position (from lane centre) was evident on day one (Monday), with drivers, on average, moving up to over 2 metres to the left from the lane centre (peaking at three seconds after resuming control). This shows that on days one, two and three (Monday, Tuesday and Wednesday) the vehicle actually crossed the lane demarcation and moved into the adjoining ('inside') lane (the dotted line in Figure 3.23. shows the location of the centre of the vehicle at the point at which the edge of the vehicle would cross the lane boundary).

Figure 3.22: Mean lateral movement (expressed as the absolute position of centre of vehicle at each time interval from lane centre) in one-second intervals after resuming manual control

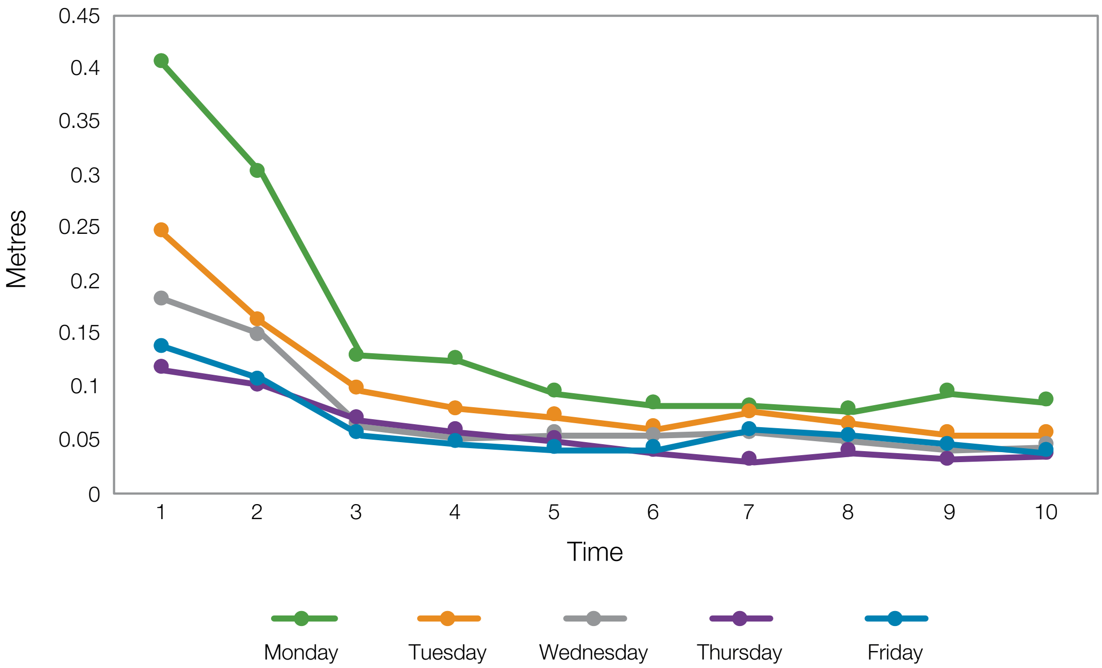


Source: Authors' own
Note: '0' distance represents lane centre, i.e. all movement is to the left (towards the inside/left lane)

It is also notable that the level of lateral control demonstrated by drivers tended to improve as the week progressed, as might be expected. On day one (Monday), drivers typically did not manage to regain their lane position even after ten seconds of manual driving, remaining notably approximately 1.5 metres outside of their lane. On days two and three (Tuesday and Wednesday), it took drivers eight seconds on average to recover their vehicle to within the lane limits. On days four and five (Thursday and Friday), drivers managed to keep their vehicle within the lane boundaries, though still with notable (approximately 0.5 m to 0.8 m) lateral deviation. Interestingly, the smallest deviation from lane centre (arguably the 'best' performance) was evident on day four (Thursday), after the emergency handover.

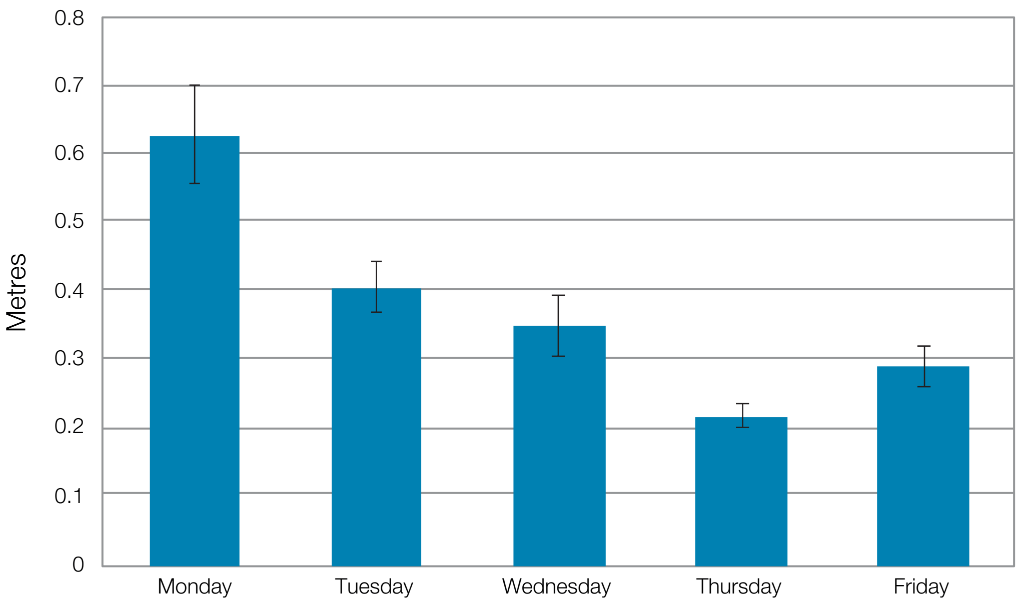
The standard deviation of lane position (SDLP) is a measure of unstable 'wavering' behaviour, with higher values indicative of greater instability. Calculated during the same one-second intervals, values for SDLP are consistent with the absolute lateral lane position, with the highest initial variability (largest SDLP) on day one (Monday), and again, improvements were evident as the week progressed (Figure 3.23). Moreover, the 'best' performance (lowest lane instability) again appears to occur on day four (Thursday), following the emergency handover. It is also evident that for each day a similar pattern emerges, with the SDLP settling down (suggesting improved control) after approximately three seconds, and thereafter remaining more consistent, though some instability is still notably apparent at a level of between 0.05 and 0.1 metres.

Figure 3.23: Mean standard deviation of lane position (variability during each time period) in one-second intervals after resuming manual control



Source: Authors' own

Figure 3.24: Mean standard deviation of lane position (lane variability) during the full ten seconds after resuming manual control, with standard error bars



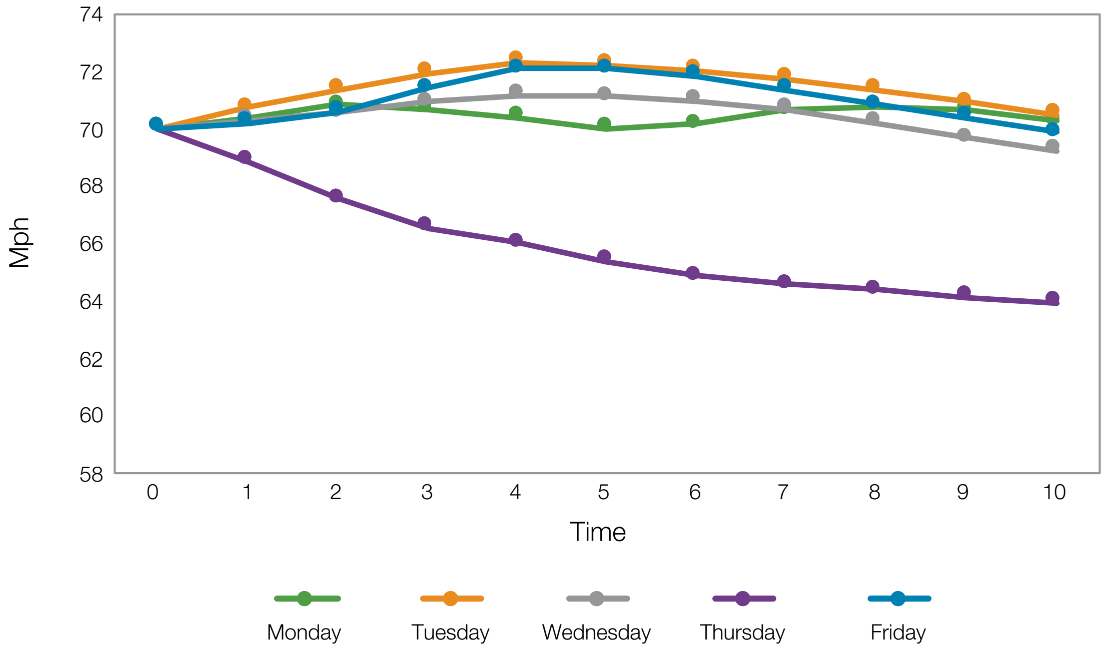
Source: Authors' own

Considered over the entire ten-second period after the resumption of manual control (Figure 3.24), the standard deviation of lane position appears much greater overall (compared to Figure 3.23), as the figures encompass the large variability on day one (with lateral deviations of up to 2 metres during the first 1.0-second time interval – see Figure 3.22), as well as the more controlled behaviour during the latter time intervals (with lateral lane positions in the order of 1.5.metres). Therefore, the effective range of movement (variability) over the entire 10-second period is much greater than during each of the constituent 1-second intervals. Nevertheless, the pattern of behaviour is comparable, with the highest SDLP evident on day one (Monday). Thereafter, lateral vehicle control tends to improve as the week progresses. Moreover, the lowest SDLP (suggesting the 'best' lateral control) appears to occur on day four (Thursday). An ANOVA test shows that differences were indeed significant between days ($F(4,184) = 19.3$, $p < .001$, $\eta_p^2 = .300$). Pairwise comparisons with Bonferroni corrections for multiple comparisons showed that the SDLP on day one was higher than on all other days ($p_{max} = .002$). There was also a significant reduction from day three to day four ($p = .040$). Moreover, the SDLP on day four was significantly lower than on days one, two and three ($p_{max} = .040$), but there was no significant difference in the SDLP between days four and five ($p = .279$).

3.4.2 Speed and speed variability

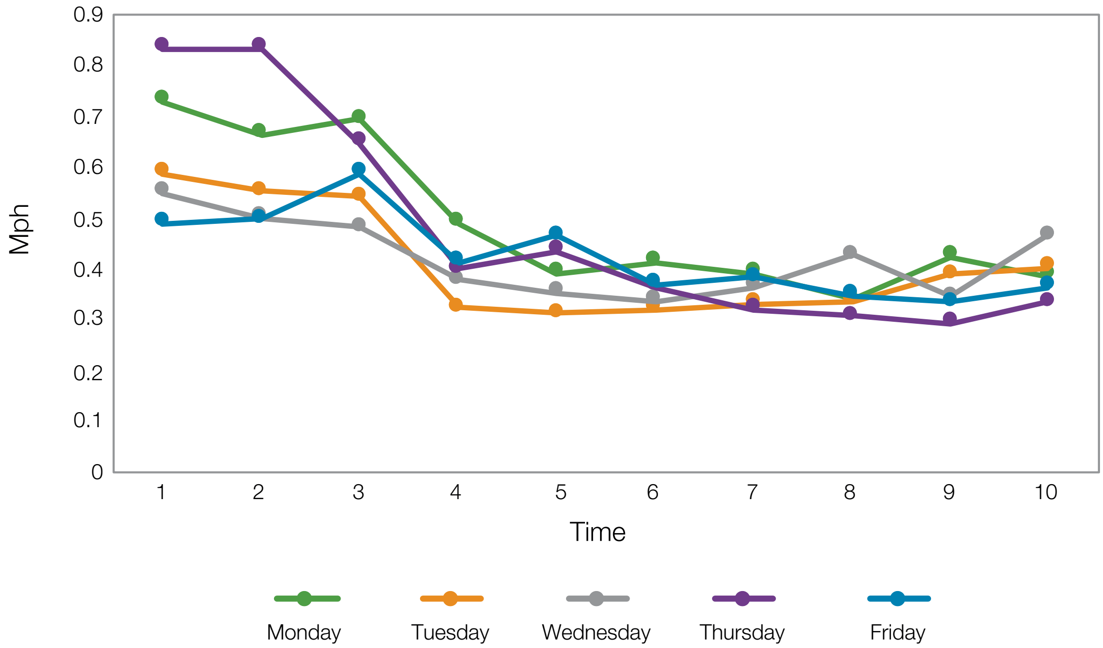
In the absence of any direct distance-based measurement, such as headway (owing to there being no lead vehicle), speed and speed variability is used to provide an indication of longitudinal control (Figure 3.25 and Figure 3.26). The speed profile in Figure 3.25 shows a general increase in speed immediately upon resumption of manual driving, lasting approximately five seconds. Thereafter the speed returned to approximately 70 mph (the speed at which the automated vehicle travelled, and the UK national speed limit on a dual carriageway). The anomaly on day four (Thursday) (evident on Figure 3.25) was in response to the vehicle handing back control following exposure to the inclement weather (fog). It is evident that in this situation, drivers generally managed a reduction in the speed of the vehicle by either applying the brakes or allowing the car to lose momentum under engine braking. Figure 3.26 shows the speed variability (standard deviation of speed) over the same timeframe – an increase in the standard deviation of speed is typically associated with an increase in workload [17]. As with the SDLP, it is evident that the speed remains most variable for the first three to four seconds or so, following the handover of control, suggesting highest workload at this time.

Figure 3.25: Mean speed (mph) in one-second intervals after resuming manual control



Source: Authors' own

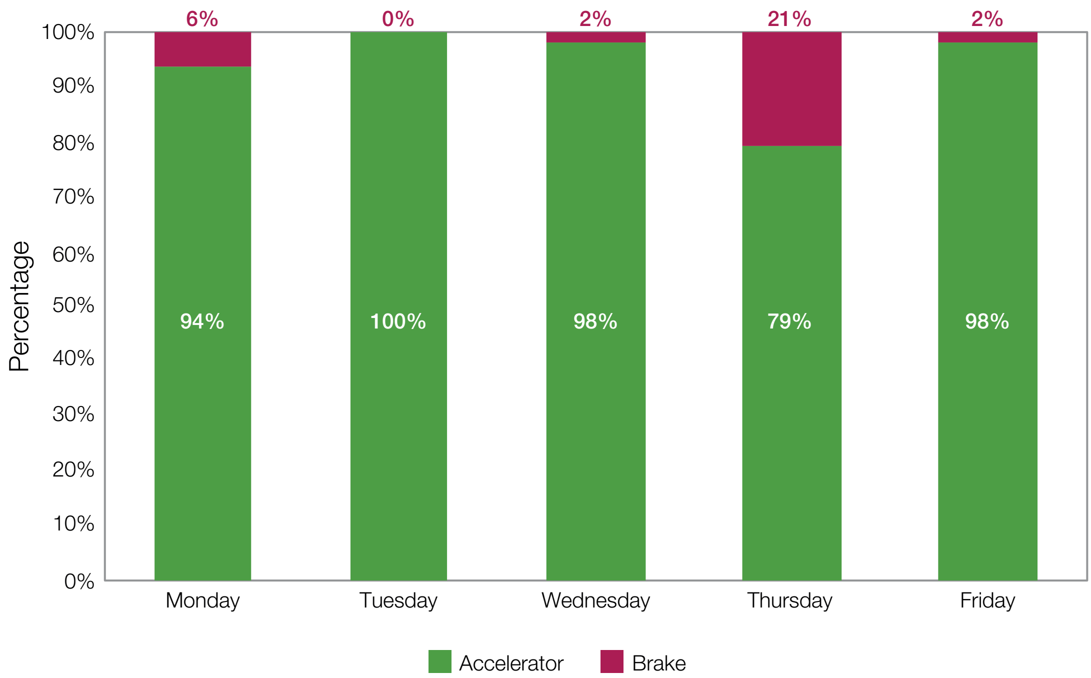
Figure 3.26: Speed variability (mph) in one-second intervals after resuming manual control



Source: Authors' own

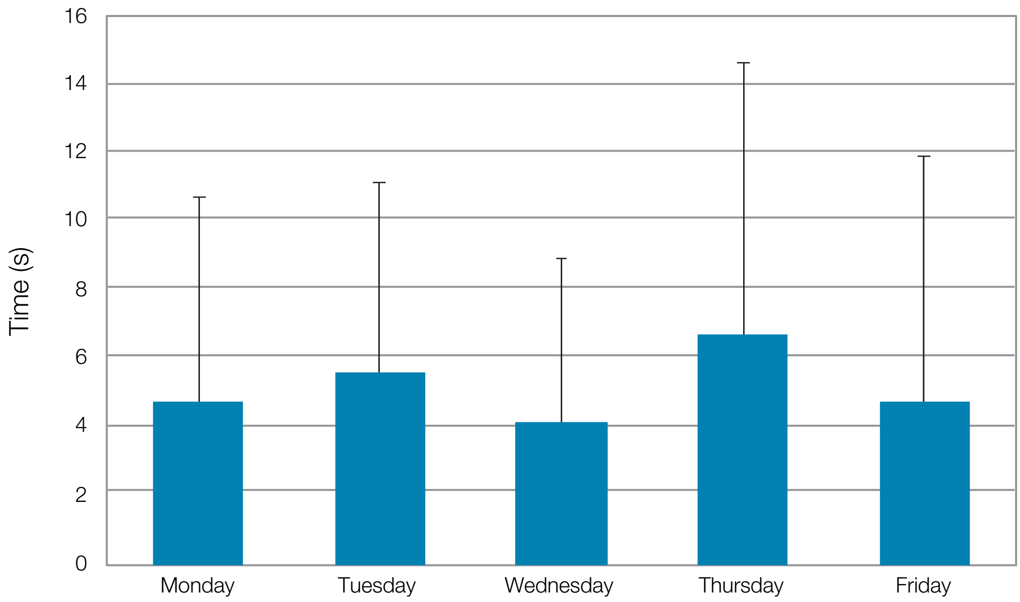
Speed behaviour is also reflected in the first control inputs made by the drivers (Figure 3.27). Indeed, the majority of drivers (on all days) chose to accelerate following the handover of control (also highlighted by the positive gradients for all days except Thursday in Figure 3.26). A larger proportion of drivers applied the brakes on day four (Thursday), following the emergency handover of control, although this is likely to be in response to the inclement weather conditions, which severely restricted visibility, rather than necessarily in response to the nature of the handover (emergency vs routine). It is also evident from Figure 3.27 that the first control input came later on day four, suggesting that drivers in this situation chose to reduce speed by initially allowing the car to coast rather than by actively providing a control input.

Figure 3.27: First control input (accelerator or brake) after resuming manual control (percentage of participants)



Source: Authors' own

Figure 3.28: Mean time before first input (accelerator or brake) made, with standard deviation error bars



Source: Authors' own

3.5 Behavioural adaptations

While the driving performance data provides an objective statement of vehicle behaviour, it can be difficult to elucidate the reasons for the behaviours witnessed from the data alone. By analysing the split-view videos during the transition period, in other words between the delivery of the prepare-to-drive notification and the provision of manual control, it is possible to begin to interpret participants' behaviour and provide possible reasons for the apparent degradations in performance observed once manual control has begun. Moreover, by analysing this behaviour on day one and then again on day five, comparisons are enabled between the different types of handover situations (routine and emergency), as well as possible behavioural adaptations during the course of the week. The following section is based on indicators of 'readiness to drive' (e.g. [9]), including several bespoke measures, with both quantitative analysis of behavioural indices during transitions and qualitative (video-based) analysis of behaviours.

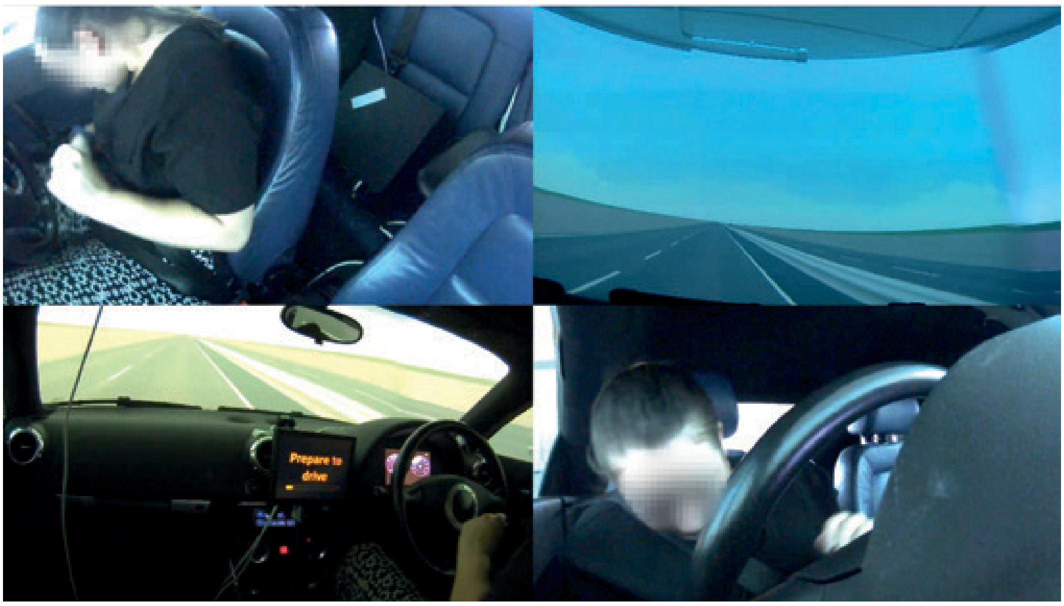
3.5.1 Activity during prepare-to-drive phase

Analysis of participants' glance behaviour following the delivery of the instruction "prepare to drive" shows that 57% of drivers visually checked where to place their feet during the transition period (i.e. by glancing to the footwell, as shown for example in Figure 3.29 and Figure 3.30). By day five, this number had reduced, but it remained a noticeable feature, with 44% of drivers still visually checking where to place their feet, often on multiple occasions during the handover period.

Figure 3.29: Example of participant visually confirming location of feet on pedals

Source: Authors' own image from driving simulator

Figure 3.30: Example of participant visually confirming location of feet on pedals



Source: Authors' own image from driving simulator

In addition, on day one, 31 drivers continued to direct visual attention towards their secondary activity (albeit sporadically) following the "prepare to drive" instruction (Figure 3.31 and Figure 3.32), with four of these participants glancing at the device more than five times. On day five, 29 drivers continued to direct visual attention to their secondary activity, with six of these looking more than six times. It was also evident that those drivers who returned their gaze to their secondary activity on multiple occasions during the prepare-to-drive phase, used the in-vehicle HMI as a timed indicator for ‘resume control’ and ‘manual mode engagement’ (particularly in the case of those drivers for whom a countdown timer was provided). There was also an increase over the week in the number of drivers continuing to interact with their secondary devices (i.e. not just glancing) during the prepare-to-drive phase – for example, continuing to compose a message on a smartphone (Figure 3.32), and actively ‘packing away’ their devices (Figure 3.33) despite being instructed to prepare to drive; this number increased from 14 participants on day one to 17 participants on day five.

Figure 3.31: Example of participant continuing to engage with their smartphone during prepare-to-drive notification (visible on in-vehicle screen)

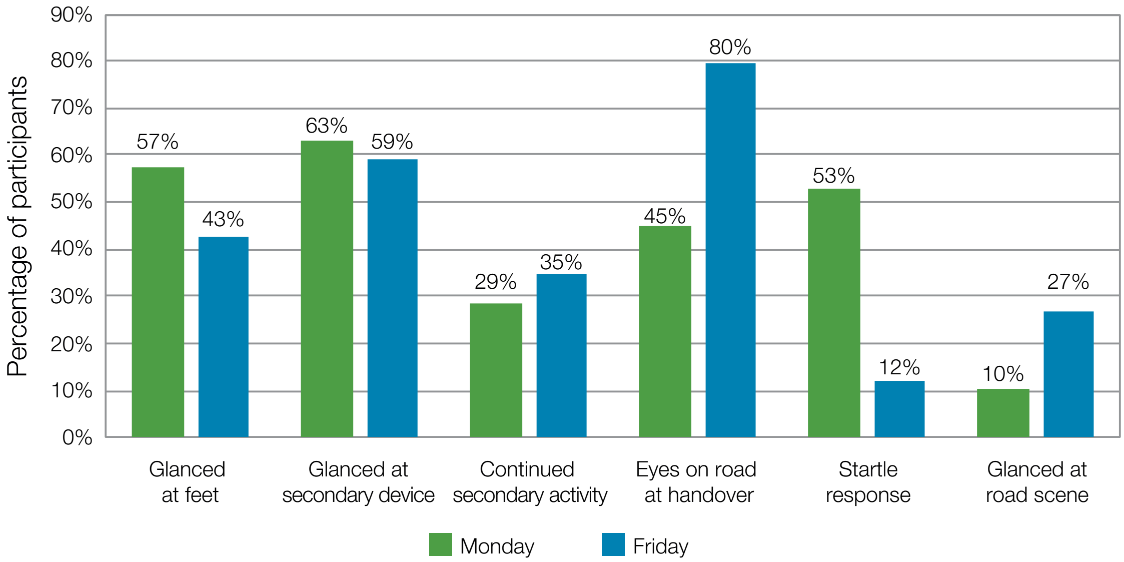
Source: Authors’ own image from driving simulator

Figure 3.32: Example of participant packing away their secondary item (book) after being instructed to prepare to drive

Source: Authors' own image from driving simulator

The average time from the prepare-to-drive request being delivered until drivers placed their hands on the steering wheel (defined as the time at which the participant placed both hands on the steering wheel, in any position) was 16 seconds on day one, increasing to 20 seconds on day five. Two drivers took in excess of one minute to place their hands on the wheel after the prepare-to-drive request on day one; on day five, this increased to four drivers. Of note is that three of these four were provided with the countdown timer function.

Figure 3.33: Driver behaviour during transition period – following delivery of "prepare to drive" warning



Source: Authors' own

3.5.2 Monitoring the road scene

There was an increase over the week in the number of drivers who were observed to glance at the road scene following delivery of the prepare-to-drive notification but prior to 'manual mode engaged' (i.e. while the vehicle was still in control). This increased from 5 drivers on day one (10%) to 13 drivers (27%) on day five (Figure 3.33).

It is also interesting to note when drivers first fixated on the road scene following delivery of the prepare-to-drive notification. On average, drivers took seven seconds on day one before directing their eyes on the road (defined as a glance out of the front windscreen of the car); this reduced to four seconds on day five. Additionally, there were nine drivers who took ten seconds or more before placing their 'eyes on the road' on day one, and six drivers on day five. These differences, albeit small, suggest that the drivers were more likely to look at the road immediately on hearing the prepare-to-drive request by the end of the week.

However, the average time between the first and second glance at the road increased between day one and day five (from four to seven seconds), and the number of drivers taking ten seconds or more to make a second glance at the road doubled from six to twelve. Nevertheless, the number of drivers whose eyes were 'on the road' at the point of manual mode engagement increased by 17, from 22 to 39, between days one and five (Figure 3.33), which is to say that on day five, 80% of drivers were looking at the road scene when they assumed manual control, suggesting an improved 'preparedness to drive'. Notably, this was at the expense of glances directed towards the HMI or dashboard. In addition, 25 of these 39 drivers had their eyes on the road in anticipation of manual mode engagement and held their gaze on the road for a prolonged period. The average glance duration 'on the road' (calculated as the length of time from the recorded glance at the front windscreen until the point gaze was recorded elsewhere) was nine seconds, and the maximum gaze duration was 24 seconds. Considered with the driving performance data, this suggests, somewhat unsurprisingly, that increased visual attention directed towards the road scene at the point of takeover is likely to improve initial vehicle control.

3.5.3 Startle responses

It was also evident from the video analysis that a significant proportion of drivers were 'startled' by the handover of control, as evidenced by physical or audible declarations (looks of surprise, head movements, spoken exclamations, gasps etc. – Figure 3.34 and Figure 3.35). This was particularly apparent at the start of the week, with 26 drivers (53%) displaying such responses on day one (Figure 3.33). However, only six drivers (12%) displayed such behaviour on day five, suggesting that overall, participants were less 'surprised' by the handover at the end of the week.

Figure 3.34: Example of startle response

Source: Authors' own image from driving simulator

Figure 3.35: Example of startle response

Source: Authors' own image from driving simulator

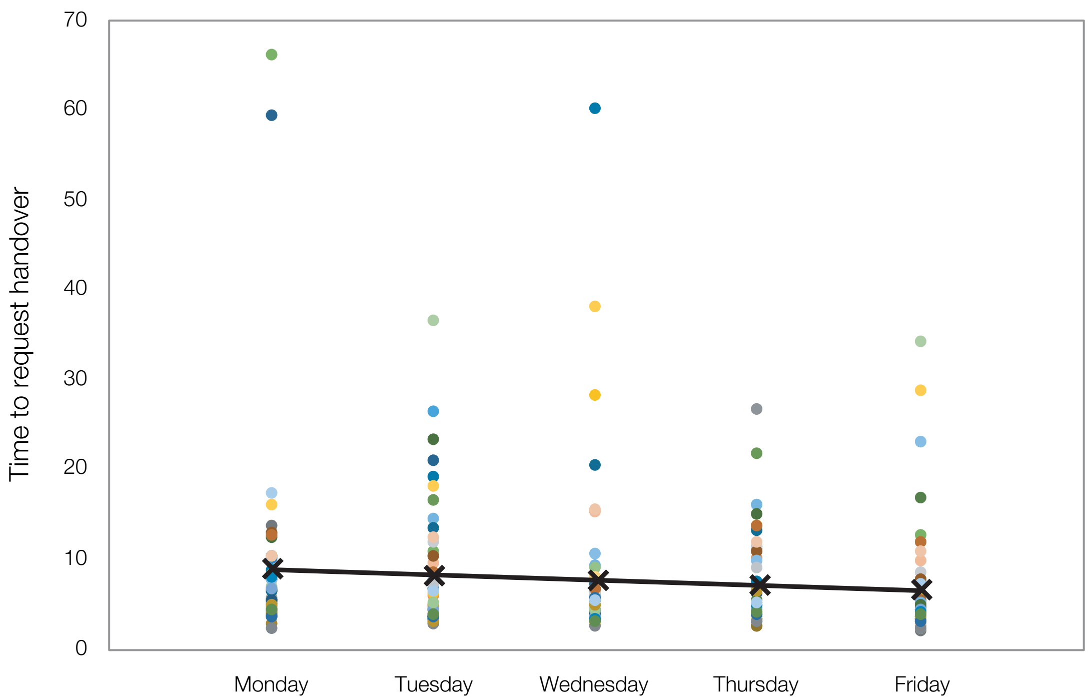
3.5.4 Behavioural indicators of trust and acceptance

It is worth highlighting again that participants were under no obligation to hand over control to the vehicle during the study – they were simply asked to imagine how they might act in such a vehicle (in terms of both the activities they undertook and their willingness and propensity to share or delegate control), and were informed where and when automation was available. They were also specifically made aware of the vehicle's capabilities –

and indeed limitations – and were, of course, required to drive manually as part of the experience. Consequently, the decision to hand over control to the automation, and indeed any decision to take back control during periods of automation, provide a good indication of the level of trust that drivers placed in the technology and their potential acceptance of it. The videos were therefore analysed further to identify 'trust indicators', such as how soon drivers activated automated control and instances of drivers actively taking back manual control. As with other measures, these were calculated for each day, and subsequently compared across the week to explore behavioural adaptations.

It was evident that drivers quickly relinquished control to the vehicle – on average approximately eight seconds after this was made available, suggesting high levels of trust even on day one (Figure 3.36). Nevertheless, some participants expressed caution on day one (Monday) (Figure 3.37). There was a trend towards the handover time reducing over the week, suggesting that drivers wanted automated control sooner as the week progressed, although differences between days did not reach statistical significance (it is suspected that this is due to the large variability in behaviour seen over the week, with some drivers taking a minute or so, before requesting control). Interestingly, there was no apparent increase in handover time on Friday (which would have indicated a reduction in trust), suggesting that there was no detriment to drivers' trust in the technology following the perturbation on Thursday.

Figure 3.36: Time from automation available to automation request/handover (each dot represents an individual value; black line indicates mean value trend line)



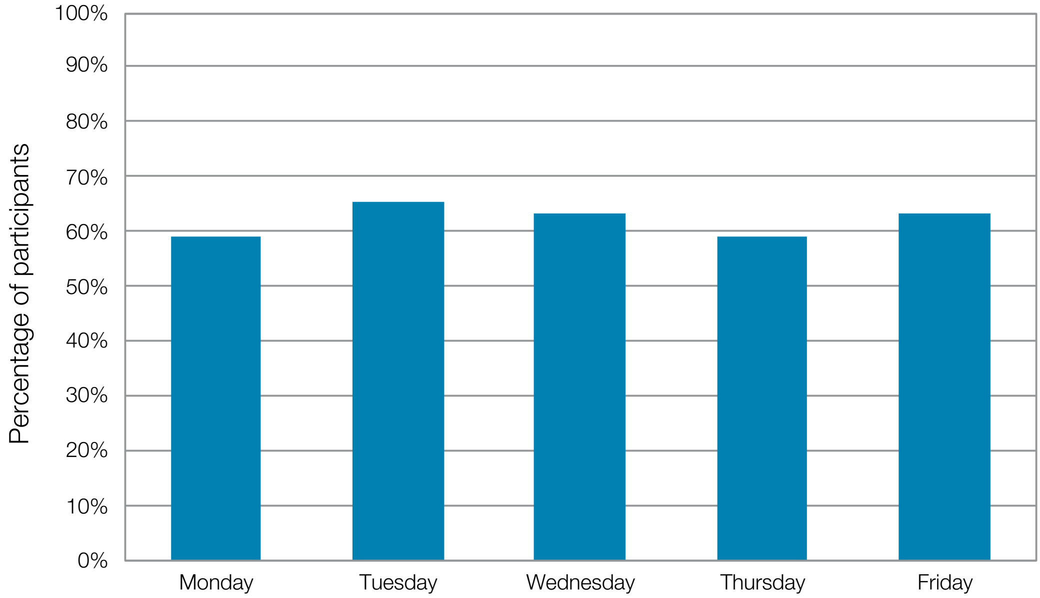
Source: Authors' own

Figure 3.37: Example of participant displaying tentative handover of control

Source: Authors' own

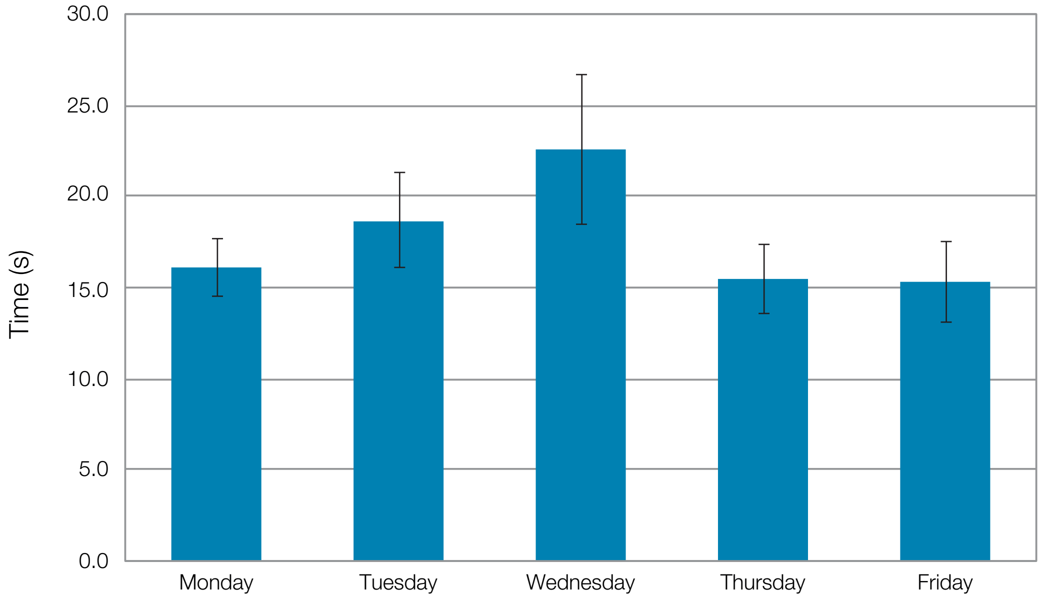
As part of the design of the scheduled handover (towards the end of the dual carriageway), drivers were provided with a "prepare to drive" warning delivered 60 seconds prior to handover, and a subsequent ten-second notification to 'resume control' (effectively delivered 50 seconds later). Nevertheless, drivers were able to request manual control sooner than this (i.e. before the 60 seconds had expired). If they decided to do so, they were immediately presented with a ten-second 'resume control' instruction. While not all drivers availed themselves of this facility, a significant proportion did (Figure 3.38). Moreover, where drivers did choose to resume control sooner, this occurred approximately 18 seconds into the handover period, on average. There was no significant trend up or down in the time taken to request control during the handover over the week (Figure 3.39).

Figure 3.38: Percentage of drivers requesting manual control during prepare-to-drive notification



Source: Authors' own

Figure 3.39: Mean prepare-to-drive time before manual control requested, with standard error bars



Source: Authors' own

3.6 Emergency handover and handover strategy

For most of the week, the journey experience was unremarkable, insofar as the handover and, in particular, the resumption of manual control occurred as expected towards the end of the dual carriageway. On such days, participants were provided with 60 seconds' warning to resume control. However, as part of the experimental design, inclement weather (thick fog) was added on day four (Thursday) part way through the period of automation. The assumption behind this is that under such conditions the vehicle would be unable to continue operating autonomously, and would therefore be required to hand back manual control to the driver. Moreover, the nature of the perturbation during the study was such that this was not only unexpected, but it was also an emergency. Therefore, participants were notified and required to resume manual control within ten seconds, rather than the prolonged 60 seconds, to which they had become accustomed.

In addition, different HMI strategies were employed to help drivers build and maintain situational awareness during handovers (Table 2.1) – but any given driver experienced only the same handover HMI strategy throughout the week. The motivation for this approach was a desire to understand the influence of HMI strategy on drivers' behaviour during the takeover of control and on ratings of trust (and other elements) generally, but also more specifically to discover whether there were any positive learning effects (instilled by encouraging positive behaviour during routine handovers) that persisted during emergency situations.

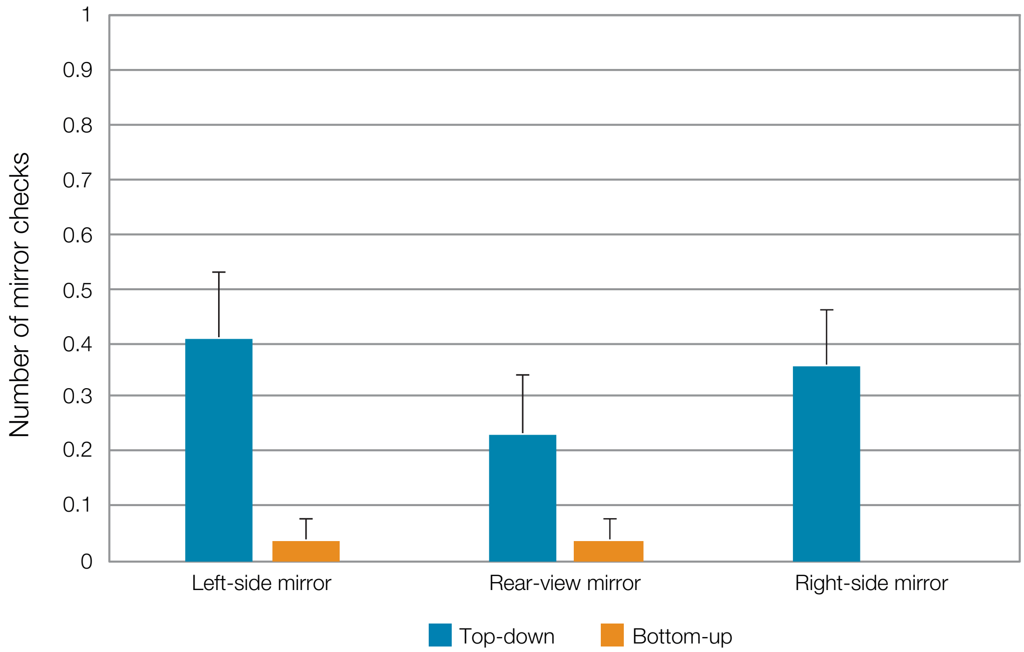
Considering the emergency handover on day four (Thursday) in isolation, further video coding was used to classify participants' mirror-checking behaviour during the takeover request (i.e. following the delivery of the takeover request but before resuming manual control). In addition, 'driver readiness' is defined as the time at which participants had made their first glance at the road scene and had at least one hand on the steering wheel, in line with other research [9]. Driving performance data, specifically associated with the emergency handover, was extracted from the STISIM Drive software and analysed to provide information on participants' standard deviation of lateral and longitudinal driving control for the first ten seconds after handover; driving performance was compared to ten seconds of manual driving on a straight road prior to engaging in automation on the same day.

3.6.1 Mirror checks

A two-way multivariate analysis of variance (MANOVA) test showed a significant main effect of handover strategy (top-down versus bottom-up) on checks to right-side, left-side and rear-view mirrors ($F(3,43) = 4.8$, $p = .006$, Wilks' $\Lambda = .748$, $\eta_p^2 = .252$) (Figure 3.40). There was no main effect of the system feedback ('health status') HMI, provided during periods of automation ($p = .841$), and no significant interaction effect of the interface during automation and the handover strategy on the frequency of mirror checks ($p = .473$). A subsequent one-way ANOVA revealed that significantly more checks were made to the right- and left-side mirrors when drivers were provided with top-down guidance. No statistically significant differences in checks to the rear-view mirror were found between handover strategies.

In contrast, no checks were made to the right-side mirror by drivers who received 'bottom-up' ("take control") advice, and only 3.7% of these drivers checked their left-side mirror (compared to 36.4% of ‘top-down’ drivers checking both left and right) (although no differences were evident between conditions in the number of checks to the rear-view mirror).

Figure 3.40: Mean number of mirror checks during top-down and bottom-up advice, with standard error bars



Source: Authors’ own

3.6.2 Time to ‘driver readiness’

A two-way ANOVA revealed that there was a significant main effect on the time to ‘driver readiness’ of system feedback during automation ($F(1,45) = 12.7$, $p = .001$, $\eta_p^2 = .221$), reducing this by 2.1 seconds compared to situations in which no feedback was provided.

3.6.3 Standard deviation of speed

A two-way mixed ANOVA was conducted, employing a between-subjects factor of condition (×4) and a within-subjects factor of sampling period (manual driving before automation or manual driving after handover). There was no significant main effect of condition on standard deviation of speed ($p = .758$), and no statistically significant interaction between condition and sampling period (before automation, after handover) ($p = .568$). However, there was a significant main effect of sampling period in standard deviation of speed ($F(1,45) = 38.6$, $p < .001$, $\eta_p^2 = .462$), indicating that the standard deviation of speed was 1.9mph lower before automation.

3.6.4 Standard deviation of lateral lane position

A two-way mixed ANOVA revealed a significant main effect of sampling period on the SDLP ($F(1,45) = 60.2$, $p < .001$, $\eta_p^2 = .572$), revealing that the SDLP was significantly larger in the manual drive after handover (mean difference = 0.424 feet) compared to the earlier manual drive. There was no significant main effect of condition ($p = .356$), and no significant interaction between condition and sampling period on the SDLP ($p = .605$). It is therefore evident that driving performance differed significantly when compared to an equivalent episode of manual driving prior to engaging automation on day four.

4. Discussion and Conclusions

The study aimed to explore the type of activities that drivers chose to undertake in a vehicle offering SAE (Society of Automotive Engineers) level 3 automation, what impact these had on the manual resumption of the driving task under both routine and emergency conditions, and, finally, how participants' behaviour changed during the course of the week. Building on a preliminary investigation conducted by the University of Nottingham [2], the study exposed drivers to a week of SAE level 3 automated 'commute'-style driving with episodes of manual and automated driving. Many of the results discussed below highlight the requirement for new forms of driver training to assist people in the use of future automobiles in which they might transition in/out of control while the vehicle is in motion.

4.1 Secondary activities

It is worth reiterating that participants were under no obligation or requirement to hand over control to the vehicle during the study – they were simply asked to imagine how they might act in such a vehicle during a commute-type journey. As part of the journey experience, they were also required to drive manually, but were informed where and when automation was available. Furthermore, prior to taking part, participants had been specifically made aware of the vehicle's capabilities – and indeed limitations. Consequently, the activities that participants undertook and their willingness and propensity to share or delegate control, provide a good indication of the level of trust that they placed in the technology and their potential acceptance of it.

Results show that drivers undertook a range of activities while the vehicle was in control – typically with high visual, manual and cognitive demands, indicating high levels of trust in and acceptance of the automation from day one. The smartphone was the most popular device, used by over 80% of participants for a variety of activities, although more traditional reading materials (books, printed papers etc.) were also popular, with up to 25% of participants engaging in some form of reading activity during the week. Participants also commonly used laptops and tablet computers during periods of automation.

While the types of devices used did not change significantly during the week, the proportion of time (indicated by the visual attention directed towards them) increased. On day one, participants spent approximately 70% of their time with their vision directed away from the road scene during periods of automation. By day five, over 80% of the time was associated with their secondary activities, i.e. less than 20% of the time was spent looking at the road scene at the end of the week.

4.2 Trust, technology acceptance and situational awareness

These observations were supported by subjective ratings made by participants at the end of each day using recognised questionnaires. Participants declared high levels of trust and technology acceptance from day one. Moreover, trust and technology acceptance ratings generally increased as the week progressed. Of particular note was that there was no apparent detriment to trust or technology acceptance after the emergency handover event on day four – either immediately thereafter or on the next day. In fact, ratings of trust were significantly higher at the end of the week than they were at the start of it, and technology acceptance was highest on day five. The level of trust and acceptance that users place in technology is expected to influence their uptake of the technology [18]. If the technology is not seen as 'acceptable' by drivers, they will probably not buy it – and even if they do, they might disable it, if and where this is possible, out of frustration (leading to disuse), or use it in a manner unintended by designers (abuse) [19].

Ratings of situational awareness revealed that for the first part of the week (Monday to Wednesday), participants tended to indicate an ongoing reduction day-on-day in the demands on and supply of their attentional resources, and an increase in their understanding of the situation. This is likely to be because they became more familiar with their experience of the automated vehicle, rather than their awareness of the driving situation per se – although it is worth considering that the effect may also be interpreted from the perspective of increased familiarity with the simulated driving experience and experimental conditions. However, the unexpected, emergency handover on day four had a marked effect – significantly increasing the demands placed on drivers' attentional resources, and reducing their understanding of the situation. While this is to be expected, given the nature of the perturbation, it is particularly interesting to observe that the ratings of situational awareness returned to their previous magnitude on the following day, indicating no residual effects from the emergency handover situation.

4.3 Transfer of control

Irrespective of their subjective ratings, the protracted abstinence from primary control inputs during periods of automation – in addition to engagement in highly absorbing non-driving-related secondary activities – meant that some drivers were inevitably ill-prepared to regain manual control quickly and effectively. This is because they were required to change state, in other words disengage from their secondary activity (physically and cognitively) as well as potentially reposition themselves physically in preparation to take over control, before re-engaging with (and recalibrating) the primary controls and concurrently building situational awareness. There was clear evidence of the impact that this required change of state had on drivers from the behavioural indicators. For example, a high proportion of drivers (57%) glanced at their feet when they were preparing to take control on day one – and this remained a feature even on day five (44%). Such a finding points towards deficiencies in proprioception (drivers' awareness or perception of the position and movements of their body) that are likely to arise for people who are 'out of the loop' with respect to the driving task for an extended period – and consequently lose sense of where their limbs (in this case legs/feet) are, in relation to the primary vehicle controls.

Equally concerning is that a significant proportion of drivers continued to engage with the secondary activities – based on both visual metrics and observed activity (e.g. continuing to compose a text message) – during the 60-second prepare-to-drive notification. Drivers also appeared to become somewhat lackadaisical in their approach to grasping the steering wheel (in preparation for taking control) as the week progressed – choosing to do so later on Friday (than at the start of the week), and in some cases after manual control had been handed back (although this could be a result of low perception of risk in the simulated driving environment).

Collectively, the evidence indicates an increase in the level of complacency and level of confidence that the drivers held regarding their own ability to take control. Moreover, it suggests that drivers were using the prepare-to-drive notification as an indication of when they needed to begin the process of dispensing with their secondary activities, rather than using it as time to actively prepare for driving (for example, attempting to improve their awareness of the road situation before engaging with and recalibrating the manual controls); this was particularly true in 'top-down' situations where a countdown timer was provided (as evident from the areas to which drivers chose to direct their visual attention). This suggests that greater clarity – and, potentially, new forms of driver training – is required as part of the handover process, regarding what actions should and should not be taken once the transition process has begun, and the order in which these actions should take place.

Nevertheless, there was some evidence to suggest that drivers recognised the importance of regaining their situational awareness in preparation for taking over control. For example, there was an increase over the course of the week in the number of drivers who glanced at the road scene following delivery of the prepare-to-drive notification, and the time before doing so also reduced. However, although drivers were more likely to get their eyes on the road more quickly as experience and exposure to handovers increased, this does not necessarily translate into an increase in readiness to drive. It may also demonstrate that participants had learned the route – for example, by identifying a distinctive roadside landmark and using this as a marker or predictor of when the vehicle would be transferring control to them. Such 'learned' behaviour raises concerns, suggesting complacency amongst drivers, in that it assumes routine or predictable behaviour (i.e. that the vehicle will always hand back control at the same point), meaning that drivers might be even less prepared for unexpected or emergency handovers.

4.4 Vehicle control

Unsurprisingly, drivers' behaviour during the handover of control had a significant impact on their actual driving performance, with data showing that lateral movement (in terms of both absolute and standard deviation of lane position) was highly variable immediately after resuming control, and remained so for up to ten seconds thereafter (and beyond in some cases).

Interestingly, lateral displacement was always to the nearside (left), suggesting that drivers inherently determined this to be a safer course of action (rather than steering towards oncoming traffic). It is worth highlighting that during the study, the vehicle operated in automated mode in lane two (the 'outside' lane) of the dual carriageway (presented to participants as a dedicated 'autonomous' driving lane). Thus, when automated control was relinquished, drivers could choose whether to remain in lane two or move into lane one. While the general tendency to 'drift left' might suggest that drivers were actually choosing to move into lane one, the fact that they ultimately attempted to regain their central position in lane two suggests that this was not in fact their intended strategy, but rather that they required time to readapt or recalibrate primary control mechanisms.

Even so, lateral control improved as the week progressed, suggesting that drivers were able to produce strategies to improve immediate takeover performance – such strategies could potentially be incorporated within training and best practices. Interestingly, the 'best' takeover performance (from the perspective of lateral control) was evident on day four, immediately after the emergency handover. Initially a counter-intuitive finding, this is suspected to be indicative of an increase in drivers' focus of attention in terms of both mental effort and mobilisation of resources (resulting in hyper-vigilance), owing to the nature of the emergency handover–in particular, the urgent alarm. This is also supported by the situational awareness rating technique (SART) ratings, which showed an increase in the supply of attentional resources – in particular – on this day.

Speed behaviour and control was also variable. Of particular note was that drivers tended to increase speed immediately after taking control – indeed, the first control input for most drivers was the accelerator. It is likely that degradations in driving performance after the resumption of manual control were due to difficulties in recalibrating the physical control actions when resuming manual driving. A similar effect was also noted in a recent 'steer-by-wire' driving study in which the steering/torque ratio was modified between each lap of a circuit. Observed steering manoeuvres differed significantly between each drive, with participants under- and overestimating steering angles, even when they were informed about changes in the steering/torque ratio in advance [20]. The authors argue that even when a driver is aware of what they need to do, they can adjust to physical controls only through 'hands-on' experience. As a consequence, it is suspected that even if drivers of automated vehicles have sufficient awareness of the driving environment and of the required driving manoeuvres (for example, by using an informative HMI (human–machine interface) to rebuild their situational awareness), there may still be detriments to driving performance after handover until they have re-established familiarity with the primary control actions (for example, steering and pedal angles). Russell et al. [20] thus argue for a period of shared control after handover to mitigate the risk associated with the adaptation/learning process. In this respect, it is possible that the automation system within a future vehicle may need to test a driver's capabilities (in terms of vehicle control, and also their visual scanning patterns) prior to them being allowed to fully resume manual control.

It is worth noting that speed behaviour was also different on day four after the emergency handover. In this situation, drivers tended to reduce speed initially by using engine braking rather than actively providing a control input. The motivation to reduce speed is likely to have been influenced by the specific emergency situation chosen for the study – adverse weather conditions, such as fog, can have a significant impact on driving performance in any situation. For example, Mueller and Trick [21] found that drivers displayed greater variability in speed and steering when driving in foggy conditions than in clear conditions.

4.5 Mirror checks

There were also some notable differences in mirror-checking behaviour – something that is considered essential for safe driving and which helps drivers to maintain situational awareness – following the top-down and bottom-up handover guidance [22]. Indeed, providing drivers with 'top-down' guidance (encouraging them to check for hazards) during the ten-second transition led to significantly more checks being made to the right- and left-side mirrors, even during the emergency situation. This suggests that such strategies could be employed to improve drivers' situational awareness prior to providing control, even during a relatively short timeframe – although it did not necessary translate into improved driving performance immediately after the handover. However, several drivers who received 'top-down' advice during the study still failed to check their mirrors, suggesting that prompting participants to check for hazards might not be a fully effective method to build situational awareness during handover. On the other hand, no lane change was required as part of the emergency handover, and surrounding traffic was sparse at the point of handover. It is therefore feasible that drivers' mirror-checking behaviour might have been different if they had been required to undertake a lane-change manoeuvre immediately after resuming control, or if traffic density were higher.

It is also noteworthy that receiving system ‘status’ feedback during periods of automation had no influence on participants’ mirror checks during the handover, suggesting that keeping participants ‘in the loop’ during automation had no impact on their behaviour during the transfer of control, and further supporting the need for the provision of additional (top-down) information or guidance during the process. However, it is possible that drivers expected the system status interface to highlight potential obstacles at the point of handover, which suggests over-reliance on technology and potential errors of omission (i.e. drivers failing to implement actions if they are not informed by the vehicle), as also observed by Eriksson et al [23].

4.6 Limitations

It is important to recognise that the research was conducted at SAE level 3 automation, insofar as participants were told that they might be required to resume manual control during periods of automation, given appropriate notice. Nevertheless, no restrictions were applied to the type of activities that drivers could undertake during periods of automation (and, consequently, secondary devices and activities were not controlled across groups). In practice, this might seem somewhat incongruous with the recognised understanding of SAE level 3 automation, a level in which drivers might still be required to take over control. It would therefore seem prudent that future SAE level 3 vehicle should not permit certain types of activities – and should warn, penalise or attempt to re-engage the driver accordingly. However, this work is intended merely to inform this debate. Moreover, the range of secondary activities undertaken may have influenced some of the results. For example, participants undertaking activities that involved high visual, manual and cognitive elements (e.g. working on a laptop placed in front of the steering wheel), may have taken considerably longer to detach from their non-driving activities than participants carrying out less demanding activities – for example, those casually glancing at their smartphone at the point of handover. Thus, it is feasible that reaction times might be influenced by the secondary device being used. Nevertheless, the intention in conducting the research in this manner was to explore the type of activities that drivers would expect to undertake, and which they believe to be acceptable in an SAE level 3 automated vehicle, in spite of the fact that they maintained an ongoing responsibility towards vehicle control and were specifically reminded of this at the start of the study.

Finally, it is worth highlighting that the results as presented relate to the specific set of controlled conditions to which participants were exposed (i.e. a medium-fidelity driving simulator, with specific experimental HMIs and so on). Whilst every effort was made to ensure that these factors were as realistic as possible (based on the study team’s expertise and experience, and their understanding and expectations of future vehicles), and the driving simulator provides good relative validity, there are aspects of the experimental set-up that were chosen for convenience (although, notably, still informed by expert opinion) that might be more complex to achieve in the real world. For example, in practice, it is debatable whether an automated vehicle would have sufficient self-awareness to be able show the current status of its sensors to its passengers with the degree of clarity that this simulation afforded. Moreover, there are unavoidable limitations inherent in conducting such research in a driving simulator, associated with the fidelity of experience, low perception of risk and so on. For these reasons, caution should be applied when drawing conclusions regarding real-life behaviour.

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Appendix A: Questionnaires

Trust in general technology questionnaire

1. I would be totally comfortable using automated vehicles.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

2. I would feel very good about how things go when I use automated vehicles.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

3. I would feel confident that the right things will happen when I use automated vehicles.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

4. I think that things will be fine when I use automated vehicles.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

5. I would feel okay using automated vehicles because they are backed by vendor protections.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

6. Product guarantees would make it feel all right to use automated vehicles.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

7. Having the backing of legal statutes and processes makes me feel secure in using automated vehicles.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

8. I believe that most technologies are effective at what they are designed to do.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

9. A large majority of technologies are excellent.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

10. Most technologies have the features needed for their domain.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

11. I think most technologies enable me to do what I need to do.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

12. My typical approach is to trust new technologies until they prove to me that I shouldn't trust them.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

13. I usually trust a technology until it gives me a reason not to trust it.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

14. I generally give a technology the benefit of the doubt when I first use it.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

Trust in a specific technology questionnaire

1. The system is a very reliable piece of technology.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

2. The system does not fail me.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

3. The system is extremely dependable.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

4. The system does not malfunction for me

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

5. The system has the functionality I need.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

6. The system has the features required for my tasks.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

7. The system has the ability to do what I want it to do.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

8. The system provides competent guidance (as needed) through a help function.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

9. The system provides very sensible and effective advice, if needed.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

Technology acceptance questionnaire

1. Assuming I have access to the system, I intend to use it.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

2. Given that I have access to the system, I predict that I would use it.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

3. My interaction with the system is clear and understandable.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

4. Interaction with the system does not require a lot of my mental effort.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

5. I find the system to be easy to use.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

6. I find it easy to get the system do what I want to do.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

7. It is faster to performing tasks with the system.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

8. The system increases the productivity of performing tasks.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

9. I will use the system on a regular basis in the future.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

10. I will frequently use the system in the future.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

11. It is likely that I will continue to use the system.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

12. I will frequently use the system in the future.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

13. I have control over using the system.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

14. I have the resources necessary to use the system.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

15. Given the resources, opportunities and knowledge it takes to use the system, it would be easy for me to use it.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

16. I find using the system to be enjoyable.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

17. The actual process of using the system is pleasant.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

18. The quality of the output I get from the system is high.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

19. I have no problem with the quality of the system's output.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

20. I rate the results from the system to be excellent.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

Situational Awareness Rating Technique (SART)

Instability of situation

How changeable was the drive? Was it highly unstable and likely to change (high) or very stable and straightforward (low)?

Low	1	2	3	4	5	6	7	High

Complexity of situation

How complicated was the drive? Was it complex with many interrelated components (high) or simple and straightforward?

Low	1	2	3	4	5	6	7	High

Variability of situation

How many variables were changing during the drive? Was there a large number of factors varying (high) or very few variables changing (low)?

Low	1	2	3	4	5	6	7	High

Arousal

How aroused were you during the drive? Were you alert and ready for activity (high) or did you have a low degree of alertness (low)?

Low	1	2	3	4	5	6	7	High

Concentration and attention

How much were you concentrating during the drive? Were you concentrating on many aspects of the situation (high) or focused on only one (low)?

Low	1	2	3	4	5	6	7	High

Division of attention

How much was your attention divided during the drive? Were you concentrating on many aspects of the situation (high) or focused on only one (low)?

Low	1	2	3	4	5	6	7	High

Spare mental capacity

How much mental capacity did you have to spare during the drive? Did you have sufficient to attend to many variables (high) or nothing to spare at all (low)?

Low	1	2	3	4	5	6	7	High

Information quantity

How much information did you gain during the drive? Did you receive and understand a great deal of knowledge (high) or very little (low)?

Low	1	2	3	4	5	6	7	High

Familiarity with situation

How familiar were you with the drive? Did you have a great deal of relevant experience (high) or was it a new situation (low)?

Low	1	2	3	4	5	6	7	High

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