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How Will Drivers and Passengers Interact in Future Automated Vehicles?

Dr David R. Large, Dr Catherine Harvey
and Professor Gary Burnett
Human Factors Research Group
University of Nottingham
June 2024

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UK | CHINA | MALAYSIA

The Royal Automobile Club Foundation for Motoring Ltd is a transport policy and research organisation which explores the economic, mobility, safety and environmental issues relating to roads and their users. The Foundation publishes independent and authoritative research with which it promotes informed debate and advocates policy in the interest of the responsible motorist.

RAC Foundation
89–91 Pall Mall
London
SW1Y 5HS

Tel no: 020 7747 3445
www.racfoundation.org

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About the Authors

Dr David R. Large is an accomplished academic researcher and Senior Research Fellow with the Human Factors Research Group at the University of Nottingham. David has over 13 years' experience of leading and delivering industry-, UK- and EU-funded projects concerning the human-centred design, evaluation and user acceptance of novel and emerging automotive interfaces and technology, and has authored over 100 peer-reviewed publications. His specific research interests and expertise include 'natural' methods of interaction (spoken language, gestures, etc.), novel methodological approaches, and the application and appropriation of anthropomorphism in technology design and acceptance.

Dr Catherine Harvey is an Assistant Professor and Deputy Head of the Human Factors Research Group at the University of Nottingham. Catherine has over 17 years' research experience in human factors, focusing on user experience, design and evaluation, and human–computer interaction. Catherine has applied this expertise in a variety of domains including road transport, sociotechnical systems and aviation. She has published in leading journals and international conferences, and has authored books and book chapters on human factors methodology.

Professor Gary Burnett is a Professor of Digital Creativity at Loughborough University within the School of Design and Creative Arts. Prior to August 2023, he was a Professor of Transport Human Factors at the University of Nottingham and Head of the Human Factors Research Group. He has over 30 years' experience in research investigating human-centred design and evaluation issues for new technologies in a driving context – with a particular focus on novel human–machine interfaces (HMIs). He has authored over 200 peer-reviewed journal and conference papers which have been cited over 5,000 times.

Acknowledgements

The current report concludes a triumvirate of studies conducted by the Human Factors Research Group at the University of Nottingham which aim to explore how drivers, and their passengers, will behave in future SAE Level 3 automated vehicles. The authors would like to thank everybody who has been involved at the University of Nottingham during all three studies, in particular Emily Shaw, Sparsh Khandeparker, Dr Davide Salanitri and Hannah White, and, of course, all of our participants. In addition, we would like to thank Dr Elizabeth Box and Steve Gooding, and, indeed, all members of the RAC Foundation, for their valuable guidance and support throughout.

Disclaimer

This report has been prepared for the RAC Foundation by Dr David R. Large, Dr Catherine Harvey and Professor Gary Burnett. Any errors or omissions are the authors' sole responsibility. The report content reflects the views of the authors and not necessarily those of the RAC Foundation.

When the terms "we", "our" and "us" are used in this report, the authors are referring to their own team, and no reference to the RAC Foundation is implied.

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List of Abbreviations

ALKS	automated lane keeping system
ANOVA	analysis of variance
CHAT	CHeck, Assess and Takeover
CRM	crew resource management
eHMI	external human–machine interface
HMI	human–machine interface
NASA-TLX	NASA-Task Load Index
NDRT	non-driving-related task
SAE	Society of Automotive Engineers
SART	situational awareness rating technique
SDLP	standard deviation of lane position
STS-AD	Situational Trust Scale for Automated Driving

Foreword

It's hard to argue against the ambition for fully driverless cars to make our roads safer by reducing the human errors which contribute to collisions. But the path to this panacea is not straightforward, indeed, many still doubt whether fully automated driving – any road, anytime, anywhere – is a realistic aim. Meantime the transition to a world where the driver of the car becomes the passenger, at least some of the time, raises important questions about the human-machine interface – how and when can the driver cede control to the car and, more importantly, how and when would the car need to give control back?

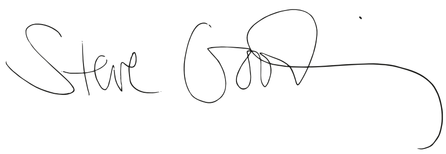
This report covers the third of three studies the RAC Foundation has commissioned from the University of Nottingham to investigate how human factors need to be taken into account in the design of systems providing conditional, semi-automation – vehicles where a human driver still has a part to play. The previous studies focused on scenarios involving only one person in the car.

For this third piece of research we asked the Nottingham team to envisage a scenario where there are two people in the vehicle. How might they interact with each other? How would they interact with the world around them? And, crucially, what might that mean for the way they interact with the car when it seeks to hand back control?

The results reinforce the headline findings of Nottingham's previous work: auto-designers need to develop systems that recognise how people, with all their foibles and fallibilities, are likely to react in the real world with all its distractions. Is having a 'passenger' as well as a 'driver' a blessing or a curse? The research suggests there's potential for a bit of both.

Technology which has at its heart the goal of eradicating human input from driving needs to avoid reliance on making us humans responsible for the split-second decision-making which it finds too difficult, because that's where some of the greatest road safety risks are to be found.

Steve Gooding



Director, RAC Foundation

Executive Summary

The presence of one or more passengers has been shown to distract drivers during manual driving, with reported reductions in situational awareness, an increase in the risk of taking unsafe actions, and an increased risk of a fatal crash, particularly in the case of young drivers. However, the presence of a passenger during Society of Automotive Engineers (SAE) Level 3 conditional driving automation (SAE, 2021) has, to date, received no empirical attention. Building on previous studies funded by the RAC Foundation (Burnett et al., 2019; Shaw et al., 2020), we invited 18 driver/passenger pairings (12 of the passengers in which were also themselves qualified and experienced drivers) to undertake three authentic journeys in the Human Factors Research Group's driving simulator at the University of Nottingham. As before, SAE Level 3 conditional driving automation was activated on the motorway, and drivers and passengers were free to undertake any activities they deemed acceptable while the vehicle was in control, with the aim of preserving important motivational aspects. Inspired by our previous work, the research questions posed by the current study were:

1. What will drivers and passengers naturally do in future automated vehicles?
2. What impact does the presence of a passenger have on the driving task – that is, during periods of automation and also during the resumption of the driving task?
3. How does the presence of a passenger affect levels of situational awareness, workload, trust and acceptance?

All participants demonstrated some form of interaction with one another during the journeys. New participatory behaviours emerged, with many drivers and passengers partaking in non-driving-related tasks (NDRTs) that engaged both vehicle occupants in co-operative tasks, such as watching shared content or playing games together on a smartphone, jointly solving crossword puzzles, or playing cards. These joint tasks often directed the driver's (and indeed the passenger's) visual, cognitive and manual attention away from the road situation and driving task, and delayed takeovers, with some drivers missing their designated exit on their first drive, ostensibly because they were engrossed in a competitive game or co-operative activity with their passenger.

The presence of a passenger also naturally afforded dialogue between vehicle occupants. Indeed, for some participants, talking was their predominant activity. The amount of dialogue differed notably between pairs, with some participants apparently content to remain in extended periods of silence, offering only occasional, often perfunctory, comments or questions. For more loquacious participants, conversation was typically interrupted by short, intermittent glances directed towards their smartphone or smartwatch to check message notifications. For other participants, conversation was notably inspired by, or required for, the shared activity or NDRT (for example, discussing clues to a crossword or commenting on their partner's chess prowess). In most situations, dialogue appeared to move seamlessly between different topics, which included aspects of the driving task (road situation, route choice, etc.). Moreover, the side-by-side front seating arrangement allowed both driver and passenger to remain forward-facing with their gaze notionally directed to the forward driving scene. This meant that features in the road environment (for example the behaviour of other vehicles or road signage) were routinely observed and commented upon, as was the behaviour of their own automated vehicle in response to other road users and, indeed, the overall experience of travelling in an SAE Level 3 automated vehicle, which was described by several participants as “boring”.

Analysis of conversation also revealed that passengers provided help and advice during the takeover of control. Interestingly, it was more the control aspects of the driving task that were discussed during routine handovers (during drives one and two), that is, those relating to the operation of the vehicle – speed adherence, steering and so on – whereas tactical and strategic elements featured more dominantly in dialogue during the unexpected, emergency takeover request in drive three. These latter elements were more commonly related to road positioning and lane selection (the tactical), and determining the remaining distance to their required exit immediately following resumption of manual driving (the strategic), rather than the control aspects of the driving task.

In a post-study questionnaire, drivers declared high confidence in their own ability to resume control when required to do so, describing the positive actions they took (placing their hands on the wheel, checking the mirrors, etc.), and felt that, overall, they were successful. Even so, both drivers and passengers recognised the positive and supportive role played by the passenger during periods of automation, and in particular when resuming control, or deciding when to do so – citing examples of the passenger helping to find the correct junction and to decide when to take control, or helping to the keep driver awake and alert; these examples suggest a notional sharing of the driving task and responsibilities. Nevertheless, passengers tended to rate their own role and influence during these situations more highly than the corresponding ratings made by their accompanying driver.

There were also examples of the passenger playing a mediating role, for example expressing their opinion regarding what the driver should or should not be doing while the vehicle was in automated driving mode, or even reprimanding the driver if they attempted to undertake an activity that they, the passenger, deemed unacceptable, such as sleeping. Nevertheless, passengers’ comments also demonstrate that they were acutely aware of the potential distraction they posed to the driver, recognising that the driver was ultimately in control of the vehicle. Indeed, passengers tended to delegate specific driving-related tasks to the driver, such as initiating the resumption of control using a voice command; moreover, some drivers were noted reprimanding their passenger if they attempted to do so on their behalf.

In other cases, the driver and passenger appeared to take it in turns to remain alert; for example, there were episodes in which the passenger continued to watch and engage with the driving situation while the driver was resting or even sleeping, and vice versa. It was therefore notable that the driver and passenger purportedly experienced the same level of situational awareness and workload during periods of automation, and that their trust and acceptance of the automation technology were comparable, based on their responses to existing, well-established rating scales and questionnaires administered during the study.

Overall, the study reveals both distractive and protective behaviours when a front-seat passenger is present during SAE Level 3 conditional driving automation (SAE, 2021), demonstrating the importance of involving all potential users in the design of future vehicles. While the emerging participatory activities have the potential to distract drivers and reduce their attention, they were also intrinsically linked to conversation, and this enabled drivers and passengers to develop a joint engagement with the driving situation.

The work forms part of a triumvirate of studies conducted by the authors between 2019 and 2024 which aim to explore how drivers and passengers will behave in future, automated vehicles. The findings are important and timely given the rapid progression of the Automated Vehicles Bill through UK Parliament, which will "set the legal framework for the safe deployment of self-driving vehicles in Great Britain" (DfT, 2024a; UK Parliament, 2023). More generally, these insights can inform the debate regarding what activities should be permissible during SAE Level 3 conditional driving automation (SAE, 2021) and the design of in-vehicle information and functions to support and promote the safety of drivers and passengers, and, indeed, all road users.

1. Introduction

1.1 Previous studies

Over recent years, there has been considerable interest in future automated vehicles that possess the capability to sense the environment, control their own actions and interact with other road users, all without any input from a human driver. Such vehicles have the potential to revolutionise future transport, with benefits expected in terms of safety, convenience, accessibility and efficiency. In some respects, these vehicles may seem to simply reflect the next step in current technological advancement, but in practice they represent a radical change in ideology, completely redefining the role of and expectations placed on the human driver, particularly in situations where he or she may be required to resume manual driving after periods of automation, potentially unexpectedly and at short notice.

The potential to disengage from manual driving activities (visually attending to the road scene, steering, braking, etc.) while the vehicle is under automated control provides the opportunity for drivers to engage in non-driving-related tasks (NDRTs). Empirical studies are subsequently required to understand what activities drivers will naturally choose to undertake while the vehicle is in control; what impact these activities have on the driving task, and in particular on the resumption of manual control in different situations; and how drivers' skills and attitudes will change over time. Answers to these questions can help to inform legislation (outlining what is permissible in future automated vehicles) and is also of interest to vehicle manufacturers and designers.

In previous work funded by the RAC Foundation – study one: *How will Drivers Interact with Vehicles of the Future*? (Burnett et al., 2019) – we devised a novel, longitudinal driving simulator methodology to provide empirical evidence to seek answers to these questions. A total of 49 experienced drivers (27 male, 22 female; mean age: 32 with age range: 21–64; mean annual mileage: 5,621) undertook a 30-minute commute-style journey on each of five consecutive days over the course of a week. They were asked to imagine what they might do in a future automated vehicle during such a journey and to bring with them their own devices or artefacts to use. The journey involved periods of manual and automated driving, defined as Society of Automotive Engineers (SAE) Level 3 conditional driving automation (SAE, 2021), meaning that participants were told that they might be required to resume manual control, given appropriate notice, during periods of automation, but were otherwise given agency to do as they pleased.

Results of study one highlighted the unintended consequences, and potentially deleterious effects, of introducing partially automated vehicles onto the roads without considering the needs and capabilities of the attending human driver. For example, drivers were quick to relinquish control, demonstrating very high levels of trust in and acceptance of the automation, and undertook a range of activities while the vehicle was in control. Typically, these activities had high visual, manual and cognitive demands. For example, over 80% of participants used their smartphone during periods of automation, ostensibly to review notifications and messages or watch digital content. In addition, approximately 25% of participants engaged in some form of reading activity (such as reading a book or magazine). Other drivers were observed using a laptop or tablet computer, and there were also some incidents, albeit rare, of drivers sleeping for short periods.

While the types of devices and activities did not change significantly during the week in study one, the proportion of time (as determined by the visual attention directed towards them rather than at the road scene) increased to more than 80% on day five. By comparison, drivers had spent almost one third of the time looking at the road on day one. In addition, driving performance immediately after resuming manual control was generally poor, with high levels of lateral instability (swerving) and speed variability (erratic braking or accelerating) during the ten seconds immediately following scheduled handovers. Driving performance was arguably better following the unexpected emergency handover, although this was suspected to be due to heightened driver arousal in response to the emergency event notification. Collectively, results from study one demonstrate a significant (and rapid) increase in trust and acceptance of the technology as the week (and drivers' experience of automation) progressed.

Fundamentally, study one highlighted a lack of awareness and skills with which to operate and interact with automated vehicles in a safe and appropriate manner, suggesting the importance of and need for new forms of training and awareness to ensure that drivers are prepared. In particular, there was a fundamental need to provide, from the outset, clear and consistent learning strategies for fostering the development of accurate mental models with which to understand how the system works, including the limits of its capability.

In study two: *Driver Training for Future Automated Vehicles: Introducing CHAT (CHeck, Assess and Takeover)* (Shaw et al., 2020), behavioural change theories and expert knowledge were applied to develop a proof-of-concept, behavioural training intervention. Framed by an extensive literature review, which draws in part on experience and literature from the aviation domain, and informed by interviews with experienced drivers and expert driving instructors, we created a short, self-paced, professionally narrated presentation that aimed to improve drivers' understanding of vehicle automation, outline their role and responsibilities at Level 3 automation, and provide best-practice guidance for driving and interacting with such vehicles. As part of this, we introduced a standardised operating procedure relating to the transition of control. This was defined by the acronym and mnemonic strategy, 'CHAT' (CHeck, Assess and Takeover) (Shaw et al., 2021), which specifically draws attention to the actions necessary, and the order in which they are required, before taking over physical control of the vehicle. The behavioural (CHAT) training was subsequently evaluated in a between-subjects, driving simulator study, in which we recruited 25 participants (20 male, 5 female; mean age: 35, age range: 21–59; annual mileage range: 5,680 to 26,000), all of whom were experienced drivers with an individual mean of over 14 years' driving experience.

Results of study two demonstrated immediate, quantifiable benefits associated with the new, behavioural CHAT training approach, with the greatest positive impact evident on drivers' visual behaviour (additional mirror checks, increased likelihood of noticing hazards, etc.). In addition, the standardised operating procedure (CHAT) was deemed to be a useful aide-memoire (akin to 'mirror–signal–manoeuvre') to help guide appropriate behaviour during the transition of control and to mitigate some of the performance issues identified in study one. Consequently, it was suggested that CHAT could be integrated into training programmes for new drivers, or delivered on a standalone basis to experienced drivers.

Both study one and study two also highlighted the importance of the design of the human–machine interface (HMI) in facilitating the efficient resumption of control. For example, when a tactical ('top-down') handover HMI as part of study one, which encouraged drivers to check for hazards prior to assuming control was provided, it was noticeable that drivers made more mirror checks during the transition of control, compared to situations in which they were provided with a control (or 'bottom-up') HMI advising drivers simply to "take control"; this difference was evident even during the emergency handover.

1.2 Presence of a passenger

Whilst study one and study two (and, indeed, the overwhelming majority of related works) have considered the impact of automation on the behaviour of the driver, it is widely known that a significant proportion of cars on the road at any one time are carrying at least one passenger (over one third in the UK according to recent figures from DfT (2024b)). Moreover, there is an expectation that multiple-occupant travel is likely to increase due to behavioural changes predicted to accompany the shift from single occupancy to shared mobility solutions, or the adoption of mobility-as-a-service. The presence of one or more passengers has been shown to distract drivers during manual driving, with reported reductions in situational awareness, an increase in the risk of taking unsafe actions, and an increased risk of a fatal crash, particularly in the case of young drivers (Ouimet et al., 2015). Moreover, in the presence of other vehicle occupants, the car becomes a social space (Laurier et al., 2008; Bremers et al., 2023); this can lead to 'social discomfort' caused by contentious conversations with passengers known to the driver, and is thought to have a negative impact on safe driving (Bremers et al., 2023). Nevertheless, the presence of a passenger during SAE Level 3 conditional driving automation (SAE, 2021) has, to date, received no empirical attention. Aiming to address this oversight, we conducted a third study (study three, reported in full herein), inspired by our previous studies in methodological design, but on this occasion involving the recruitment of participants in driver/passenger pairs. The study aims to explore how the presence of a passenger affects driver behaviour in future automated vehicles. This report documents study three in detail, but also brings together all three studies as a complete body of work. We begin with a review of the relevant literature.

2. Presence of Passengers in Cars: Literature Review

2.1 Introduction

There is a scarcity of published works regarding the presence of a passenger in SAE Level 3 conditional driving automation (SAE, 2021). Nevertheless, passengers frequently appear in driving research more generally, where their presence has been shown to significantly influence driving performance, attention allocation and risk-taking behaviour. Moreover, there is a widely held belief that passengers are a distraction for drivers in manually driven cars, and their presence increases crash risk. While it is easy to find data to corroborate this (e.g. Theofilatos et al., 2018), the literature is in fact rather nuanced, with evidence also suggesting that the presence of a passenger in manually driven cars can, in some situations, reduce crash risk as compared to driving alone (Rueda-Domingo et al., 2004). These contradictory effects appear to be influenced by certain driver and passenger characteristics, such as age, gender and the number of passengers, as well as the context and complexity of the driving activity in question (Ouimet et al., 2015). Moreover, it has been noted that the car becomes a social space when a passenger is present (Laurier et al., 2008; Bremers et al., 2023). Thus, passengers can act as a source of social control, thereby facilitating and regulating driving behaviour; or they can actually contribute to 'social discomfort', which can distract drivers. Crucially, the presence of a passenger does not appear to have the same effect in all situations and for all drivers (Orsi et al., 2013). In the following sections, we bring together relevant literature associated with the presence of a passenger in manually driven cars and consider the implications that this might have for automated vehicles.

2.2 Distraction

Where passengers are present in the vehicle, interaction with the driver is almost inevitable. This interaction usually takes the form of conversation, but it might develop into something more, for instance into an argument, or "dealing with children" (McEvoy et al., 2007) (although it has been noted that "well-behaved" child passengers reportedly decrease the likelihood of a crash (Eriksen & Gielen, 1983)). Passengers may also engage in physical activities within the car, such as adjusting the radio or using electronic devices, and this can divert the driver's attention from driving tasks. However, it has also been noted that the driver's involvement in secondary activities (exemplified by interaction with a handheld mobile phone) reduced when a passenger was present (Sagberg et al., 2019). In their interview study, Sagberg et al. (2019) conjecture that this is either because the passenger can undertake that secondary task on the driver's behalf (for example using their mobile phone or adjusting the radio or navigation system) or because the presence of a passenger has an inhibitory effect on the driver's motivation for undertaking secondary tasks.

Regardless, interaction (most commonly conversation) with a passenger is generally considered to be a "distraction" (Theofilatos et al., 2018). This is because it can impose additional mental workload on the driver, and thus slow their reaction times to events (the time to mentally register something in the environment and the time to physically react to it) (Papantoniou et al., 2015; Stutts et al., 2001). In line with other driver distractions, interaction with a passenger has been shown to reduce situational awareness (Chandrasekaran et al., 2019), and result in changes to acceleration, speed and road position, including the changing of lane (Aarts & Van Schagen, 2006), all of which are often cited as causal factors in road crashes. In addition, interacting with a passenger increases the risk of taking unsafe actions, more generally (Bédard & Meyers, 2004; Ouimet et al., 2015).

Several studies have highlighted correlations between interaction with passengers and road crashes (Lam, 2002; Neyens & Boyle, 2008). For example, Theofilatos et al. (2018) conducted a meta-analysis of existing literature. Although they highlight differences between studies in analytical methods, sampling frames and outcome indicators, they nevertheless conclude that interaction with passengers is one of the most frequent distracting activities undertaken by drivers and results in a 'non-negligible' amount of crashes (in their meta-analysis, passenger interaction-related crashes appeared with a percentage of 3.6% amongst all causes). Moreover, Theofilatos et al. (2018) show that there is a significant increase in injury severity amongst drivers if a passenger is present, compared to injuries sustained when a driver is alone. Similarly, Orsi et al. (2013) undertook an analysis of accident data, and highlight passenger presence as a factor influencing crash outcome. They also highlight that the influence of passenger presence on crash outcome severity for drivers was found to depend on driver age: amongst young drivers (under 25 years of age), the consequences of a road crash were more severe if there were passengers in the car. These findings are in line with the results of other studies which show an increased risk of injury or death in young drivers carrying passengers (Lin & Fearn, 2003; Chen et al., 2000; Rice et al., 2003).

Moreover, Orsi et al. (2013) report that crash outcomes for young drivers are more likely to be severe when the passenger is male. Indeed, other studies have also highlighted an increased risk of crashes (Williams et al., 2007) and risky driving behaviour (Simons-Morton et al., 2005) in the presence of male passengers. Such findings are also supported by Ouimet et al. (2015), who conducted a systematic review of the literature to appraise the evidence from epidemiological studies of crash risk in young drivers accompanied by passengers, compared with young drivers on their own. Their analysis of fatal crash data showed increased risk, compared with solo driving, for young drivers with at least one passenger. An increase in risk of both fatal crashes and combined/non-fatal crashes was also found for two variables: male versus female passengers, and younger versus older drivers (Ouimet et al., 2015). As for the effect of passenger age on the incidence of combined or non-fatal crashes, results were mixed, with no clear evidence that teenage passengers, or passengers of any age, are associated with increased risk – although there was some evidence of a protective effect (that is, reduced risk) associated with male driver / female passenger partnering (Chen et al., 2000; Rueda-Domingo et al., 2004).

2.3 Conversation

In manually driven cars, interactions with a passenger are (to a large extent) limited to conversation (Theofilatos et al., 2018), and this can have both positive and negative implications. Indeed, passengers reportedly modify their conversation based on their perception of the road situation (Drews et al., 2008). For example, passengers frequently and intuitively withdraw from a conversation when the driver approaches a complex junction. In contrast, similar modifications to conversation are less evident during a mobile phone conversation, because the so-called 'remote passenger' is not experiencing the driving situation first-hand; consequently, conducting a conversation using a mobile phone while driving can interfere more seriously with the driving task (Gugerty et al., 2004). There is also evidence that drivers compensate for their reduced attention when talking to a passenger by facilitating the driving task, for example by driving more slowly (Lee & Abdel-Aty, 2008).

If the passenger is an experienced driver themselves, their conversation can actually support the driver and enhance their situational awareness, to the extent that it can improve their perception of critical factors in the environment (Chandrasekaran et al., 2019). For example, passengers who are familiar with the driving task can highlight significant features and events in the driving environment, or monitor the condition and performance of the vehicle – or, indeed, the driver (e.g. as being tired or affected by alcohol) (Bédard & Meyers, 2004; Charlton, 2009; Regan & Mitsopoulos, 2001). Mitsopoulos et al. (2005) even explored the notion of training passengers to support the driver using crew resource management (CRM) techniques inspired by the aviation and medicine domains. They concluded that the application of CRM had the potential to significantly enhance the positive – and reduce the negative – effects of passengers on young driver behaviour, and thus provided recommendations for the development of a young-driver CRM training program.

Passengers have also been observed actively assisting with the navigation task when approaching an exit (Drews et al., 2008). This can contribute to a shared awareness of the road situation (Charlton & Starkey, 2020), and may facilitate other potential benefits, for example the encouragement of positive safe-driving behaviours such as taking a break on a long drive (Drews et al., 2008). Nevertheless, it has been noted that certain driving cues such as traffic signs, apparent hazards or warnings, often go unnoticed by passengers (Vollrath et al., 2002).

In contrast, a passenger with no, or only very limited, driving experience can have a negative impact on the driver's situational awareness (Chandrasekaran et al., 2019). This is because conversation is a distraction in and of itself, requiring attention and imposing cognitive load, and, as such, can divert the driver's attention from the primary driving task, regardless of topic (Strayer & Drews, 2004; 2007). Indeed, "talking to passengers" is one of the most commonly reported distractions by drivers (McEvoy et al., 2006), with 21% of distractions attributed to passengers and their verbal interactions (Strayer et al., 2013). Moreover, driver/passenger conversation reportedly contributes to up to 20% of distraction-related road accidents (Horberry et al., 2006).

The nature of the relationship between the driver and their conversational partner has also been explored in the context of driver distraction. Notably, drivers who are romantically involved with their passenger often engage in contentious or emotionally charged conversations (Lansdown & Stephens, 2013). If their partner is present in the vehicle, this can adversely affect vehicle control (longitudinal and lateral), compared to situations when the driver talks to their (romantic) partner on a hands-free mobile phone (Lansdown & Stephens, 2013).

Laurier et al. (2008) go further, to suggest that the privacy of the car is an occasion that enables, or even encourages, conversations on "very serious or difficult" topics. They highlight the fact that car-bound partners cannot walk away from the conversation, and the extended silences (which are accepted as an ordinary feature of conversations in a car) allow for slow and considered responses to complex or difficult issues. Moreover, Laurier et al. (2008) highlight the fact that in manual driving, the driver and their passenger are both facing forward (and the driver is notionally required to remain so), and this avoids them having to make "awkward" eye contact during difficult discussions.

2.4 Social discomfort

Regardless of conversational topic, the presence of a passenger can lead to unpleasant or difficult social interactions, or 'social discomfort', more generally (Bremers et al., 2023). This in itself can induce strong emotions (Theofilatos et al., 2018), which in turn can have negative consequences for driving safety. In traditional human factors and automotive engineering, the focus for mitigating discomfort typically requires the identification and elimination of physical or physiological sources of discomfort, such as uncomfortable seats, motion sickness, or characteristics related to air conditioning, noise, space or smell (Constantin et al., 2014). In contrast, there is limited empirical work published on social discomfort in a car, although it has been highlighted by a number of authors (Bremers et al., 2023; Laurier et al., 2008). Laurier et al. (2008) explain that social discomfort is influenced by the enclosed space, and could be influenced also by long uncomfortable silences, disagreement about directions, or discussion about which car was in the wrong in an ambiguous scenario (Laurier et al., 2008).

2.5 Protective effects on driver behaviour

Whereas many of the aforementioned studies show that the presence of a passenger distracts the driver and increases crash risk, there are also many studies that show that passengers can actually enhance driver safety by encouraging safe-driving behaviours. For example, Lee and Abdel-Aty (2008) report a higher likelihood of a driver's seat belt usage and a lower likelihood of their use of alcohol in the presence of passengers. Furthermore, in their analysis of accident data, Isaac et al. (1995) reported that alcohol-impaired drivers were less likely to be fatally injured when they were accompanied by passengers. They suggested that this is because unimpaired passengers can reduce the severity and probability of alcohol-related crashes. They attribute this largely to strategies of social control for tackling drunk driving at the time, such as the Drunk Driving Prevention campaign (*Friends don't let friends drive drunk,* ANA Educational Foundation, n.d.). It is worth noting that this campaign encouraged the unimpaired passenger to intervene or to offer themselves as an alternative driver, rather than relying on their presence to invite safer driving behaviour.

Protective effects have also been reported based on the driver's and passenger's age and gender. For example, Rueda-Domingo et al. (2004) found that the presence of passengers had a more protective effect for older drivers than younger drivers. Although Vollrath et al. (2002) also report protective effects associated with passenger presence in their analysis of accident data, they cite a number of modifying variables, such as the driver's age or the time of day (for example, young drivers and night-time driving negate the protective effect). Lee and Abdel-Aty (2008) also comment that the protective effect they observed was smallest in situations where a large amount of attention was needed, such as in busy or complicated road situations. They therefore suggest that this may explain why there is an absence of a protective effect amongst younger drivers, who are more likely to be, by definition, less experienced in driving and therefore need to direct more of their attention to the road situation.

Rosenbloom and Perlman (2016) noted during their roadside observation of over 1,000 vehicles that drivers were less likely to commit a traffic violation if one or more passengers were present. They attribute this finding to social facilitation theory (Bond & Titus, 1983), which describes how people are affected differentially by the presence of others (also referred to as the 'audience' or 'spectator effect'). In actual fact, social facilitation theory may also explain the various aforementioned associations reported between passengers and driving behaviour among drivers.

Indeed, young drivers in particular are thought to be more susceptible to peer pressure than older drivers (Chein, 2015; Chein et al., 2011; Simons-Morton et al., 2012). It is suggested that young people are keenly attuned to the behaviour and attitudes of their peers, and in the driving context, that this translates into an increased propensity for risk-taking when young passengers are also present (Baxter et al., 1990). In addition to the aforementioned examples, it has also been reported that seat belt use is reduced – and thus the risk of injury increased – when teenage drivers and young/teenage passengers travel in the same car (Williams & Shabanova, 2002). The authors also report that driver seat belt use decreased with increasing number of passengers, and note that seat belt use was highest when passengers were aged 30 and older, suggesting that passengers in this latter example were likely to be the parents of the teenage driver.

2.6 Passengers in automated vehicles

As highlighted at the outset, there is currently a scarcity of published works regarding the effect of passenger presence in automated vehicles. Nevertheless, some preliminary investigations have been reported. Indeed, Tang et al. (2020) employed user enactment (or "imaginary exploration") to enable participants in their study to envision the types of activities that they might engage in during automated driving, and highlight the effect of passenger presence on the emerging in-vehicle activities. Significantly, participants' envisioned activities were no longer confined to conversation as with a manually driven car. In fact, results suggest increased participatory NDRTs when a passenger is present, with suggested examples of playing video games, board games and conversing. In addition, fewer private NDRTs were envisioned in situations where a passenger was also present, such as changing clothes, making phone calls and trading stocks. Participants were also reportedly more inclined to rest or sleep in the presence of a passenger, which the authors attribute to high trust in their vehicle (and indeed their passenger also). It is worth highlighting that in their exploration, Tang et al. (2020) were primarily considering higher levels of automation (including fully autonomous vehicles requiring no driver input), and their results were therefore intended to inform the design of futuristic vehicle interiors to support NDRTs. This so-called 'interior metamorphosis' has been explored by several authors (Jorlov et al., 2017; Pettersson & Karlsson, 2015; Large et al., 2017), with the futuristic vehicle interior often visualised as an 'extended living room' (Pettersson & Karlsson, 2015). With this in mind, Tang et al.'s (2020) recommendations include the design of "more comfortable and personalised environment[s]" and "more flexible and adaptive design[s]", such as adjustable and multifunctional seating that can rotate to interact with passengers in the rear of the car, expand to become a small bed and thus allow passengers to lie down or sleep during autonomous driving, or collapse to release more space.

2.7 Literature summary

The literature shows clear effects of passenger presence on driver behaviour and performance in manual driving. While much of the literature confirms the commonly held belief that passengers are a distraction to drivers in manually driven cars, and that their presence can therefore increase crash risk, reported findings are somewhat nuanced. Indeed, the effect of passenger presence appears to be highly dependent on the driving context and on certain driver and passenger characteristics, such as age and gender, with the highest risk attributed to young, male drivers and young, male passengers. However, there are also many situations described in the literature in which a passenger can provide a supportive or protective effect during manual driving, thereby minimising crash risk, by means such as encouraging and promoting good driving behaviours, or helping the driver with specific driving-related tasks, such as route-finding.

It is also clear from the literature that interactions with a passenger during manual driving are largely limited to conversation. Although conversation can, in and of itself, become a distraction, particularly if conversational topics are contentious, passengers have been shown to modify their dialogue and verbosity of conversational interactions in response to the road situation, recognising and attempting to minimise the distraction they knowingly pose.

Clearly, future levels of automated driving will present new opportunities for driver/passenger interactions and activities, above and beyond conversation, and further empirical research is required to understand what these will consist of and what issues will become evident.

3. Study Three – How Does the Presence of a Passenger Affect Driver Behaviour in Future Automated Vehicles?

3.1 Introduction

Over one third of cars on the road at any one time are carrying at least one passenger (DfT, 2024b). The presence of one or more passengers has been shown to distract drivers during manual driving, with reported reductions in situational awareness and increases in the risk of taking unsafe actions – factors that elevate crash risk, particularly for young drivers and passengers (Ouimet et al., 2015). Moreover, social discomfort caused by contentious conversations with passengers known to the driver is thought to have a negative impact on safe driving (Bremers et al., 2023; Lansdown & Stephens, 2013). Nevertheless, passengers have also been shown to support drivers and reinforce safe-driving behaviours (Bédard & Meyers, 2004; Charlton, 2009; Regan & Mitsopoulos 2001).

The presence of a driver and a passenger during SAE Level 3 conditional driving automation has – to date – received no empirical attention. Aiming to address this oversight, we conducted a study similar in design to the aforementioned investigation by Burnett et al. (2019), but on this occasion jointly recruited both drivers and passengers, who took part together. The work forms part of our triumvirate of studies exploring how drivers and passengers behave in future, automated vehicles.

3.2 Aims

The overall aim of study three was to conduct exploratory research into the safety-related behaviour and performance of drivers in the presence of a passenger during conditional driving automation (SAE Level 3) (SAE, 2021). In particular, we were seeking to reveal the impact of social dynamics during periods of automation and the resumption of the manual driving task, and to provide qualitative data to support policymaking, driver training and the design of future vehicles. The research aimed to address the following research questions:

1. What will drivers and passengers naturally do in future automated vehicles?
2. What impact does the presence of a passenger have on the driving task – that is, during periods of automation and also during the resumption of the driving task?
3. How does the presence of a passenger affect levels of situational awareness, workload, trust and acceptance?

3.3 Methodology and approach

3.3.1 Participants

We anticipated recruiting 15 driver/passenger pairings (n = 30) for the simulator study, and aimed to include a representative cohort of younger drivers, given their preponderance in passenger-related literature. Interested participants were encouraged to volunteer together (as a driver and passenger pair), so that each driver/passenger pairing would be known to each other. A total of 18 driver/passenger pairings (n = 36) were subsequently recruited to take part. Unfortunately, one pair withdrew partway through the study due to simulator sickness. All subsequent data refers to the remaining 17 pairs (n = 34).

All driver/passenger pairings were in fact known to each other, and participants were asked to self-describe their relationship with one another. Relationships were variously described as ‘friends’ (six pairs), ‘partners’ (eight pairs) and ‘colleagues’ (four pairs, reduced to three after the withdrawal just mentioned). Full demographic details of all participants are shown in Table 3.1.

All participants completed a consent form and received a £30 shopping voucher as a token of goodwill for taking part. The study design was approved by the University of Nottingham Faculty of Engineering ethics committee.

Table 3.1: Participant demographics

Group name	Terms used by participants to describe their relationship	No. of pairs	Mean no. of years in relationship	Gender profile	Age profile, range (n)
Friends	'friend', 'friends', 'close friend', 'brother'	6	6.1	Male (7) Female (5)	18–24 (2) 25–34 (10) 35–44 (0) 45–54 (0) 55–64 (0) 65+ (0)
Partners	'partner', 'husband', 'wife', 'girlfriend', 'spouse'	8	16.3	Male (8) Female (8)	18–24 (5) 25–34 (3) 35–44 (2) 45–54 (2) 55–64 (4) 65+ (0)
Colleagues	'work colleague', 'workmate', 'colleague'	3	0.9	Male (6) Female (0)	18–24 (0) 25–34 (4) 35–44 (2) 45–54 (0) 55–64 (0) 65+ (0)

Source: Authors' own

3.3.2 Driving simulator

The study took place in the University of Nottingham's Human Factors Research Group driving simulator (Figure 3.1). The University of Nottingham driving simulator comprises a right-hand drive, Audi TT Mk1 car. Three ceiling-mounted, high-definition projectors provide an approximately 270 degrees forward and side view of the dynamic, unfolding driving scene on a curved screen, with edge blending and image warping ensuring that a contiguous image is presented to participants. Side mirror displays are integrated within the original mirror housings. Rear view is displayed via a display screen placed behind the vehicle. Vehicle performance data is presented on a seven-inch LCD screen, replacing the original Audi instrument cluster. A Thrustmaster T500RS force feedback steering wheel and pedal set are integrated with the existing Audi primary controls and cabin environment.

Figure 3.1: University of Nottingham's Human Factors Research Group driving simulator, showing (clockwise from top left): side view, vehicle cabin/interior, control room and full vehicle with surrounding screen

Source: Authors' own image from driving simulator

Figure 3.2: Motorway scenario rendered in SCANeR simulation software

Source: Authors' own image from AVSimulation SCANeR studio software

The simulated driving environment for the study was created using AVSimulation SCANeR software (www.avsimulation.com/scaner). The driving scenario was designed to replicate an extensive UK road network comprising suburban and three-lane motorway elements (Figure 3.2). Road layout, junctions, markings and signage conformed with UK standards, as far as practicable, although road names and locations were fictitious. Traffic levels were moderate to heavy throughout the journey to reflect typical, changing traffic conditions. The same road network was used for all drives.

The participants' vehicle (also referred to as the 'ego vehicle') was modified to reflect SAE Level 3 conditional driving automation, thereby permitting both manual and automated driving, and transition between these states. Vehicle capabilities and limitations were described to participants, in line with SAE definitions (SAE, 2021). Participants were told that they could make transitions between automated and manual driving states using a voice command. In reality, this prompted the researcher in the control room to manually change driving state using a software command. The current status (manual driving, automation available, automated driving, etc.) was communicated multimodally, as a text-based notification on a screen located in the centre console of the vehicle and a simultaneous voice message describing the new state, for example "automated driving available".

Automation was available only at the approach to the motorway and on it. During periods of automation, the ego vehicle aimed to achieve a speed of 65–70 mph, in line with UK regulations, and therefore moved between lanes in response to the behaviour of other road vehicles – for example, to overtake a slower vehicle. In practice, all vehicle manoeuvres were pre-programmed to encourage a comparable driving experience between participants.

3.3.3 Journey experiences

Three journeys were expertly curated and framed to reflect genuine experiences, with the aim of eliciting authentic behaviours rather than for experimental convenience or control. The three journeys were framed as 'days out' occurring over a week. These were: visiting a shopping outlet on Monday, a walk in the country on Wednesday and dinner with friends on Friday. Participants were encouraged to take all their belongings with them into the car, particularly if they felt that they may have been useful at their fictitious destination (for example, bags for the shopping trip or coats for their walk), rather than leaving them in the control room as would normally be the case during a study. The aim of this was to add further authenticity and validity to the experience. In practice, the three journeys occurred during the same day to aid participant recruitment and retention. However, participants left the vehicle and laboratory with their belongings between each journey and were asked to complete various questionnaires, thereby isolating each journey experience. Participants were subsequently welcomed to each subsequent drive as if it were a new day and a new experience.

Each journey began in the same residential setting, described as the driver's home. Participants drove manually to the motorway (a journey lasting approximately five minutes) and always joined at 'Junction 27'. Automation was made available as they approached the motorway and routinely activated on the slip road. Participants were then required to resume manual control and to leave the motorway at the correct exit based on the specified journey. Therefore, the duration of automated driving differed between journeys, but was anticipated to last between 20 and 30 minutes (that is, up to approximately 30 miles), depending on the required destination. During periods of automation, participants were told that they were free to undertake any activities they deemed acceptable in the context; no restrictions were placed on the types of activities they could do. Participants were reminded, however, that they would be video-recorded, so should not discuss any topics, or reveal any information, that they would not want a stranger to hear. For the sake of consistency, participants fulfilled the same role (either driver or passenger) during each journey.

Examples of commonly occurring, driving-related situations were created within the scenario to enhance ecological validity (meaning that the findings of the study were thus made generalisable to real-life settings) and encourage interactions between the driver and passenger. These included a collision and subsequent traffic jam on the counter-carriageway (Figure 3.3), unusual vehicular activity on crossing bridges, and vexatious behaviour of nearby vehicles (e.g. speeding / undertaking the ego vehicle).

Figure 3.3: SCANeR rendering of accident and traffic jam on counter carriageway

Source: Authors' own image from AVSimulation SCANeR studio software

Ahead of each journey, the desired destination was communicated in detail to the driver and passenger, and along with the destination, the motorway junction and expected duration, providing much the same information as one might need for preparation ahead of a journey. For example: "You're going shopping in Tyson's outlet shopping centre. You will need to exit the motorway at Junction 33, signposted to A68 Tysons. This journey should take approximately 25–30 minutes." Journey details were also displayed in text on the internal display in the car prior to starting the journey. The three journeys are detailed in Table 3.2.

Table 3.2: Details of the three journeys, as described to participants

Drive number / notional day	Description
1. Monday	"You're going shopping in Tyson's outlet shopping centre. You need to exit the motorway at Junction 33, signposted to A68 Tysons. This journey should take approximately 25–30 minutes."
2. Wednesday	"You're going out for a country walk in Aspen Hill. You need to exit the motorway at Junction 31, signposted A46 Aspen Hill. This journey should take approximately 20–25 minutes."
3. Friday	"You're going out for dinner with friends in Falls Church. You need to exit the motorway at Junction 32, signposted A27 Falls Church. This journey should take approximately 25 minutes."

Source: Authors' own

When participants wanted to resume control (presumably in preparation to exit the motorway), they were required to use the voice command "Autocar: resume control", ("Autocar" being the keyword required to precede any command, in much the same way as Amazon Alexa and Google Assistant operate), which begin a ten-second countdown until manual driving was activated. The vehicle responded to a voice command from either the driver or the passenger, as might be expected, as well as close derivatives of the command (for example "Autocar: take control", "Autocar: take over", etc.), although these capabilities were not specifically communicated to participants prior to taking part. Participants could request control at any time, but the expectation (based on the study design) was that control would be resumed only prior to exiting the motorway. The ten-second countdown was shown on the centre console interface as descending numerals. An audible tone signified the precise moment of the handover of control.

On Friday (day three), an unexpected (to the participants) situation necessitated the emergency handover of control prior to the required junction (Figure 3.4). This was communicated to them using the in-vehicle HMI and described as inclement weather (i.e. heavy rainfall) affecting the vehicle sensors. The unexpected, emergency handover occurred approximately 11 minutes into the drive and was accompanied by an appropriate degradation in weather conditions. At the point that manual control was requested, rainfall was severe.

Figure 3.4: SCANeR rendering of inclement weather prompting unexpected, emergency handover on drive three

Source: Authors' own image from AVSimulation SCANeR studio software

3.3.4 Measures and analysis

The study was designed to provide a corpus of novel and interesting data in and of itself. However, we also wanted to compare our findings with those from previous studies, where practicable, to understand the impact of the presence of a passenger during periods of automation and on the decision to resume manual control. The range of measures and analytical techniques were therefore chosen with this in mind. As a reminder, the study aimed to seek answers to the following research questions:

1. What will drivers and passengers naturally do in future automated vehicles?
2. What impact does the presence of a passenger have on the driving task – that is, during periods of automation and also during the resumption of the driving task?
3. How does the presence of a passenger affect levels of situational awareness, workload, trust and acceptance?

To relate the findings to the previous two studies, the same measures and analysis techniques were used, as far as practicable. All journeys were video-recorded. In line with previous studies, videographic data was used to determine the activities undertaken by the driver and passenger, and their behaviour immediately prior to and during the handover of control. Questionnaires were completed independently by both the driver and the passenger. It should be noted, however, that although they contribute to the same overall body of work, the three studies were designed and conducted independently and actually took place over a period of several years. During this time, there were changes in the driving simulator software, vehicle setup and so on, and for this reason statistical comparisons between the three studies of the triumvirate are not possible. Instead, comparisons are largely qualitative in nature, utilising descriptive rather than inferential statistics.

As a standalone study, the overall aim of study three is to reveal new and unexpected behaviours and situations created by the presence and social interactions of a passenger during SAE Level 3 conditional driving automation (SAE, 2021). The following measures are thus reported and, where feasible and appropriate, compared between studies.

Secondary activities

The types of secondary activities and number of participants (driver/passenger) engaging in them. To enable comparison with study one, the coding scheme was based primarily on that used in study one – that is, behaviours were coded at device level by specifying the primary device used rather than the specific activity undertaken; for example, ‘smartphone’ was reported rather than, say, ‘accessing email’. This was, in part, due to the lack of task perspicuity, given that we were unable to use eye-tracking glasses for both practical and ethical reasons (primarily, to preserve the privacy and anonymity of participants).

Conversation and speech acts

Salient dialogue occurring during the takeover of control in both routine and unexpected situations was transcribed and analysed using speech act theory (Searle et al., 1980; Lampert et al., 2006). The central premise of speech act theory is that verbal utterances convey meaning in the form of an action, with each utterance (or speech act) categorised as a warning, question, advisement, or statement. We conducted speech acts content analysis (inspired by Lampert et al.'s (2006) classifications) by applying the driving skills hierarchy (Michon, 1985) as a framework. Michon's driving skills hierarchy deconstructs the driving task into control, tactical and strategic elements. Thus, in our analysis we identified speech acts and associated each with the relevant aspect of the driving task (control, tactical or strategic). In addition, episodes of perspicuous dialogue were extracted and presented verbatim to support the analysis.

Subjective ratings

Subjective, Likert scale ratings of situational awareness, situational trust, trust in automation and technology acceptance were captured using the same questionnaires and scales used in study one. Ratings of situational awareness and situational trust were captured immediately after each of the three drives. Ratings of trust in automation and technology acceptance were captured before and after the full experience (that is, all three drives). In addition, ratings of workload were captured after each drive. All ratings were provided, independently, by both the driver and the passenger.

Driver/passenger attitudes and opinions

Finally, a bespoke questionnaire examined the perceived role and influence of the passenger during automation and the resumption of manual control (from both the driver's and passenger's perspective), using Likert rating scales and written responses.

Driving behaviour and performance

Driving data was captured by the simulation software. Vehicle control data immediately following the resumption of control is reported, in line with previous studies (that is: lane position, lateral instability, speed and speed variability, first primary control input). Tactical and strategic driving elements are revealed through route choice (for example, whether they selected the correct exit) and through dialogue during the transfer of control.

3.4 Results and analysis

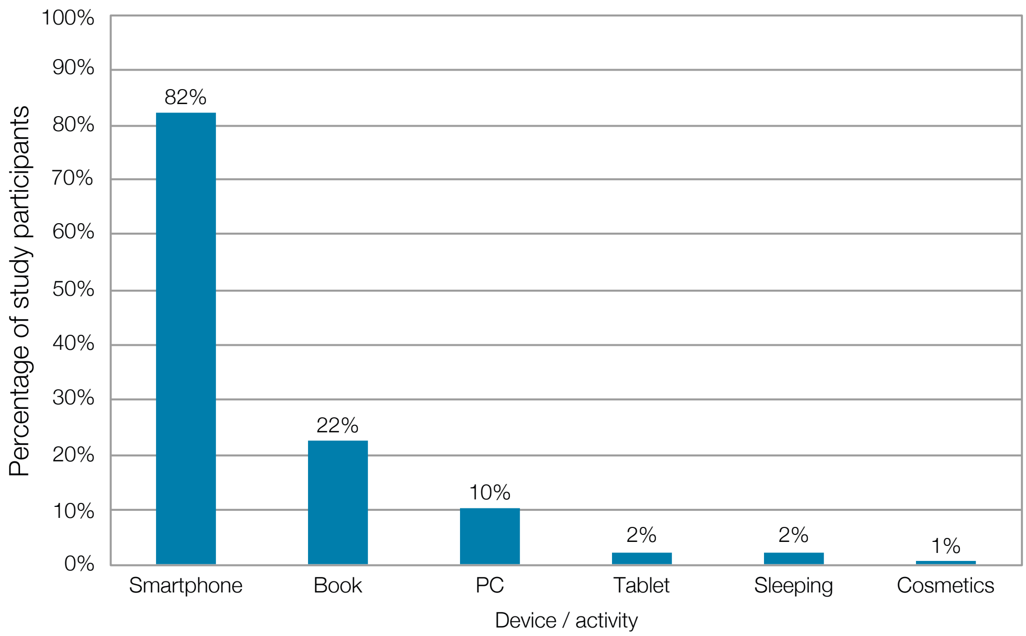
3.4.1 Secondary activities

One of the most fundamental, hitherto unanswered questions posed by the current research is: *What will drivers and passengers naturally do in future automated vehicles?* In our first study, we gave participants (in that case, drivers only) agency to undertake activities and exhibit behaviours that were most natural to them. This approach aimed to preserve important motivational factors that could have a significant bearing on their behaviour, and thereby enhance the ecological validity of the study. Indeed, there were numerous instances in study one of drivers choosing to prioritise their own NDRT over re-engagement with the driving task, thereby delaying or impacting the resumption of control. These motivational factors are unlikely to be present if drivers are given a standardised, experimental NDRT. Moreover, allowing participants to select their own NDRT reveals the types of activities that may arise, whether permitted or not, within an automated vehicle.

We therefore adopted the same approach in study three, allowing drivers and passengers to choose their own NDRTs and bring with them any devices or artefacts that they required to enable these. Naturally, the presence of a passenger also provides the opportunity to engage in joint or shared tasks. To enable qualitative comparisons with study one, we applied the same analysis approach and coding scheme. Videographic recordings of the interior of the car were interrogated to identify the devices that drivers and passengers used and the activities which they undertook during periods of automation. As before, behaviours were initially coded at device level, by which we mean that we documented the primary device used rather than the specific activity undertaken. It became apparent, however, that many of the activities during the current study were discussed between occupants (e.g. the contents of an email or details of their online shopping), or were by their very nature obvious – for example the driver and passenger used their smartphones to play a game of chess, or enter solutions to an online crossword (following discussions and agreement between the two of them). Because of this, we were able to interpret many of the behaviours and activities associated with a device at a more granular level, and where appropriate have used the dialogue between driver and passenger to help enrich our descriptions below.

Of note during study one was the predominance of smartphone use, with over 80% of participants using a smartphone during the week (Figure 3.5). Other recorded activities during study one were using a laptop ('PC' in the graph) or tablet computer, and there were also some incidents of drivers sleeping, although this was rare. Most of these activities were highly engaging, generally involving strong visual, cognitive and manual elements, and thereby intrinsically directing the driver's attention away from the driving situation. There were also some incidents of participants repurposing their cabin or relaxing their seating position or posture to accommodate secondary task execution. Moreover, participants in study one appeared quite comfortable, even from day one, engaging with their NDRTs as soon as the opportunity presented itself, despite their ongoing responsibilities towards the vehicle operating at SAE Level 3 conditional driving automation (SAE, 2021). Their attitude was reflected in high subjective ratings of trust and acceptance.

Figure 3.5: Secondary devices used and activities undertaken by drivers during periods of automation in study one



Source: Burnett et al. (2019)

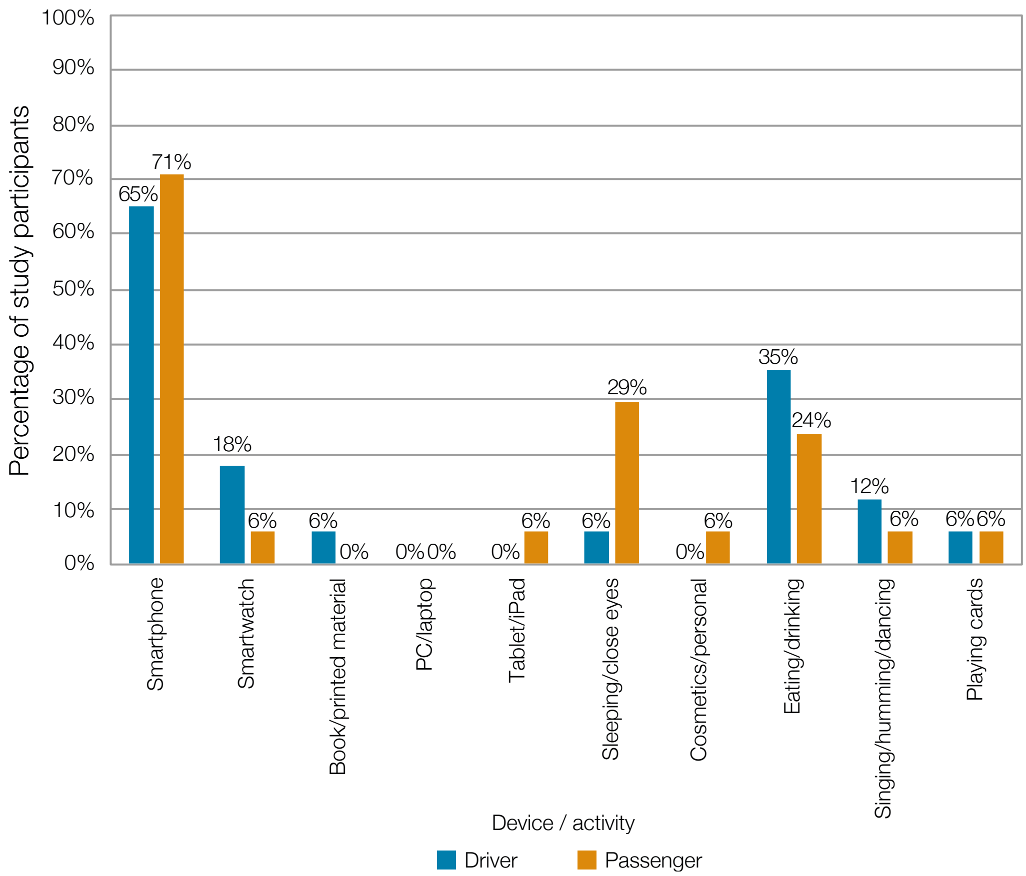
In comparison, smartphone use was also popular amongst drivers and passengers during the current study, with 65% of drivers and 71% of passengers engaging with their smartphone during the drive (Figure 3.6). Again, this is largely unremarkable, given the role that smartphones play in many people's daily lives. However, there were also some incidents of drivers and passengers using smartwatches, ostensibly as a surrogate to using a smartphone (for example to read or respond to messages) (Figure 3.7); such devices are more commonplace than when the first study was conducted.

Despite the prevalence of smartphone use, there were some concerns expressed by passengers regarding whether the driver should be allowed to use their phone or not, even during periods of automation.

> Driver: "I do have my phone, but I don't really want to go on it." Passenger: "I don't want you to go on it either." (Pair 15)

> Passenger: "You're looking at your phone!" Driver: "I'm allowed to. I'm not driving." (Pair 8)

Figure 3.6: Secondary devices used and activities undertaken by drivers and passengers during periods of automation



Source: Authors' own

Figure 3.7: Driver and passenger accessing messages using their smartwatch

Source: Authors' own image from driving simulator

There are some notable differences between drivers and passengers in the activities they conducted (Figure 3.6). For example, passengers tended to relax ('sleep') more and use their smartphones for longer periods than drivers. Participants' comments suggested that many thought the passenger was more able to completely disengage from the driving task (for example by sleeping, or watching engaging content on their phone) than the driver, who ultimately retained responsibility for driving and the vehicle (Passenger: "Even though I can sleep, you can't!" Pair 1). Some passengers therefore admonished the driver if they suggested that they may sleep (Driver: "I suppose I could have a nap really." Passenger: "No, no." Pair 15). However, some drivers were quite prepared to sleep (often reclining their seat to do so) and were supported in their decision by their passenger (Driver: "Can I sleep?" Passenger: "Yeah. You don't need to drive." Pair 2), and there were also examples where the driver and passenger appeared to notionally share the driving task – for example, by taking turns to rest or sleep, while the other stayed alert (Figure 3.8 and Figure 3.9). Notably, this task sharing was not necessarily negotiated verbally, but rather appeared to be somewhat intuitive and instinctive behaviour.

Figure 3.8: Driver remains alert while passenger sleeps

Source: Authors' own image from driving simulator

Figure 3.9: Passenger remains alert while driver reclines and relaxes and uses smartphone

Source: Authors' own image from driving simulator

While some activities were initially undertaken in isolation (for example, the driver and passenger each used their own smartphone to check their messages and updates), they often subsequently engaged their partner – for example by sharing their news, typically by physically showing their partner the phone. There were examples of both the passenger showing smartphone content to the driver and the driver showing content to the passenger (Figure 3.10 and Figure 3.11).

Figure 3.10: Passenger showing driver content on smartphone

Source: Authors' own image from driving simulator

Figure 3.11: Driver showing passenger content on smartphone

Source: Authors' own image from driving simulator

It was also common for the driver and passenger to use their smartphones to facilitate joint gaming activities (for example, playing a game of chess in Figure 3.12 solving an online crossword puzzle or playing a word game). However, not all joint activities were digital or device-based; there were also examples of drivers and passengers availing themselves of the opportunity to play games in a more traditional manner, such as playing a game of cards (with physical playing cards) (Figure 3.13). Notably, the participants in Figure 3.12 and Figure 3.13, who were jointly engaged in gaming, both missed their junction in drive one, prioritising their game (the NDRT) above preparations to resume control and exit the motorway. Some joint activities, such as sharing drinks and snacks, enabled the driver and passenger to remain visibly attentive to the road – at least to the extent that their gaze was notionally directed to the forward driving scene (Figure 3.14).

Figure 3.12: Driver and passenger using smartphones to play chess together

Source: Authors' own image from driving simulator

Figure 3.13: Driver and passenger playing a game of cards

Source: Authors' own image from driving simulator

Figure 3.14: Driver and passenger sharing snacks while their gaze remains on road

Source: Authors' own image from driving simulator

Arguably, the most notable finding was that participants were often quite content to sit and talk while the car was in control, with no secondary device or activity. The natural, side-by-side forward-facing seating configuration ensured that they were notionally looking ahead while they interacted and talked, and their glance behaviour and comments suggested that they continued to attend visually to the road scene, often highlighting or discussing the behaviour of other vehicles on the road or features in the scenario. Indeed, topics of conversation between drivers and passengers included: the road situation and other road users (in Figure 3.15, the driver points out vehicles crossing the bridge ahead), the behaviour of their car, their journey (and when they should resume control and take over) and their attitudes towards automation more generally. There were also numerous examples of drivers explaining road signs and interpreting the behaviour of other road users for the benefit of the passenger, particularly in situations where the passenger was not a licensed or experienced driver themselves.

In situations where participants were also engaged in a joint NDRT, the conversation appeared to move seamlessly between this and driving. For example, even while playing chess, the driver and passenger in Figure 3.12 tended to glance back at the road between turns (though notably still missed their exit in this example); other participants (both drivers and passengers) looked up in response to the noise of a passing vehicle or in response to their vehicle changing lanes. In addition, we observed drivers and passengers waving to other motorists in the simulation (Figure 3.16). This natural inclination to share observations and engage with other road users not only shows good immersion in the simulated driving environment, from a methodological perspective, but also suggests the potential for continued engagement with the road situation even during periods of automation.

Nevertheless, participants commonly described their experience in the automated vehicle as somewhat tedious: Driver: “It’s actually really boring.” (Pair 2); Driver: “After five minutes, I’ll be sleeping. Very boring.” (Pair 14); Driver: “If you didn’t have to do anything, it would be so boring.” (Pair 16), confirming common knowledge that it is challenging to stay attentive and alert during long periods of automation.

Figure 3.15: Driver highlights features in environment

Source: Authors’ own image from driving simulator

Figure 3.16: Passenger waves to driver of passing vehicle

Source: Authors’ own image from driving simulator

3.4.2 Conversation and speech acts

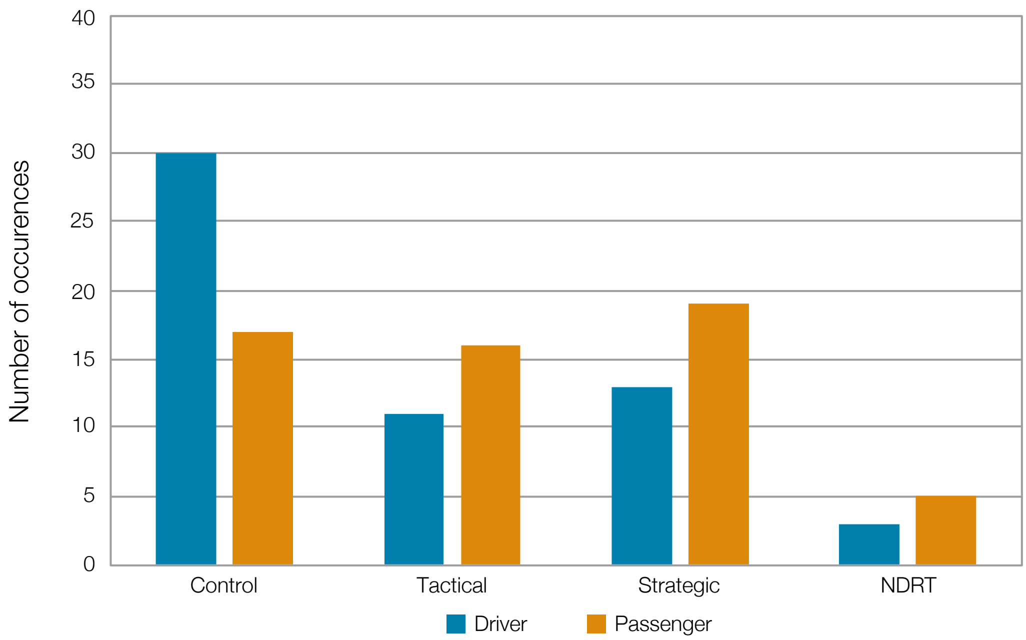
To allow us to make comparisons with study one, we have reported secondary activities at an aggregate level; that is to say, Figure 3.6 shows the total number of participants who have engaged in each category at some point during their journey. Presented in this way, the results tend to suggest some similarities between study one and the current study. Indeed, items such as the smartphone continued to play an important role.

However, there were also marked differences, even above and beyond the sharing of activities. For example, engagement in NDRTs was often very short – 'using a mobile phone' might constitute no more than removing the device from a pocket following a message notification, and returning it there shortly after reading the message. Moreover, Figure 3.6 fails to reflect any of conversation that occurred between drivers and passengers. Significantly, with many of the participants, conversation was the main (and for some, the only) activity undertaken. Furthermore, some NDRTs were in and of themselves intrinsically linked to conversation. For example, when sharing content on a phone or playing a game together, drivers and passengers would naturally engage in conversation regarding the shared content or their partner's turn in the game.

Conversation was particularly revealing when drivers were deciding when to resume control and during the takeover itself, with drivers often discussing and negotiating this decision with their accompanying passenger. To explore this further, we transcribed all dialogue that occurred between the driver and passenger during the routine takeover on drive one and during the unexpected, emergency handover on drive three. For the routine handover, this also included any dialogue associated with the decision to resume control, immediately before the takeover was initiated, until the car left the motorway. For the unexpected, emergency handover, all dialogue associated with the emergency itself was transcribed until manual driving was successfully resumed. This included any dialogue in response to the emergency notification as well as any associated with the conditions leading to the unexpected handover – for example, if the driver or passenger noticed and commented on the degradation in weather conditions which prompted the takeover request, prior to the request actually being made.

As already noted, we conducted speech acts content analysis (inspired by Lampert et al.'s (2006) classifications) of the transcribed speech using the driving skills hierarchy (Michon, 1985) as a framework. In essence, we aimed to uncover how (and what) driving-related information was shared and by whom during the takeover of control. All speech acts were coded based on whether they related to the control, tactical or strategic level of Michon's hierarchy, or if they were related to the NDRT. The **strategic** level defines the general planning of the journey and therefore includes route choice (recall that participants were required to select the correct exit from the motorway). At the **tactical** level, drivers make decisions to manoeuvre their vehicle in response to other road users and the prevailing circumstances (avoiding obstacles, changing lanes, overtaking vehicles, etc.). **Control**-level tasks define the actual inputs made by the driver to determine the course of the vehicle (steering, braking, accelerating, etc.). Control actions support the tactical-level tasks, which in turn are informed by the goals set at the strategic level. In study one, we explored the control-level actions when drivers resumed control, that is to say, how well the driver controlled the vehicle (in terms of speed adherence, lane positioning, etc.) when they took over driving. By adding a navigation element to the current study, which required participants to select the correct exit and manoeuvre the vehicle appropriately, we aimed to introduce tactical and strategic elements to the takeover task. Speech acts content analysis naturally provides a mechanism to evaluate how these aspects of the driving task were discussed and negotiated between the driver and passenger.

Figure 3.17: Types of driving-related information appearing in speech acts during routine takeover (drive one)



Source: Authors' own

Overall, participants tended to discuss more control aspects during routine takeovers (Figure 3.17), whereas more conversational turns and speech acts were dedicated to tactical and strategic aspects during the unexpected, emergency takeover (Figure 3.18). This arguably reflects the nature of the experience: during routine handovers, participants had already decided to resume manual driving, meaning that they were, to some degree, strategically prepared (having already decided *when* to resume control) and had made some assessment of the road situation in preparation for this (the tactical element). Their focus during routine takeovers was thus arguably directed more to the control aspects of resuming control.

Passenger: Hey! Hands on the wheel.

[manual control engaged]

Driver: How… can we go fast? Can I drift? (Pair 3)

Driver: Oh. Ah. I immediately accelerated above 70 miles an hour. (Pair 8)

Driver: Need to speed up.

Passenger: Don't do that. Don't do that.

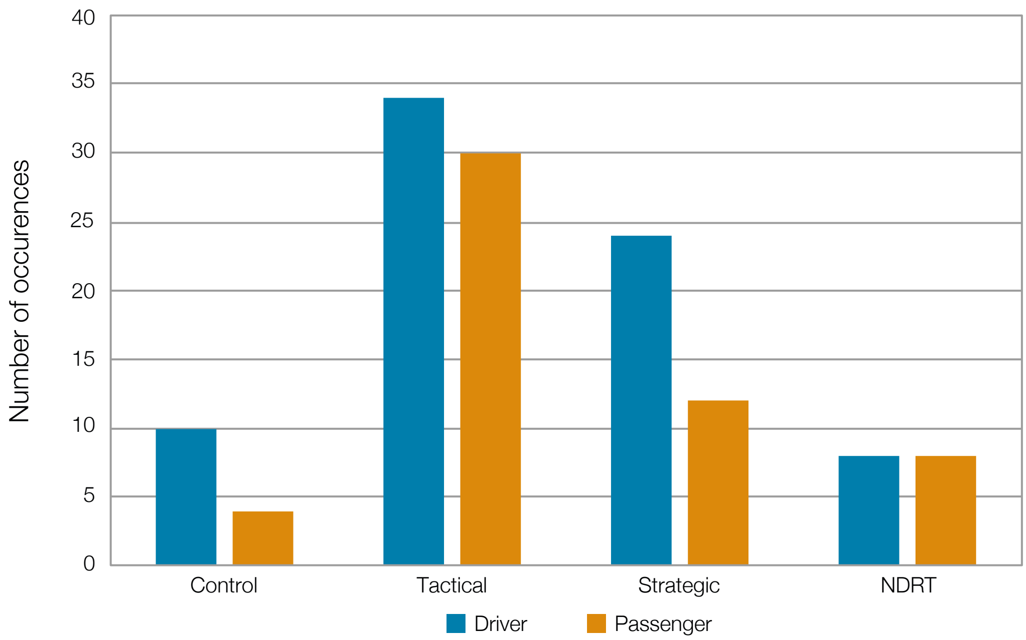
Driver: Just feels slow

Passenger: [reads countdown signs] Three, two. Oh, yeah, you need to start indicating off at two… (Pair 11)

Driver: It's a lot more sensitive than [my car]. I'm doing 75. This is like proving that maybe the automated thing is safer than me. We're slowing down now. I can't keep constant pace… Oh, wait, actually, if I don't move the steering wheel at all, we don't wiggle that much. (Pair 13)

Driver: Better not put my foot down too much as we don't have much petrol left. (Pair 16)

Figure 3.18: Types of driving-related information appearing in speech acts during unexpected, emergency takeover (drive three)



Source: Authors' own

In the third drive, however, participants were not expecting to take over control so soon, having prepared for a longer journey, and were therefore required to stop any NDRTs, make a quick assessment of the tactical situation and then consider the strategic elements following the emergency notification (for example, assessing where their required junction was in relation to their current position). This was subsequently reflected in the additional dialogue and speech acts associated with tactical and strategic elements (Figure 3.18). In contrast, the control aspects of taking over were less commonly discussed during the unexpected, emergency handover as this was largely imposed upon drivers by the very nature of the unexpected takeover.

> Passenger: I think we need (Junction) 32. A36. No, this was A36… 33?
>
> Passenger [in response to rain]: Oooh.
>
> Driver: Shall we turn on the wipers? It's a bit heavy. (Pair 4)

> Driver: Oh, it's raining.
>
> Passenger: That was confusing.
>
> Driver: Let's get the window wipers on.
>
> Passenger: Oh?

[emergency takeover request]

Driver: [passing phone and playing cards]: Hold that.

Driver: Phone please! [passenger passes phone back to driver, who puts it in pocket]

Driver: Caught me off guard, that has. (Pair 9)

Driver: OK, so it's now just drive to the next junction. (Pair 11)

Driver: Hold it for me [passes phone to passenger] … OK, that was stressful.

Passenger: And it's also five miles to our exit. So shouldn't be too long.

Driver: We are almost there?

Passenger: Five miles to our exit.

Driver: (Junction) 29. (Pair 12)

Driver: Let's get in the fast lane

Passenger: Are we going slower, or are we still at…

Driver: 70

Passenger: 70. I would stay in this lane, because we don't know when we're going to need to come off.

Driver: It's the one after. Oh, no, there's two after this. (Pair 13)

Driver: (Do you??) remember our exit?

Passenger: Ah. Yeah. Errr. Fall's Church. Here's 29. Must take the exit. Probably the next exit. (Pair 17)

Needless to say, while these show general behaviours, there were in fact individual differences in the behaviour (and conversational topics) across the different partnerships. Indeed, some passengers were more vocal in their 'support' than others.

Driver: Oh, rain. Should I get the wipers on?

Passenger: Get them on! Get them on! Get them on! Oh my God! Get them on! Get them on!

[driver puts wipers on]

Passenger: More than that.

Passenger: Resume control

[emergency takeover request]

Passenger: Do you want me to say it?

Driver: Autocar, Autocar: take control.

Passenger: You're doing it. You're doing it. Doing it. Oh God.

Driver: Should I get the wipers on?

Driver: Take over in… Take my phone. Take my phone. [driver hands phone to passenger]

[manual driving engaged]

Passenger: Can you change lane?

Driver: Oh God.

Passenger: Accelerate, accelerate, accelerate. Ahhh!

Driver: I'm accelerating

Passenger: We're going to get hit! We're going to get hit! Oh my God! Did you not accelerate?

Driver: I did. I did. Just not quick enough.

Passenger: […] You just cruising it behind this thing?

Driver: Yeah, we're doing 70, so

Passenger: OK. (Pair 15)

3.4.3 Subjective rating scales

As with study one, we asked drivers, and in the current study passengers also, to provide subjective ratings of their experience. We employed established rating scales and questionnaires to determine situational awareness, trust, workload, technology acceptance and so on. These allow us to make a quantitative judgement of these constructs in the context of the current study, and to compare ratings between the driver and the passenger, and, indeed, between drives. It also allows us to make a qualitative comparison with findings from study one, in which, where applicable, the same rating scales and questionnaires were used.

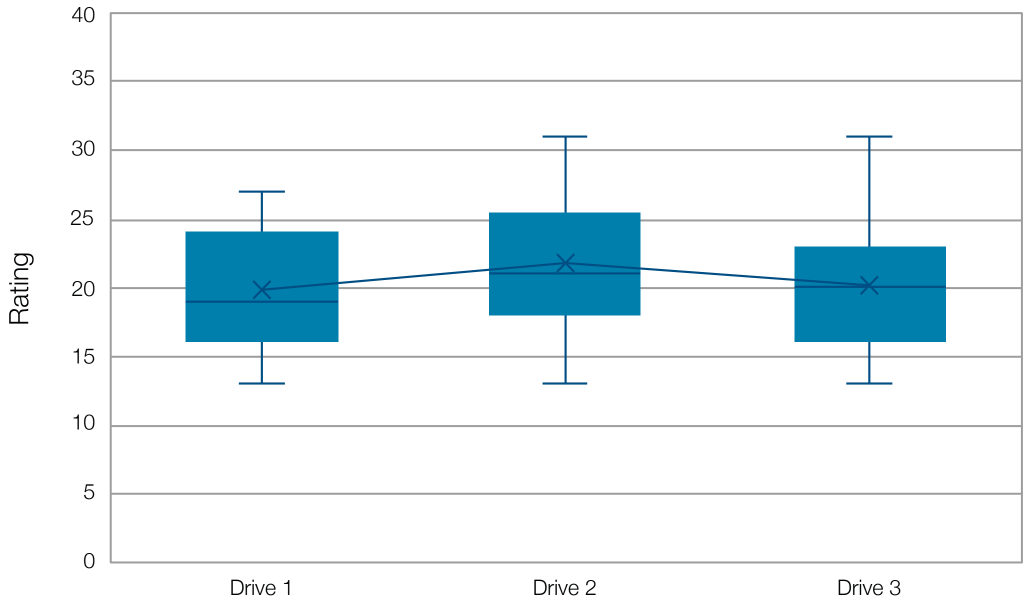
Situational awareness rating technique

Ratings of situational awareness, provided independently by both the driver and the passenger, were captured after each drive using the situational awareness rating technique (SART) (Taylor, 2011). Ratings were subsequently compared between the three drives using a repeated-measures ANOVA[1] (or analysis of variance) statistical test conducted using the statistical software package SPSS (www.ibm.com/spss), with the role (driver or passenger) as a between-subjects factor.

SART ratings are shown as box-and-whisker plots in Figure 3.19 and Figure 3.20. A higher numerical rating indicates better subjective situational awareness. The graphs suggest that drivers' and passengers' ratings are numerically similar, with both groups tending to provide higher mean ratings (indicating better situational awareness) during drive two (driver mean = 21.8, passenger mean = 20.5, shown by the × symbol), compared to drive one (driver mean = 19.8, passenger mean = 17.3) and drive three (driver mean = 20.2, passenger mean = 19.8). The interquartile range of responses (which accounts for 50% of the data) tends to be larger for passengers, particularly after drive three, suggesting a wider range of responses following this drive. However, no statistically significant differences are evident from the inferential analysis, indicating that drivers' and passengers' ratings of situational awareness are statistically comparable between drives ($F(2,64) = 2.35$, $p = .10$), and, indeed, between roles ($F(2,64) = 0.26$, $p = .77$). In comparison, during study one, situational awareness tended to drop as the week continued, suggesting an ever-decreasing engagement with the environment (and it is interesting also to note that in study one, the use of secondary devices increased over the week). Situational awareness was significantly higher following an emergency takeover on the penultimate day in study one, which was thought to be associated with the extra demands placed on the driver, but it then dropped again on the final day.

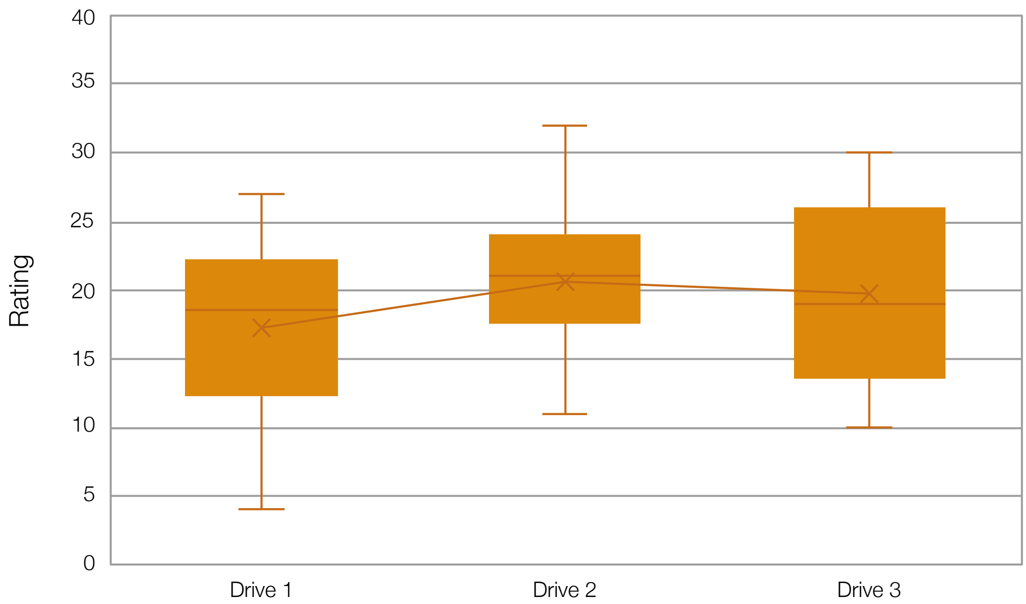
1 The ANOVA statistical test is based on the assumption that the data from the different groups under examination (specifically, the variation among group mean, or average, values) are similar. That is to say, in the current example, the ANOVA test assumes that there are no differences between ratings made after each drive (that is, between the three different groups: drive 1, drive 2 and drive 3), and, furthermore, that there are no differences between drivers' and passengers' ratings (the 'between-subjects' factor) (these statements are considered the 'null hypotheses'). Results from the ANOVA test must thus be interpreted to determine the likelihood, or probability, that ratings are actually different (regardless of whether they appear visually so or not on a graph). As a convention, a probability, or *p*-value, of less than 5% (reported as $p < .05$) indicates that any observed differences are unlikely to be due to random sampling, and therefore likely to be significant. The *F*-statistic, which is also reported, describes the ratio of the two mean square values. If the null hypothesis is true (that is, the variation among group mean values are *not* significantly different), the *F*-statistic would typically have a value of 1 or less; in contrast, a large *F*-statistic suggests that the variation among group means is more than would be expected to be seen by chance.

Figure 3.19: Drivers' subjective ratings of situational awareness (SART) (Taylor, 2011)



Source: Authors' own

Figure 3.20: Passengers' subjective ratings of situational awareness (SART) (Taylor, 2011)



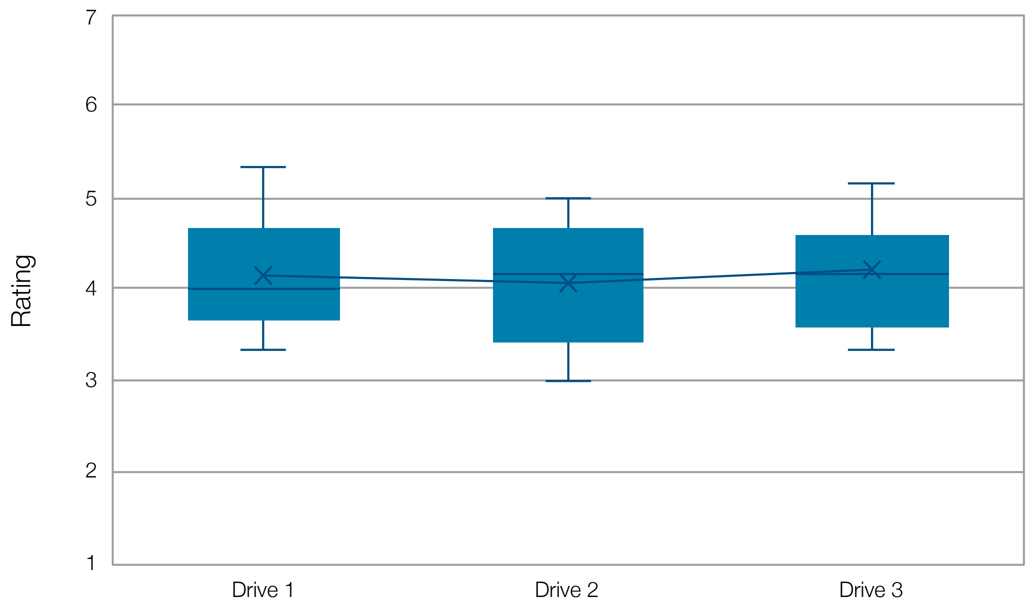
Source: Authors' own

Situational Trust Scale for Automated Driving

Ratings of trust were captured after each drive using the situational trust scale for automated driving (STS-AD) (Holthausen et al., 2020) and were provided independently by both the driver and the passenger. Ratings were subsequently compared across the three drives using a repeated-measures ANOVA statistical test conducted using SPSS software, with the role (driver or passenger) as a between-subjects factor.

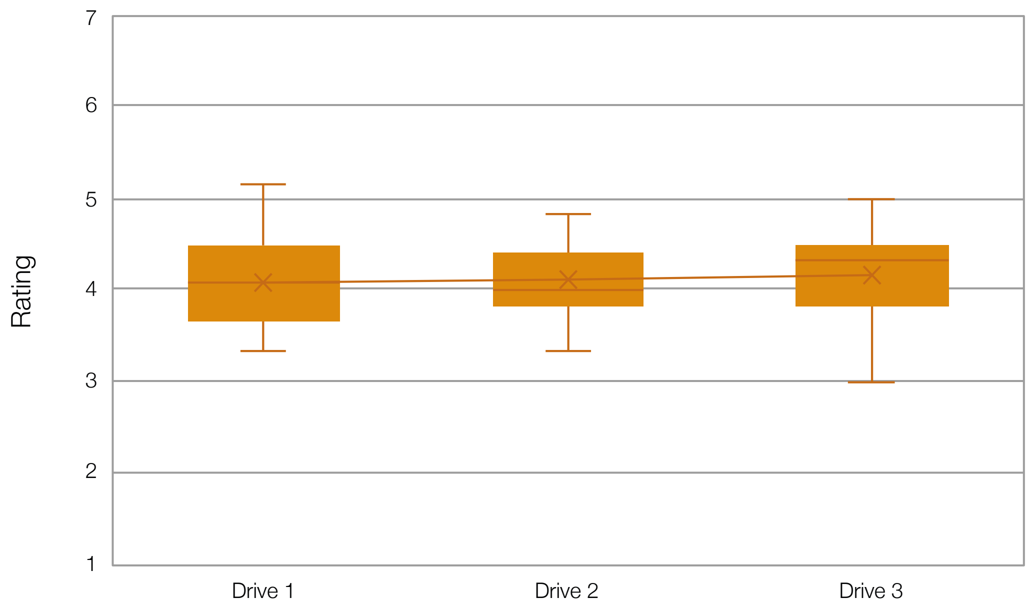
STS-AD ratings are shown as box-and-whisker plots in Figure 3.21 and Figure 3.22. A higher numerical rating indicates higher subjective situational trust. The graphs suggest that drivers' and passengers' mean ratings are numerically similar, with both groups tending to provide comparable mean ratings for all three drives (driver means: drive one = 4.1, drive two = 4.1, drive three = 4.2; passenger means: drive one = 4.1, drive two = 4.1, drive three = 4.2). The interquartile range of responses (which accounts for 50% of the data) tends to be larger for drivers, particularly from drive two onwards, suggesting a wider range of responses following this drive. However, no statistically significant differences are evident from the inferential analysis, indicating that drivers' and passengers' ratings of situational trust are statistically comparable between drives ($F(2,64) = 0.46$, $p = .63$), and, indeed, between roles ($F(2,64) = 0.09$, $p = .92$). The STS-AD was a newly conceived questionnaire that has emerged since study one was conducted. It provides a quick and targeted measure of situational trust specifically during automated driving and was therefore deemed relevant here, although its use unfortunately renders direct comparison with study one impossible. During study one, trust (measured in this case by means of the trust in a specific technology questionnaire; McKnight et al., 2011) increased significantly over the week, with no apparent detriment to participants' ratings following the unexpected, emergency takeover request on day four.

Figure 3.21: Drivers' subjective ratings of situational trust (STS-AD) (Holthausen et al., 2020)



Source: Authors' own

Figure 3.22: Passengers' subjective ratings of situational trust (STS-AD) (Holthausen et al., 2020)



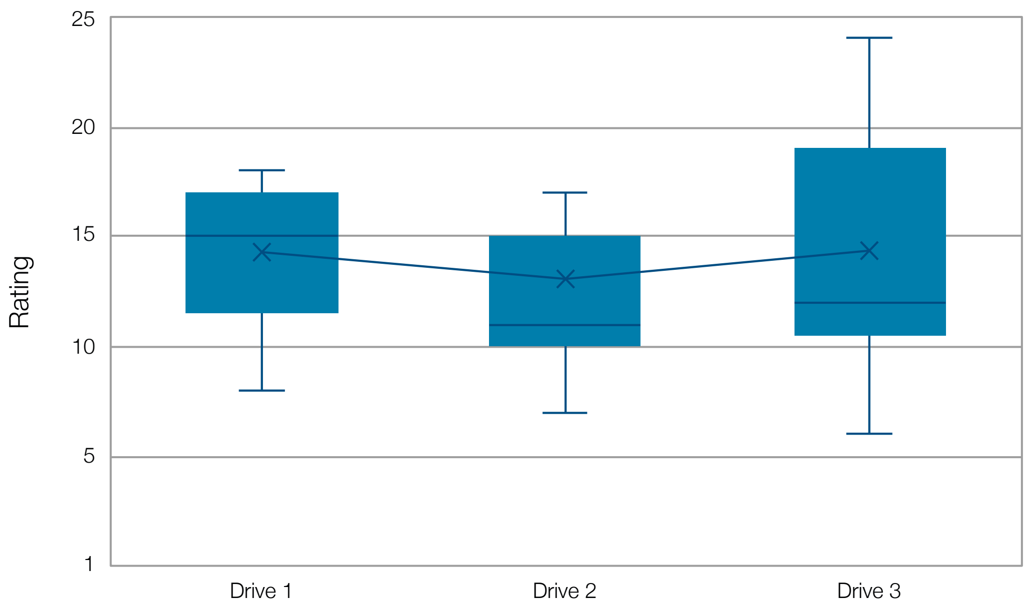
Source: Authors' own

NASA-Task Load Index workload rating

Ratings of workload were captured after each drive using the NASA-Task Load Index workload rating (NASA-TLX) (Hart & Staveland, 1988) and were provided independently by both the driver and the passenger. Ratings were subsequently compared across the three drives using a repeated-measures ANOVA statistical test conducted using SPSS software, with the role (driver or passenger) as a between-subjects factor.

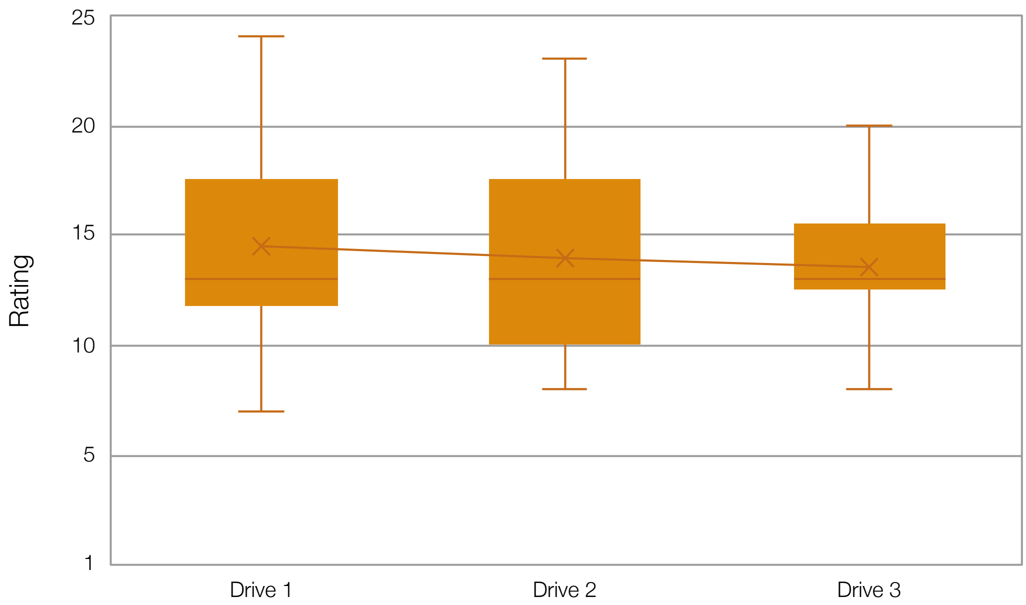
NASA-TLX ratings are shown as box-and-whisker plots in Figure 3.23 and Figure 3.24. A higher numerical rating indicates higher subjective workload. The graphs suggest that drivers' and passengers' mean ratings are, generally speaking, numerically similar, with both groups tending to provide similar mean ratings for all three drives (driver means: drive one = 14.3, drive two = 13.1, drive three = 14.4; passenger means: drive one = 14.8, drive two = 13.9, drive three = 13.5). On closer inspection, the drivers' mean rating after drive two appears marginally lower, indicating potentially lower workload associated with this drive. In addition, the interquartile range of responses (which accounts for 50% of the data) tends to be larger for drivers, particularly following drive three, with some drivers associating very high workload with this drive. However, no statistically significant differences are evident from the inferential analysis, indicating that drivers' and passengers' ratings of workload are statistically comparable between drives ($F(2,64) = 0.86$, $p = .43$), and, indeed, between roles ($F(2,64) = 0.62$, $p = .54$). Workload ratings were not captured during study one.

Figure 3.23: Drivers' subjective ratings of workload (NASA-TLX) (Hart & Staveland, 1988)



Source: Authors' own

Figure 3.24: Passengers' subjective ratings of workload (NASA-TLX) (Hart & Staveland, 1988)



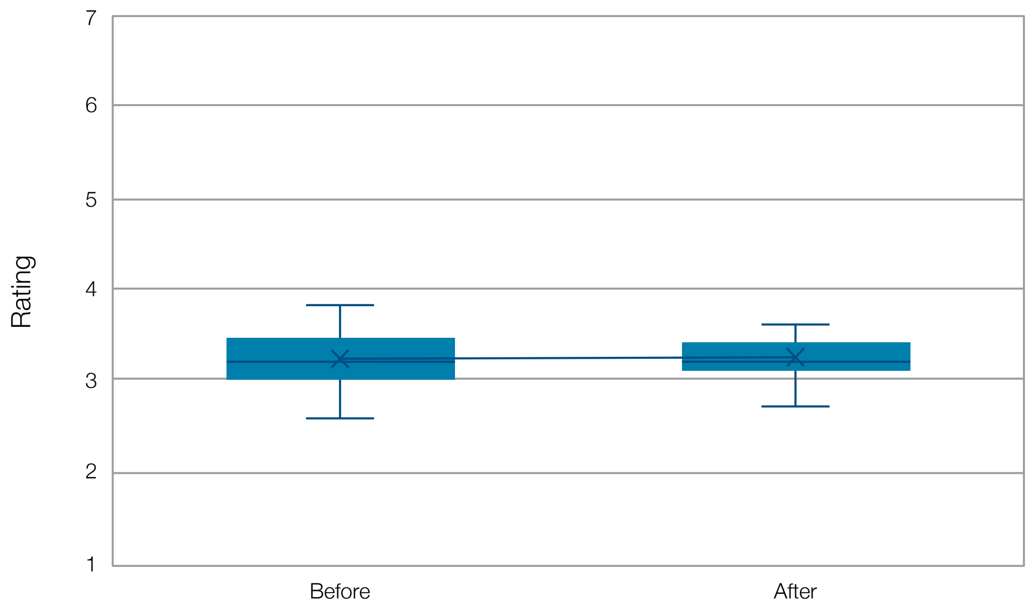
Source: Authors' own

Trust in automation

Ratings of trust in automation were captured at the start of the study and again after all three drives had been completed, using the trust-in-automation questionnaire (Gold et al., 2015). Responses were provided independently by both the driver and the passenger. To highlight any changes in their attitudes as a result of the study, drivers' and passengers' trust ratings before the study were compared with their ratings captured after the study using two paired-samples *t*-tests. A *t*-test is an inferential statistic used to determine whether there is a significant difference between the means of two different groups (for more than two groups, an ANOVA test would be required). In this case, the first paired-samples t-test compared drivers' before ratings with drivers' after ratings (Figure 3.25), and the second paired-samples t-test compared passengers' before ratings with passengers' after ratings (Figure 3.26). To highlight any differences between drivers' and passengers' attitudes, their trust ratings before the study were compared with each other using an independent samples t-test; similarly, drivers' and passengers' trust ratings after the study were compared using a second independent samples t-test (in other words, the data in Figure 3.25 was compared with the data in Figure 3.26. Trust in automation ratings are shown as box-and-whisker plots in Figure 3.25 and Figure 3.26

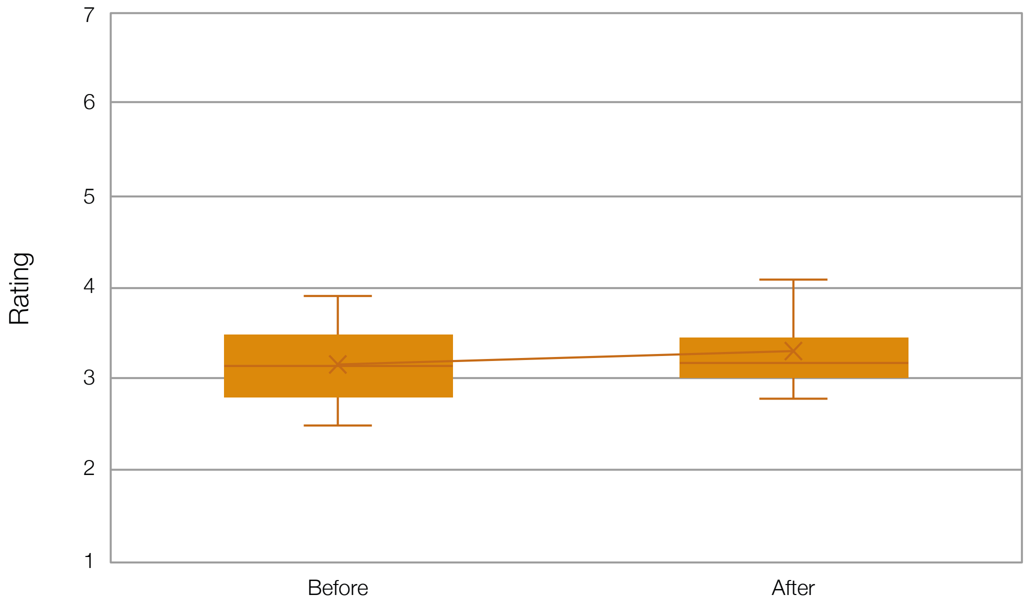
A higher numerical rating indicates a higher level of trust in automation. The graphs tend to suggest that drivers' and passengers' mean ratings are numerically similar, with both groups providing similar mean ratings before and after the drives (driver means: before = 3.3, after = 3.3; passenger means: before = 3.2, after = 3.3). Notably, the mean values are all below the scale median (4.0), suggesting low trust in automation. There are no statistically significant differences between drivers' ratings before and after the drives ($t(16) = 0.24$, $p = .81$). However, passengers' ratings show a significant increase after the drives ($t(16) = 2.19$, $p = .04$), suggesting higher trust (though notably still below the scale median). The independent samples t-tests show no significant differences overall between drivers' and passengers' ratings ($t(66) = 0.39$, $p = .70$). As highlighted above, during study one, trust was notably high from the outset and increased significantly over the week, with no apparent detriment to participants' ratings following the unexpected, emergency takeover request on day four.

Figure 3.25: Drivers' subjective ratings of trust in automation (Gold et al., 2015)



Source: Authors' own

Figure 3.26: Passengers' subjective ratings of trust in automation (Gold et al., 2015)



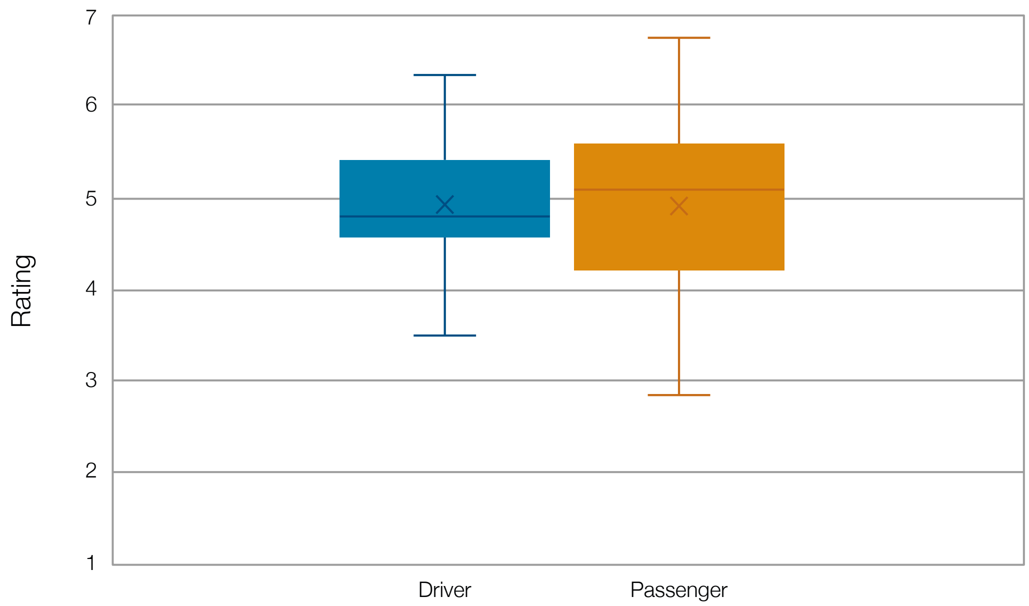
Source: Authors' own

Technology acceptance

Ratings of technology acceptance were captured after all drives had been completed, using the technology-acceptance questionnaire (Venkatesh & Bala, 2008; Hernandez-Ortega, 2011). Ratings were provided independently by both the driver and the passenger, who were asked to consider the SAE Level 3 automation as the 'technology' under evaluation when deciding upon their response. Mean ratings were subsequently compared between drivers and passengers using an independent samples t-test.

Technology acceptance ratings are shown as a box-and-whisker plot in Figure 3.27. A higher numerical rating indicates a higher level of technology acceptance. The graph shows that drivers' and passengers' mean ratings are numerically very similar (driver mean = 4.9; passenger mean = 4.9), although the range of values provided by the passengers is visibly larger, suggesting a wider diversity of opinion amongst passengers regarding their acceptance of the technology. Notably, the mean values for both drivers and passengers are above the scale median (4.0), suggesting favourable acceptance, on average. The independent samples *t*-test showed no significant differences overall between drivers' and passengers' ratings of technology acceptance ($t(32) = 0.05$, $p = .96$). During study one, ratings of technology acceptance increased over the week, and were significantly higher with each day as the week progressed. As with ratings of trust, there was no detriment to participants' ratings of technology acceptance following the emergency handover in study one. In fact, technology acceptance was significantly higher on the following, final day.

Figure 3.27: Drivers' and passengers' subjective ratings of technology acceptance (Venkatesh & Bala, 2008; Hernandez-Ortega, 2011)



Source: Authors' own

3.4.4 Post-study questionnaires

The bespoke post-study questionnaire explored drivers' and passengers' views on the role and impact of the passenger during periods of automation and the transfer of control. Thirteen statements were rated independently by the driver and passenger using seven-point Likert scales, where 1 was labelled "completely disagree" and 7 meant "completely agree", higher numerical ratings thus indicating a stronger agreement with the statement. Where possible, statements were worded identically for the driver and passenger. For example, the statement: "I attempted to maintain awareness of the driving scene while the vehicle was in control" was rated by both the driver and passenger. In situations where individual roles and attitudes were under scrutiny, statements were worded accordingly. For example, to explore how distracting the passenger was during automation, drivers were asked to rate the following statement: "I was distracted by my passenger during periods of automation", whereas passengers were asked to rate: "I distracted the driver during periods of automation." For analysis purposes, several statements were reverse-scaled, such that a higher numerical value indicated a more positive attitude towards the stated behaviour, or a more positively perceived impact of the passenger. Statements were grouped into three episodes for analysis: (1) during automation, (2) decision to take over, and (3) during takeover. Cumulative ratings for each of the three episodes were computed by amalgamating and scaling participants' responses to the relevant individual statements (see: Appendix A). Drivers' and passengers' ratings were subsequently compared using independent-samples *t*-tests to determine any statistically significant differences between their responses (Table 3.3).

Table 3.3: Summary of drivers' and passengers' cumulative ratings of the impact of the passenger during the three episodes, with statistical test results (differences are significant if $p < .05$)

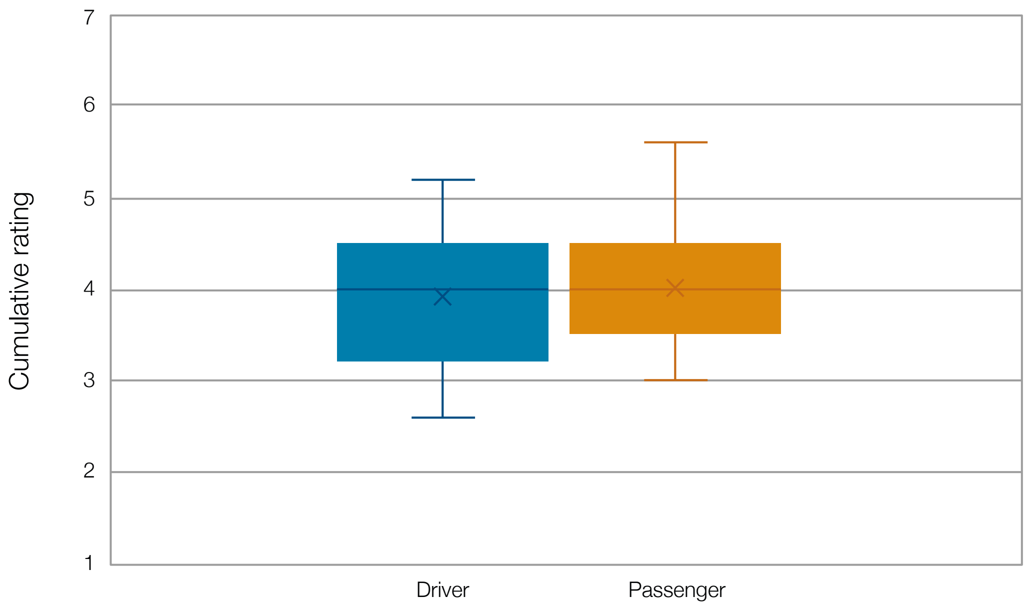
Episode	Role	Mean rating	Standard deviation	Statistical test result
During automation	Driver	3.9	.79	No significant difference ($p > .05$)
	Passenger	4.0	.69	
Decision to take over	Driver	5.1	.98	No significant difference ($p > .05$)
	Passenger	5.1	1.37	
During takeover	Driver	4.7	.54	No significant difference ($p > .05$)
	Passenger	5.0	.90	

Source: Authors' own
Note: Rating scales ranged from 1 to 7, with a higher mean numerical rating indicating a more positively perceived impact of the passenger.

Impact of passenger during automation

Drivers' and passengers' ratings of the impact of the passenger during automation were comparable (driver mean = 3.9, passenger mean = 4.0) (Figure 3.28). Although mean ratings made by drivers and passengers were both close to the scale median of 4.0, their actual ratings ranged from 2.6 to 5.2 for drivers and from 3.0 to 5.6 for passengers, indicating a range of attitudes amongst both parties; some participants were quite positive about the impact of the passenger during automation, and some participants were less so. There were no significant differences between ratings made by the driver and ratings made by the passenger ($t(32) = 0.37$, $p = .71$).

Figure 3.28: Drivers' and passengers' subjective ratings of the impact of the passenger during automation

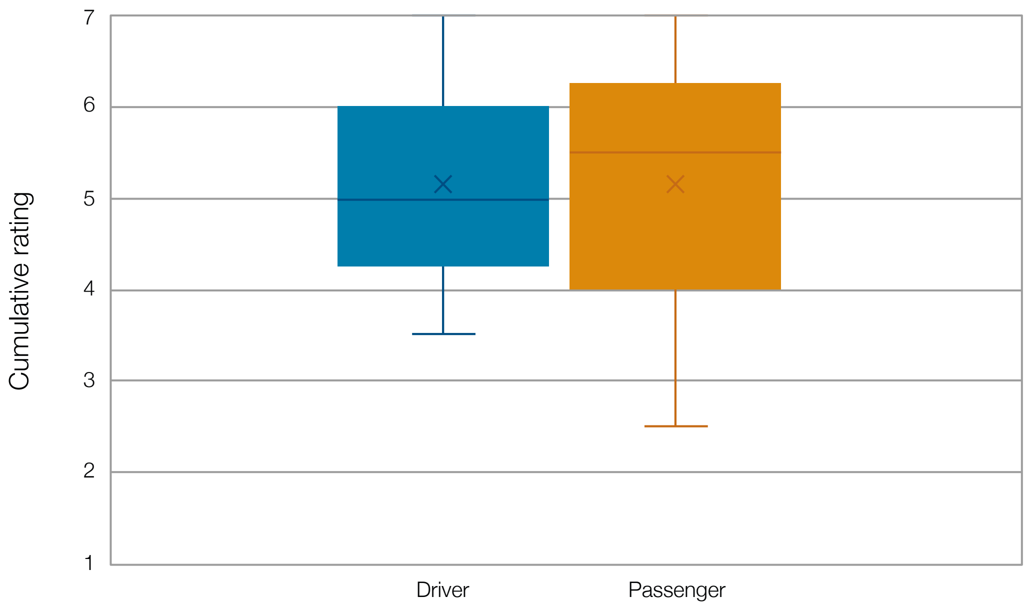


Source: Authors' own

Impact of passenger on decision to take over control

Drivers' and passengers' ratings of passenger impact at the decision stage were visibly similar, suggesting that both parties believed that the presence of a passenger impacted equally on the decision to take back control (Figure 3.29). The mean ratings were above the scale median of 4.0 (driver mean = 5.1, passenger mean = 5.1), suggesting that, generally, the impact was felt to be positive. In other words, the passenger was believed to have helped the driver decide when to request manual control and did not delay or interrupt this decision. Although there were no significant differences between mean ratings made by the driver and by the passenger ($t(32) = 0.00$, $p = 1.00$), the range of responses (and hence standard deviation) from passengers was larger than that of those from drivers, indicating a broader diversity of opinion. In addition, the median value is noticeably higher than the mean value for the passengers, suggesting that the distribution of responses from passengers is 'negatively (or left) skewed'; in other words, the majority of passengers' ratings were medium or high, whereas there were also a few ratings that were much smaller than the rest (thereby reducing the magnitude of the mean value).

Figure 3.29: Drivers' and passengers' subjective ratings of the impact of the passenger in deciding when to take over control

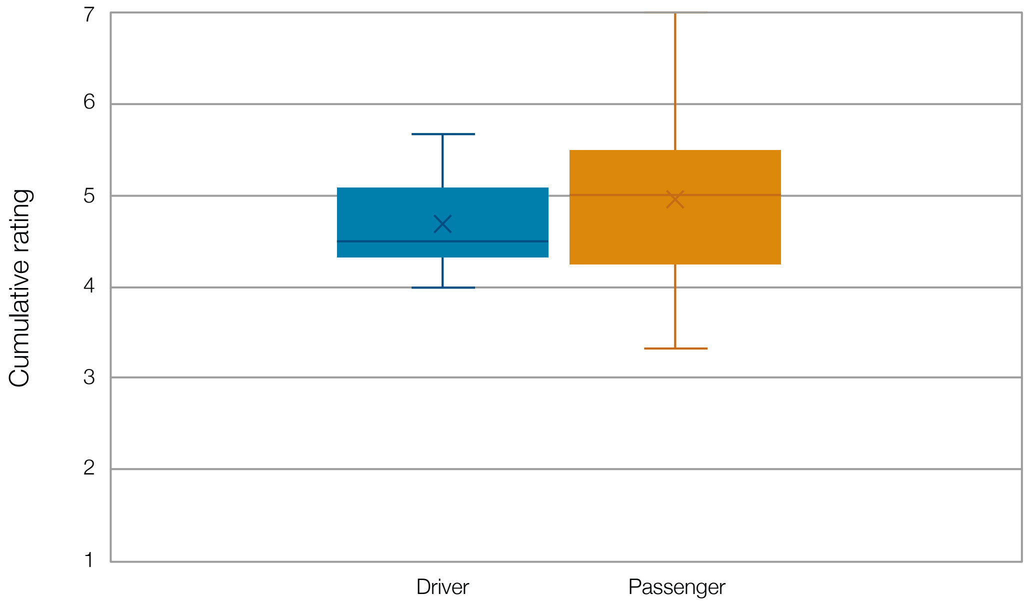


Source: Authors' own

Impact of passenger during the takeover of control

Overall, mean ratings related to the impact of the passenger *during* the takeover of control were visibly similar between driver and passenger, although the range of responses from passengers was larger than that of those from drivers. Mean ratings were above the scale median of 4.0 (driver mean = 4.7, passenger mean = 5.0) (Figure 3.30), indicating that, on average, the impact was perceived to be positive. There were no statistically significant differences between ratings made by the driver and those made by the passenger ($t(32) = 1.04$, $p = .31$). However, there was a larger range of responses from passengers, suggesting a wider diversity of opinion amongst passengers regarding their impact during the takeover.

Figure 3.30: Drivers' and passengers' subjective ratings of impact of passenger during takeover of control



Source: Authors' own

Overall, there were no significant differences in mean ratings made by drivers and passengers regarding the presence of the passenger during automation, on the timing of the decision to resume control, or during the takeover itself. Nevertheless, mean ratings were generally above the scale median, suggesting that drivers and passengers thought the passenger's presence had a positive impact, on average, in all three situations. The larger range of responses from passengers regarding their impact on the decision to resume control and during the takeover itself suggests a wider diversity of opinion amongst passengers regarding the effect of their presence in these situations. Notably, some passengers felt that they had a very positive impact (more so than their counterpart drivers' ratings might suggest), particularly during the takeover itself.

Perceived roles during takeover

At the end of the study, drivers and passengers were asked to comment on the role that they had played (and the role their partner played) during the three drives, by answering the following questions. Responses were taken independently from drivers and passengers.

1. What did the driver do during the takeover of control and how did their behaviour differ over the three drives?
2. What did the passenger do during the takeover of control and how did their behaviour differ over the three drives?
3. What effect did the presence of a passenger have on the driver's behaviour?

Responses to Question 1: What did the driver do during the takeover of control and how did their behaviour differ over the three drives?

When asked to describe their own role during the takeover of control, drivers' comments reflect high confidence in their own ability to take over control, with responses highlighting specific actions which they took before assuming control, such as positioning their hands and feet on controls, checking their surroundings, checking mirrors and so on. As such, most drivers felt that they were successful in resuming control and handled the vehicle appropriately.

Passengers' comments suggest that they agreed that the takeovers were generally successful, but actually felt that drivers were initially stressed, and highlighted instances of missed exits and one driver forgetting to depress the accelerator pedal to maintain their speed after resuming control.

Over the course of the three drives, drivers stated that they felt more and more relaxed and comfortable, trusting the vehicle to make the right decisions.

> "The first drive I was quite wary of how much control the car had and was more vigilant about checking the mirrors. The second drive, less so. The third drive, I was more comfortable that the system was safe, and felt more relaxed." (Driver, Pair 4)

This increased comfort was reflected in drivers' decisions to engage in other activities while the vehicle was in control and, in their confidence in the system's safety and reliability.

> "I felt more at ease on the last two drives as it felt safe and smooth, so I was able to concentrate on performing different activities whilst in the vehicle." (Driver, Pair 9)

Despite the unexpected, emergency warning on drive three, drivers' comments indicate increasing comfort and trust in the automated driving technology as the journey experiences progressed. Passengers also noted that drivers became more relaxed and confident with continued drives, noting the negative impact this had on drivers' awareness of their environment.

> "[The driver] became less and less aware of the surroundings each time."
> (Passenger, Pair 15)

Responses to Question 2: What did the passenger do during the takeover of control and how did their behaviour differ over the three drives?

Drivers acknowledged that their passenger assisted in finding the correct junction and helped them to decide when to take control, either through verbal reminders or reading directions aloud. Drivers stated that their passengers remained calm during the transition of control, allowing them to focus on the takeover task. Overall, drivers believed that passengers played a supportive role in facilitating smooth transitions and ensuring good awareness during manual control takeovers, but recognised that it was the driver's role and responsibility to decide when to take over control.

> “We discussed the best time to take over control, but the passenger left me to it during this section of the drive.” (Driver, Pair 1)

Passengers specifically stated that they provided reminders about safety checks, alerted their driver to potential hazards or the need to take control, and helped navigate by identifying the correct exit and monitoring road signs.

> “[As the passenger] I was focused on the road as I was looking at each sign to determine what the next junction was and how far away the exit junction was. I helped the driver determine when he should go to manual before the junction. He made the right decision himself though.” (Passenger, Pair 9)

Passengers stated that although they involved the driver in secondary activities, such as playing card games or engaging in conversation, they also remained focused on the road and actively assisted with decision-making regarding the takeover of control. Overall, passengers stated that their primary aim was to support the driver and help them maintain awareness during the journey.

> “When the driver was required to take control, they… corrected their sitting position to have both hands on the wheel and feet on pedals. I tried to avoid speaking so that they could concentrate on what they were doing.” (Passenger, Pair 13)

Several passengers also highlighted specific tasks they undertook during the takeover, such as taking charge of the driver’s belongings.

> “I mostly just held onto the items we had in the car and tried to not distract them.” (Passenger, Pair 13)

Comments suggest that drivers recognised that passengers also felt more at ease as the drives progressed.

> “I could tell that the passenger felt more at ease during the last two drives, as she looked relaxed and comfortable, and didn’t seem stressed regarding me taking control over the vehicle.” (Driver, Pair 9)

Passengers’ comments confirm that they became more relaxed, but also less focused during later drives.

> “I believe I began to trust the system more, spending less time concentrating on the road.” (Passenger, Pair 11)

Others, by way of contrast, suggested that their attention (as passenger) improved over the drives.

> "I felt more observant as the drives went on as I didn't want to miss a junction and wanted to be aware of which junction we were on each time. I would say I was more concentrated as the drives went on." (Participant, Pair 9)

Responses to Question 3: What effect did the presence of a passenger have on the driver's behaviour?

Most drivers acknowledged that the presence of a passenger led to more distractions and reduced their focus on the road and surroundings compared to driving alone.

> "More distractions due to passenger. I would be more focused on the road without a passenger." (Driver, Pair 1)

However, some commented that the presence of a passenger allowed them to share driving-related tasks, such as route-finding, or believed that the passenger had no effect on their driving.

> "Yes, I spent more time engaging in other activities as I could rely on the passenger to also watch the road and watch which junction I should take." (Driver, Pair 11)

> "No, the driving behaviour is totally controlled by me." (Driver, Pair 3)

Passengers also recognised that their presence led to distractions, such as conversations and sharing content on their smartphone, although it was noted that the content of conversations could have some relevance to the driving task. Some passengers believed their presence helped the driver to stay awake and focused and alleviated boredom, particularly as the journeys were long and monotonous.

> "However, the driver claimed to feel sleepy and tired from not engaging in the active driving process, so the presence of the passenger might have helped him to stay awake and aware." (Passenger, Pair 4)

Overall, passengers acknowledged that their presence could affect drivers' behaviour and level of engagement with driving.

> "I think behaviours would have been very different without me [the passenger] there, as I provided lots of talking and such that would have been distracting… I do think [the driver] would have still looked at the phone if I wasn't in the car but probably spent more time looking for exit signs." (Passenger, Pair 13)

3.4.5 Driving behaviour and performance

Vehicle control data was captured by the simulator software and analysed for the first ten seconds after participants resumed manual control of the vehicle during drive one. In line with study one, we report data pertaining to lateral control (absolute lane position and its variability) and longitudinal control (absolute speed and its variability). In addition, we report the first primary control input (accelerator/brake/steering) after manual control was resumed. Descriptive comparisons are made with the results of study one.

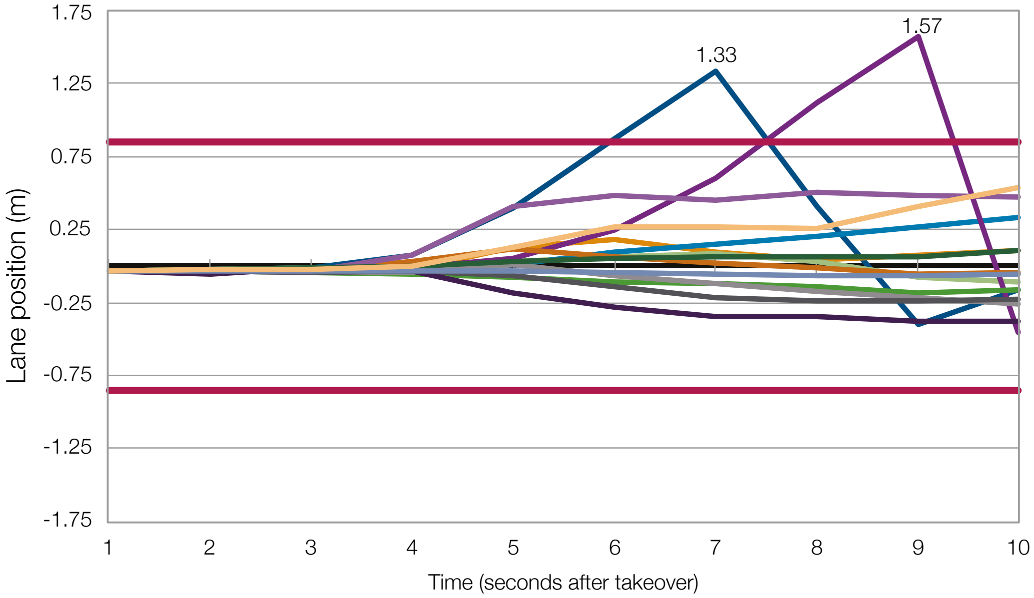
Route choice

During the first drive, 5 out of the 17 drivers (29%) failed to resume control within sufficient time to exit the motorway at the correct exit, ostensibly because they were distracted. While two of these (Pair 2 and Pair 9) requested control, but were too late to exit the motorway following the ten-second transfer of control (that is, they requested control with less than ten seconds to go), three drivers (Pair 3, Pair 5 and Pair 14) were apparently so engaged in and distracted by their chosen activities that they did not request control. The latter three drivers are excluded from the following analyses. This is because they showed no evidence of resuming manual driving even after several minutes of additional automation and the experimenter consequently intervened and stopped the vehicle. For those who were successful in their route choice, control was requested, on average, shortly after the 'one mile to junction' road sign.

Lane position and variability

Figure 3.31 shows the absolute lane position for each participant (expressed as the absolute position of the centre of the vehicle from the lane centre) during the first ten seconds after manual driving was resumed in drive one, with each separate plot representing the geometric centre of a different participant's vehicle. Mean lane variability during each second interval (expressed in line with convention as standard deviation of lane position, SDLP) is shown in Figure 3.32. There is a tendency for initial control during the first three seconds or so to be good, with all drivers appearing to maintain a steady central lane position (Figure 3.31) and negligible variability in lane position (Figure 3.32). Thereafter, lane position and variability become more erratic – up to approximately 1.5 m, and in both directions. It is worth noting that the lane width is 3.5 m and the car is 1.8 m wide. Thus, any lateral position exceeding a magnitude of 0.85 m results in the edge of the vehicle exceeding the lane boundary – as was the case for the worst two offenders. After ten seconds, lane position remains somewhat variable.

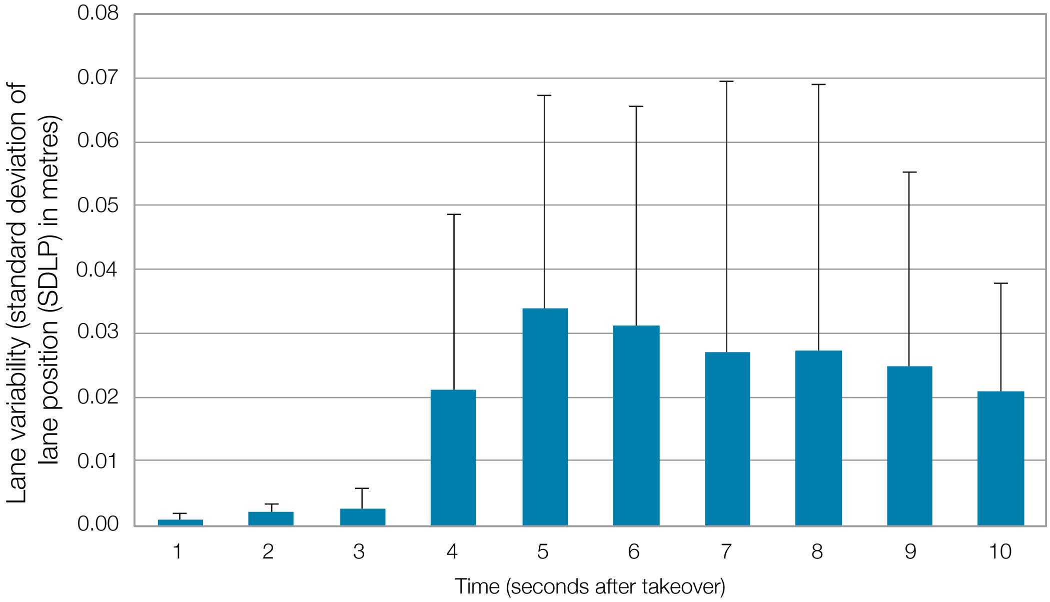
Figure 3.31: Lane position in one-second intervals after taking over manual control of vehicle on drive one, expressed as the absolute position of the centre of vehicle at each time interval from lane centre



Source: Authors' own

Note: Lane position = 0 indicates the centre of the lane; lane width = 3.5 m so vertical axis precisely covers lane one; each plot represents a different participant; horizontal red lines at +/- 0.85m indicate lane positions beyond which (above or below in graph) the edge of the vehicle will exceed the lane boundary.

Figure 3.32: Lane variability in one-second intervals after taking over manual control of vehicle on drive one, expressed as standard deviation of lane position (SDLP)



Source: Authors' own

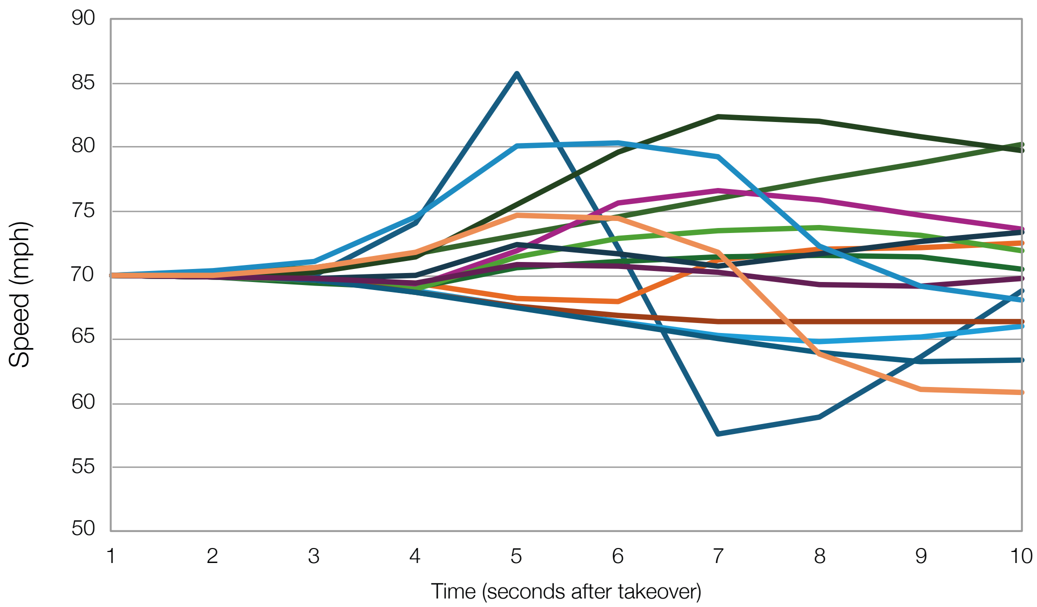
Note: Each bar represents the mean value for all participants during that one-second interval; error bars (lines extending vertically above each bar) represent the standard deviation of values during that one-second interval.

In contrast, during study one, lateral control was poor immediately after resuming control, with drivers moving up to approximately 2 m away from the lane centre during the first three seconds on drive one, and variability (SDLP) in the order of approximately 0.4 m during the first second after resuming manual control. In the ensuing seconds, lane position and variability improved somewhat during study one. Nevertheless, even after ten seconds of manual driving, participants typically did not manage to regain their central lane position, remaining notably approximately 1.5 m adrift of the lane centre, with a SDLP of approximately 0.05 to 0.10 m, and thereby encroaching on – and probably exceeding – the lane boundary. This notable contrast between the two studies, which used different simulation software, is discussed in Chapter 4.

Speed and speed variability

Figure 3.33 shows the vehicle speed during the first ten seconds of manual driving after control had been transferred to the driver, with speed variability (interpreted as standard deviation of speed) over the same time period shown in Figure 3.34. These show a similar pattern to lane position and SDLP in Figure 3.31 and Figure 3.32 respectively, in that initial control and variability is good, whereas there is a notable variability in speed after approximately three seconds. It is also notable that the first active control input from all drivers in drive one was the accelerator (Figure 3.35), with this occurring, on average, after 2.1 seconds. As with lateral position, speed variability was initially high during the first drive in study one but improved over the course of the ten-second period.

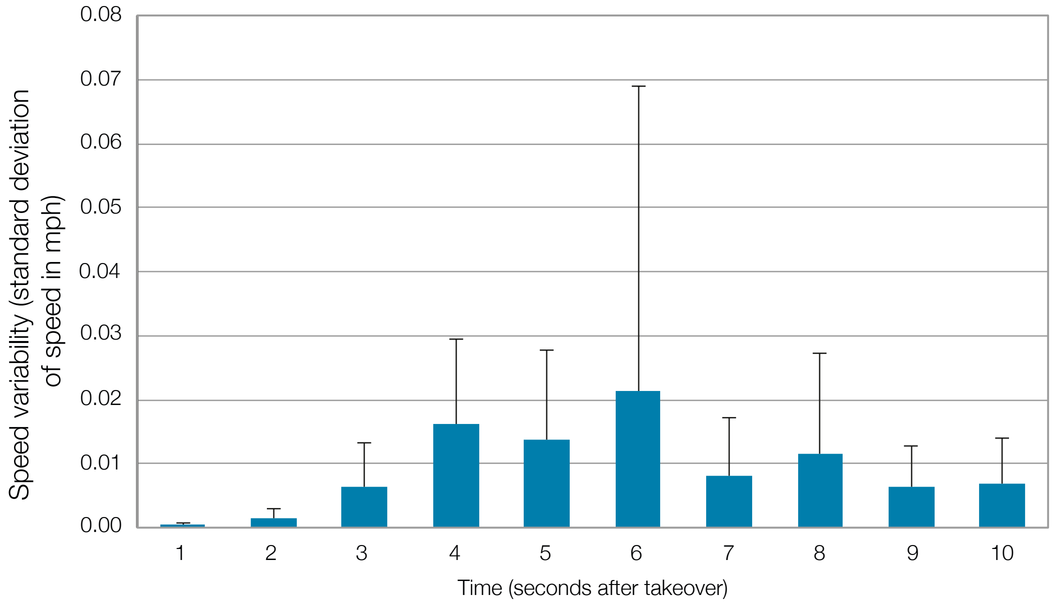
Figure 3.33: Vehicle speed in one-second intervals after taking over manual control of vehicle on drive one



Source: Authors' own

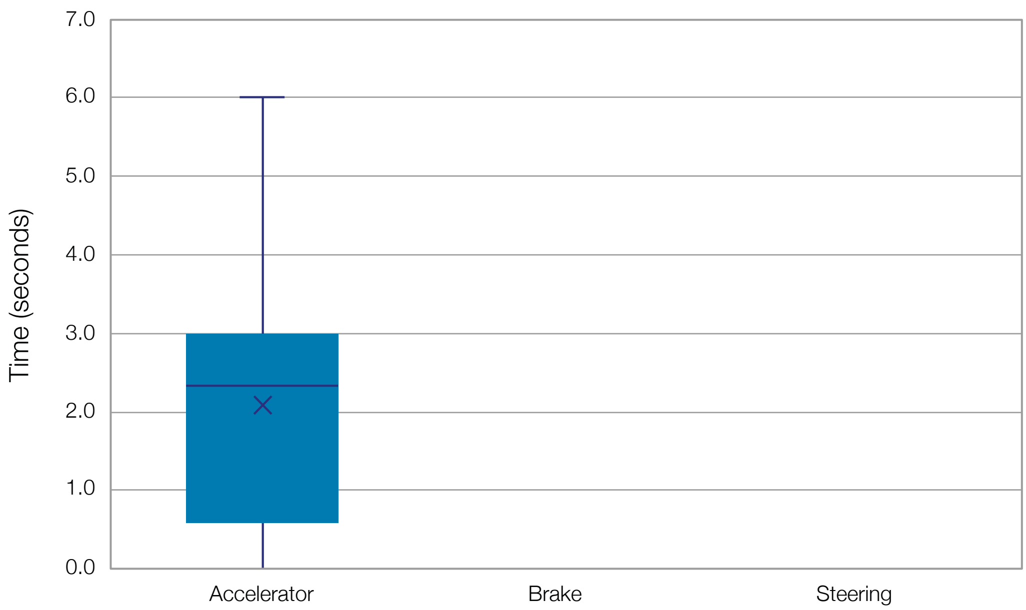
Note: Each plot represents a different participant.

Figure 3.34: Speed variability in one-second intervals after taking over manual control of vehicle on drive one, expressed as the standard deviation of speed



Source: Authors' own
Note: Each bar represents the mean value for all participants during that one-second interval; error bars (lines extending vertically above each bar) represent the standard deviation of values in that one-second interval.

Figure 3.35: Time to first active control input after transfer to manual driving



Source: Authors' own

4. Discussion of Findings

4.1 Programme of work

The current study aimed to uncover the natural behaviours of drivers who were accompanied by a front-seat passenger during periods of automation, as defined by SAE Level 3 conditional driving automation (SAE Level 3 in SAE, 2021). In so doing, we build on the findings from two previous studies conducted for the RAC Foundation (Burnett et al., 2019; Shaw et al., 2020), which considered the behaviour of the driver alone.

In study one (Burnett et al., 2019), we explored the type of activities that drivers chose to undertake in a vehicle operating at SAE Level 3, and the impact that these had on the manual resumption of the driving task under both routine (or expected) and emergency (or unexpected) takeover conditions. Results from study one demonstrated that drivers quickly developed high levels of trust in and acceptance of the automation technology at SAE Level 3, and that they undertook a range of activities or NDRTs, often with high visual, manual and cognitive demands, during periods of automation. This included using their handheld mobile phone (over 80% of participants) and reading books or magazines (approximately 25% of participants). In addition, drivers were observed using their laptop or tablet computer, and there were also some incidents, albeit rare, of drivers sleeping for short periods.

Moreover, in study one, which involved multiple journeys over a week, drivers remained engaged in their chosen NDRTs for longer each day, suggesting increasing trust and complacency as the week progressed. They also focused primarily on control-level tasks when resuming manual driving (at the expense of tactical and/or strategic elements) – that is to say, drivers focused on controlling the speed and lane position of their own vehicle rather than considering the behaviour of other nearby vehicles, often with unsafe or undesirable outcomes. Results from study one thus highlighted the need for new forms of training to improve drivers' awareness and understanding of their role and responsibilities at SAE Level 3 automation.

In study two (Shaw et al., 2020) we therefore applied behavioural change theories to develop and evaluate a proof-of-concept, behavioural training intervention that aimed to improve drivers' understanding of vehicle automation, outline their role and responsibilities at SAE Level 3 automation, and provide them with best-practice guidance for driving and interacting with SAE Level 3 vehicles, and indeed other road users. Study two demonstrated immediate, quantifiable benefits associated with our new, behavioural training approach (which was, in practice, a short, narrated presentation). In particular, our mnemonic strategy, CHAT (CHeck, Assess and Takeover) (Shaw et al., 2021), specifically directed drivers' attention to the actions necessary, and the order in which they were required, before taking over physical control of the vehicle.

In study three (reported herein), we considered the presence of a passenger at SAE Level 3 automation and explored the impact that they have on the driver during periods of automation and when required to resume manual driving. Recruiting a passenger to join the driver during SAE Level 3 adds an important, but hitherto overlooked, element to the research. Indeed, over one third of cars on the road in UK at any one time are carrying at least one passenger according to recent figures (DfT, 2024b). The presence of one or more passengers has been shown to distract drivers during manual driving, with reported reductions in situational awareness and increases in the risk of taking unsafe actions – factors that elevate crash risk, particularly for young drivers and passengers (Ouimet et al., 2015).

As a reminder, in study three, which forms the focus of the current report, we specifically aimed to explore the following research questions:

1. What will drivers and passengers naturally do in future automated vehicles?
2. What impact does the presence of a passenger have on the driving task – that is, during periods of automation and also during the resumption of the driving task?
3. How does the presence of a passenger affect levels of situational awareness, workload, trust and acceptance?

4.2 Common methodological approach

In all three studies, we have applied a common and novel methodological approach. We modified our driving simulator to reflect the capabilities and qualities of SAE Level 3 conditional driving automation (SAE, 2021) and created authentic journey experiences, which were framed as 'daily commuting' (study one and study two) or 'days out' (study three). Automation was made available to participants on the motorway only, thereby effectively creating an operational driving domain. This ensured that there were periods of both manual and automated driving and thus allowed us to investigate the transfer of control and, more specifically, the impact of engagement in secondary tasks, or NDRTs, on this. For studies one and three, we also applied a longitudinal study design in which drivers undertook multiple drives in the simulator, with the aim of exploring behavioural changes over repeated exposure.

To maintain intrinsic motivational factors, we did not control or restrict the activities that drivers chose to undertake when the vehicle was in control in any of the three studies, but simply asked participants to envisage (prior to attending the study) what activities they might undertake in a conditionally automated vehicle, and to bring with them anything they needed to undertake their chosen activities. Our intention was to reveal the types of activities that a driver (and, in study three, their accompanying passenger also) would expect to undertake in a future SAE Level 3 vehicle – whether they would be permitted to do so or not. Of course, all participants (drivers and passengers) were made aware of the capabilities of the vehicle (in line with standard SAE levels of automation definitions; SAE, 2021) before taking part, and were specifically told that the driver must be ready to resume control given appropriate notice and if required to do so.

4.3 Why is this important?

Understanding how a driver, and indeed their passenger, may behave in an automated vehicle, and the types of activities which they will wish to undertake while the vehicle is in control, is particularly relevant and timely given the recent announcement and rapid progression through parliament of the UK Automated Vehicles Bill 2023 (UK Parliament, 2023), which will set the legal framework for enabling the safe deployment of self-driving vehicles in UK. Indeed, certain SAE Level 3 automated systems are already beginning to appear in vehicles on UK roads. For example, the UNECE (UN Economic Commission for Europe) automated lane keeping system (ALKS) Regulation (June 2020) now permits ALKS technology to perform the dynamic driving task instead of the driver, under certain conditions. This is paving the way for the development and deployment of systems with higher levels of automation. Furthermore, changes to the UK Highway Code in 2022 highlight the potential impact of self-driving vehicles, and attempt to clarify the driver's new responsibilities, including when they must be ready to take back control.

Despite this, there is an overwhelming body of evidence in the academic literature (e.g. Kyriakidis et al., 2019; Merat et al., 2014) documenting how new forms of driving afforded by various levels of vehicle automation will place new demands on drivers – a view also supported by our own work (Burnett et al., 2019; Shaw et al., 2020). This is because the nature of the driver's interaction with the vehicle is fundamentally changing, from active control in current, manually driven vehicles, to supervisory control and selective intervention at SAE Level 3. Moreover, at SAE Level 3, the driver may be required to assume different roles within the same journey (sometimes, in active control and sometimes, supervising), and to move between these different states at short notice.

Of major concern is that the different driver roles require fundamentally different types of skills. Indeed, at SAE Level 3, factors such as maintaining an awareness of the functionalities and operational limits of the vehicle, knowing who is in control at any given moment (the driver or the automated vehicle), and anticipating potential situations requiring manual intervention, are all critical. Thus, drivers of these future vehicles will need to be proficient in new skills associated with supervising the system, monitoring the environment (while not driving) and sharing control. These are not skills that are particularly suited to humans (Shaw et al., 2020), nor are these skills called upon during traditional manual driving, or, indeed, taught during current driver training. Moreover, drivers of future vehicles will also be expected to maintain an adequate level of core, manual driving skills for periods when the vehicle is not in control, either through choice or by necessity.

A further concern is that conditionally automated vehicles are likely to retain the same form factor as current vehicles on the road (that is, look like existing cars and have the same physical controls, and so on), and even behave in the same manner during manual driving. As such, these vehicles may not present an obvious step change in technological development to drivers, and indeed their passengers and other road users such as cyclists and pedestrians, thereby masking any perceived need to acquire new skills, or to behave differently in their presence.

It is also widely reported (Bédard & Meyers, 2004; Chandrasekaran et al., 2019; Ouimet et al., 2015) that the presence of a passenger can have a distracting effect on the driver during manual driving. This is because a passenger can divert the driver's attention away from the road scene (for example through conversation or by undertaking physical activities, such as adjusting the radio or using electronic devices, or food and drink consumption), and this can have a detrimental effect on the driver's situational awareness (Chandrasekaran et al., 2019) and their vehicular control (Aarts & Van Schagen, 2006). Moreover, the presence of a passenger can increase the risk of drivers taking unsafe actions, more generally, during manual driving (Bédard & Meyers, 2004; Ouimet et al., 2015). In practice, some of these effects can be quite nuanced depending on the sociodemographic profiles of drivers and the contexts in which they are driving, with some evidence even of supportive or protective effects when a passenger is present (Orsi et al., 2013). Nevertheless, a common point of agreement is the increase in risk associated with young drivers when accompanied by young passengers. Indeed, this knowledge has been used as the basis for the establishment of restrictions on passenger presence and number of peer passengers in several countries where teenagers have access to independent driving before the age of 18 (for example Australia, Canada, Israel and the United States), with restrictions also extending beyond 18 in some of these regions. In the UK, there have also been calls for graduated driving licences, that effectively ban new under-25-year-old drivers from taking other under-25-year-old passengers during their first year of driving (UK Government, n.d.); indeed, the UK Road Traffic (New Drivers) Act (1995) already sets out a two-year probationary period for new drivers.

However, while there is a strong theoretical case to be made for the potential distraction caused by a passenger during SAE Level 3 conditional driving automation, on the basis of evidence from manual driving and established knowledge of human behaviour and performance, there has been limited empirical evidence proffered to date, particularly regarding driver/passenger interactions in future automated vehicles that have the capability to move between states of manual and automated driving depending on context.

4.4 What will drivers and passengers naturally do in future automated vehicles?

Findings from our study show that smartphone use is still likely to be very popular during periods of automation, but we also noted the increased use of smartwatches to fulfil a similar role (ostensibly to view email and message notifications). However, although drivers and passengers often interacted with their own smartphone in isolation to undertake a specific task (for example, to check their own messages, or conduct a search on a particular topic of interest to them at that time), they commonly shared their content and news items with their partner immediately thereafter by physically showing them the phone screen. Smartphones also featured in joint, participatory tasks – for example, using one smartphone to watch shared content together, such a film or a social media video feed; another such task observed was playing online games together, with the driver and passenger each using their own smartphone as their digital playing board (for example, to each enter their chosen move during a digital game of chess). These joint, participatory tasks were often highly captivating and immersive, particularly if there was a competitive element involved, and this resulted in some drivers requesting manual control too late and subsequently missing their designated junction during drive one, thus raising significant concerns relating to distraction.

However, arguably the most notable observation was the propensity for everyday, often unremarkable, conversation that took place between the driver and passenger (as also noted by Laurier et al., 2008 during manual driving). Conversation was generally prolific during our study three, and covered a wide range of topics, suggesting at the very least that participants were largely unphased by the fact that they were taking part in a research study and being observed, and their behaviour being recorded. The prevalence of conversation also highlights that some drivers and passengers were apparently content to continue existing behaviours (insofar as conversation commonly takes place in the presence of one of more passengers during manual driving (Laurier et al., 2008)). In view of this, we should not necessarily expect all users of future SAE Level 3 conditional driving automation to develop outlandish new habits, but should rather be prepared for the continuation of conventional in-vehicle behaviours, particularly during the early stages of introduction.

As with similar observations of drivers' and passengers' interactions during manual driving (e.g. Charlton & Starkey, 2020), the amount of conversation is difficult to quantify succinctly as a NDRT in and of itself, as it "ebbed and flowed" between the passenger and driver (as noted by Charlton & Starkey, 2020): while some participants spoke almost constantly throughout the entire journey, for others their conversation was more sporadic. In addition, conversation was often intertwined with other NDRTs, such as discussing chess moves or clues to a crossword. As with everyday conversation, interactions were initiated by both the driver and the passenger, and the dialogue moved seamlessly between different topics, including aspects of the driving task (road situation, route choice, etc.). Indeed, features in the road environment were routinely observed and commented upon, as was the behaviour of participant's own automated vehicle in response to other road users, and their attitudes towards automated vehicles more generally. In addition, drivers and passengers routinely discussed more social topics, such as recent sporting events or their plans for the weekend (see also Charlton & Starkey, 2020).

It was also noted that the driver and passenger remained forward-facing due to the side-by-side seating arrangement, with their gaze notionally directed to the road ahead; this allowed them to observe and comment upon features in the driving scenario. It would therefore seem prudent to retain this seating configuration, at least when it comes to SAE Level 3 conditional driving automation, rather than attempting to create a more flexible and adaptive design. Indeed, some authors (e.g. Tang et al., 2020) have recommended that front seats should rotate to face passengers in the rear. However, suggestions for this so-called 'interior metamorphosis' (Jorlov et al., 2017; Pettersson & Karlsson, 2015) tend to be aimed at higher levels of automation, in which the driver seldom (if at all) drives manually.

4.5 What impact does the presence of a passenger have on the driving task and levels of situational awareness, workload, trust and acceptance?

4.5.1 Conversation

Analysis of conversation revealed that passengers provided help and advice in preparation for and during the takeover of control, akin to the support observed during manual driving (Charlton & Starkey, 2020). However, during routine handovers (drives one and two), discussions tended to focus on control aspects of the driving task (that is, those relating to the operation of the vehicle – speed adherence, steering, etc.), whereas tactical and strategic elements featured more dominantly in dialogue during the unexpected, emergency takeover request in drive three; these were more commonly related to road positioning and lane selection (the tactical) and the journey goals – for example, determining the remaining distance to their required exit immediately following resumption of manual driving (the strategic).

Conversation analysis also highlighted the role of the passenger as mediator, for example, reprimanding the driver if they attempted to undertake an activity that the passenger deemed unacceptable or inappropriate, such as sleeping (or sometimes even if the driver even suggested that they might consider doing so). Other examples show the passenger helping to keep the driver alert or awake in preparation for resuming control. In contrast to manual driving, however, drivers were not required to rely on their passenger to undertake tasks on their behalf during periods of automation, such as unwrapping food, opening a drink bottle, getting items that were out of reach (we observed several drivers retrieving items from their bags in the rear of the car) – in essence, acting as a second pair of hands for the driver (as noted by Charlton & Starkey, 2020). However, there were still abundant examples of the passenger acting as a second pair of eyes for the driver, for example when asked to read a road sign.

4.5.2 Subjective ratings and opinions

Although post-study comments indicated that passengers (and indeed drivers) were generally aware of the potential distraction created by their presence, they also highlighted examples of positive influences, such as helping the driver to locate the correct junction and to decide when to take control, or helping them to stay awake and alert (given how "boring" many of our participants described periods of automation as being). On average, passengers tended to rate their own role and influence during these situations more highly than did their accompanying driver, with over half of the drivers (9 out of 17) indicating that they felt the presence of a passenger had no – or only negligible – impact on their actions and behaviour. During manual driving, Charlton and Starkey (2020) noted a similar attitude, reporting that the majority of drivers (in their case, more than 70%), who responded to their survey indicated that the presence of a passenger would make no difference to their behaviour. There are, of course, notable benefits associated with helping one another retain or rebuild situational awareness during periods of automation, or taking it in turns to monitor the road situation. It is therefore important to note, on the evidence of ratings made in our post-study questionnaires, that the driver and passenger purportedly experienced statistically equivalent levels of situational awareness, trust, workload and acceptance during the drives.

4.5.3 Driving performance

The most noticeable impact on the driving task was evident amongst drivers and passengers who became so engrossed in their secondary activity that they failed to resume control within sufficient time to leave the motorway at the correct exit. However, it was also evident that vehicular control during the ten seconds immediately after resuming manual driving was generally poor in the case of all participants. It was notable that, in contrast to study one, control remained erratic (in fact initially becoming more so) even after ten seconds of manual driving. Since conducting study one, the driving simulator and associated software have been significantly upgraded, and thus one might opine that the difference in vehicle control (lane position and speed adherence, in particular) between study one and study three could be a result of changes in the simulated driving experience. Indeed, vehicle control software algorithms may well be responsible for an apparently more stable road position and speed adherence immediately after transferring control to the participant. However, we would argue that the same will be true for future automated vehicles on the road, which will have their own unique control algorithms, and may therefore prioritise different attributes to support their driver. Moreover, if the software were solely responsible for the differences between studies, one might expect vehicle control to remain stable during the current study, and this was not the case. In fact, there was an apparent tendency for control to worsen after two to three seconds and to remain erratic even after ten seconds. Considered in conjunction with the other metrics (most notably dialogue between the driver and passenger), we believe that, in some situations, this increase in speed variability (erratic accelerating and braking) and severe lateral instability (or 'wavering' in the lane) actually reflects the driver actively testing the primary control inputs (steering wheel, accelerator, brake), perhaps to demonstrate to their passenger that they were now in control.

4.5.4 Passenger demographics

Much of the related literature (e.g. Ouimet et al., 2015) highlights the impact of young drivers and young passengers on crash risk and has noted differences based on different driver/passenger relationships (e.g. Lansdown & Stephens, 2013). While we ensured that we had a cohort of younger drivers in our study, and representatives from different kinds of driver/passenger partnerships (friends, partners, colleagues), our results remain largely qualitative in these respects, and it is therefore not possible to make statistical comparisons across the different age groups or different partnerships represented. Nevertheless, the general impression was that younger drivers and passengers, and those who were friends, appeared to be more willing to relinquish control and engage in immersive NDRTs while the vehicle was in control than those of an older generation, but further work is required to quantitatively explore such possible differences based on driver/passenger demographics of note. We also recognise that in our study we explored only behaviour with one front-seat adult passenger present, leaving other common occupant configurations (multiple passengers, young children in rear seats, etc.) to be explored as well.

4.5.5 Future work

Our findings provide demonstrable evidence of both distractive and protective behaviours resulting from the presence of a front-seat passenger during SAE Level 3 conditional driving automation (SAE, 2021). Naturally, future investigations should explore strategies for removing or reducing the harmful, distractive elements, and enhancing the positive, protective influences, and could also consider how any of the exposed benefits could be applied to situations in which there is no passenger present. Indeed, technological solutions could support this: for example, considering the proliferation of conversation stimulated by the presence of a passenger, and the influence this apparently has on the driver, a voice interface (or digital assistant) could potentially encourage or invite discussion of relevant driving-related information between the driver and passenger, or even engage a lone driver as a passenger might. Furthermore, technology could be employed to mediate NDRTs so as to ensure that drivers and passengers do not become so engrossed in their activity that they miss their exit or other key driving information – for example, by enforcing natural breaks in activities, and/or encouraging re-engagement with the driving scene at appropriate intervals. In addition, simple training interventions, similar to those we evaluated in study two, could remind drivers (and also their passengers) of the potential risks associated with the presence of a passenger during periods of automation, and provide best-practice guidance for driving and interacting with such vehicles.

4.6 Other road users

By design, our triumvirate of studies has focused on direct users of SAE Level 3 conditional driving automation; that is to say, the driver and an accompanying front-seat passenger. However, there are many other users who may routinely interact with such vehicles. These so-called 'indirect users' are likely to be impacted by the behaviour of the vehicle in different ways; for example, when attempting to interpret unexpected or erratic vehicular behaviour during automation or, potentially, when the human driver attempts to resume manual control (as we have observed in our studies). This is most relevant at higher levels of automation – SAE Level 4 high driving automation and SAE Level 5 full driving automation (SAE, 2021) – in which there may still be a human driver, but they are no longer required to be ready to intervene (at SAE Level 4), or no human driver present at all (at SAE Level 5), but it may also apply in some situations at lower levels of automation. It is also most significant for vulnerable road users, such as pedestrians and cyclists, who are more likely to be seriously injured should the vehicle behave in an unexpected or erratic manner leading to a collision.

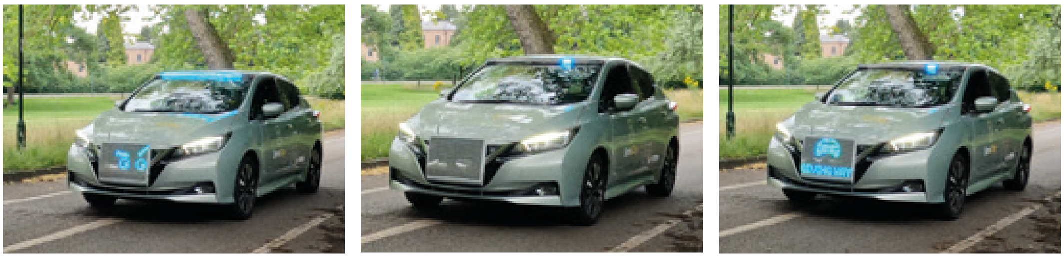
As an example, if no driver is present in the vehicle, or the driver is engaged in a secondary task and not currently in active control of the vehicle, a pedestrian may no longer be able to negotiate a safe opportunity to cross the road ahead using established social techniques such as making eye contact with the driver, or exchanging hand gestures. Alternatively, a pedestrian may make an ill-formed judgement that the driver has seen them and will respond to their presence, when in fact the driver is not actually in control of the vehicle at that moment at all. Various technological solutions have been proposed with the aim of overcoming some of these shortcomings, but they have tended to lack empirical validation.

We therefore conducted our own exploratory on-road study, in which we created three external human–machine interfaces (eHMIs) to inform pedestrians of the vehicle's behaviour and intent (Large et al., 2023a; 2023b). The work related to SAE Level 5 full driving automation, with the automated vehicle conceptualised as an autonomous taxi service (or 'robotaxi'). It was undertaken as part of the ServCity project (www.servcity.co.uk), which was funded by the UK Innovation Agency and Centre for Connected & Autonomous Vehicles (Grant number 105091).

The three eHMIs were prototyped using an individually addressable RGB–LED matrix and strip which were attached to the outside of the vehicle, located on the front of bonnet and at the top of the windscreen, respectively (Figure 4.1). The LEDs were controlled by an Arduino Mega board and push-button controls, which were manipulated by a researcher located within the rear of the vehicle. The eHMI designs employed varying degrees of anthropomorphism, notionally described as 'explicit', 'implicit' and 'low' to reflect how conspicuous the human elements were, with the aim of aiding interpretation and building trust, as has been noted by Zhou et al. (2021). The explicit eHMI included overtly recognisable 'human' elements and mannerisms, including a face (eyes and a mouth) and first-person written speech (for example "I am giving way", although the general intention was to build redundancy into the designs so that a non-English speaker could also successfully interpret the messages and behaviour of the car). By contrast, the implicit eHMI included elements based on human attributes but not necessarily immediately recognisable as such (for example, a light cluster moving from side to side on the LED strip at the top of the windscreen, intended to represent the pupillary response of a single eye scanning the road ahead). The low eHMI design primarily utilised non-human elements, such as a car icon and written text.

For each design, four states were created to describe the behaviour and intention of the vehicle: scanning, giving way (pedestrian/s on right), giving way (pedestrian/s on left) and giving way (pedestrian/s on both sides of road). The eHMIs purposefully did not provide a direct instruction to the pedestrian, such as “you may cross”, as it was felt important that this remained completely at the discretion of the pedestrian.

Figure 4.1: Vehicle with different eHMIs (from left to right: explicit, implicit, low anthropomorphism)



Source: Authors’ own

One of the challenges facing those conducting research with vehicles purporting to be at higher levels of automation (that currently either do not exist or are not as yet legal for use on UK roads), is how to authentically recreate this experience. In our study, we adopted a recognised, but still highly novel, technique to simulate SAE Level 5 full driving automation. The ‘Ghost driver’ method (Rothenbücher et al., 2016) utilises a so-called ‘Wizard-of-Oz’ approach in which the behaviour of the technology in simulated by an experimenter (the wizard). In this case, a driver is concealed within a conventional vehicle using a bespoke seat-suit (Figure 4.2) and simulates the behaviour of an automated vehicle. The driver is therefore hidden from view at least in response to a cursory glance made by a passing pedestrian or other road user, giving the impression of a fully automated vehicle, but is still able to safely operate the vehicle. Such an approach provides high ecological validity, enabling researchers to understand how pedestrians might naturally behave when faced with a genuinely driverless vehicle in real-world crossing and traffic scenarios.

Figure 4.2: ‘Ghost driver’ hidden in bespoke seat-suit

Source: Authors’ own

In the study, the ‘driverless’ car was driven around a designated, circular route on the University of Nottingham campus that included several marked zebra crossings and several unmarked (but commonly used) crossing points. Data was collected over five days, with each eHMI displayed for an equivalent duration (that is, the same number of circuits of the route). The current state of the eHMI (scanning, giving way, etc.) was determined by a second researcher located in the rear of the study vehicle in response to the behaviour and proximity of any observable pedestrians in the vicinity of the vehicle as it approached each crossing.

As an exploratory field study, the Ghost Driver study provided some valuable insights into the application of anthropomorphism in vehicle–pedestrian communication, with results suggesting that the inclusion of human elements and mannerisms within the design of eHMIs may help to gain pedestrians’ visual attention and has the potential to provide a positive user experience: more glances were directed towards the vehicle when the explicit anthropomorphism eHMI was displayed and pedestrians responded positively to this design in particular, smiling and laughing.

Overall, findings from the Ghost Driver study suggest that providing explicit communication using eHMIs (incorporating elements of anthropomorphism in their design) appears to encourage safe crossing behaviours, help pedestrians interpret vehicle behaviour and intent, and increase their confidence and build appropriate trust when interacting with a driverless vehicle. For further details of this study, see Large et al. (2023a; 2023b).

5. Conclusions

New forms of driving afforded by different levels of vehicle automation will place new demands on drivers. At Society of Automotive Engineers (SAE) Level 3 driving automation, drivers will be permitted to undertake secondary tasks while the vehicle is in control, so long as they are prepared to resume control if required to do so and are capable of doing so within an appropriate period of time. The requisite skills associated with supervising the automated system, monitoring the driving environment (while not actually driving), and sharing control are not particularly suited to humans – nor are they required during manual driving, or, indeed, taught during current driver training. It follows that SAE Level 3 automated vehicles possessing the capability to shift between human piloting and self-driving depending on contextual factors present a challenge to drivers, although many drivers are unlikely to be fully aware of the potential risks of operating one.

Despite this, we concluded from study one of a triumvirate of studies carried out over five years that drivers are likely to quickly develop high trust in SAE Level 3 conditional driving automation and become comfortable relinquishing control to their vehicle. Moreover, our results indicated that drivers would expect to undertake a diverse range of activities or non-driving-related tasks within future automated vehicles, often with high visual, manual and cognitive demands, such as using a smartphone, reading books or magazines, using their laptop or tablet computer, and even sleeping. When asked to resume control during study one, drivers took longer to respond each day as the week progressed, and focused primarily on control-level driving tasks, suggesting that they were overly optimistic about the capability of the automation, and their own ability to take over manual driving when required to do so.

In study two, we highlighted the potential of a simple training intervention to develop new skills for drivers in future vehicles, ensure that they develop an appropriate mental model of the new technology, and adopt appropriate behavioural routines to ensure safe working practices in preparation for and during the transition of control. Although we did not explore knowledge retention and the maintenance of desired behaviours as part the study, we did observe that drivers who received the behavioural training intervention (which was, in practice, a short self-paced presentation) were more likely to conduct additional checks of the internal and external driving environment during the transition from automation to manual mode, and demonstrated positive visual behaviours relating to tactical and strategic-level tasks during the automated driving mode. Thus, we concluded from study two that behavioural training can improve drivers' attitudes and behaviour, and simple routines, such as 'CHAT' (Check, Assess and Takeover) (Shaw et al., 2021) can encourage safe working practices during takeovers.

In study three, we discovered that driver behaviour at SAE Level 3 conditional driving automation is also affected by the presence of a front-seat passenger. Our findings suggest that a passenger effectively redefines the situation by introducing new opportunities for the driver to engage in shared, participatory activities with their passenger during periods of automation, such as watching shared content or playing games together on a smartphone, jointly solving crossword puzzles, and playing cards. Although the emerging, shared activities had the potential to significantly distract drivers and reduce the attention that they were able to direct to the road situation, particularly if there was a competitive element to them, the activities were often intrinsically linked to conversation and dialogue. Analysis of dialogue subsequently revealed that drivers and passengers also shared their engagement with, and responsibility towards, some aspects of the driving task. This was evidenced by examples of drivers and passengers jointly observing and discussing the behaviour of other road users during periods of automation, discussing and negotiating what were perceived to be appropriate secondary activities to undertake (for example, whether sleeping is permissible), and discussing tactical and strategic elements during the transfer of control. We therefore conclude from study three that a front-seat passenger at SAE Level 3 automated driving can offer both distractive and protective effects, but would recommend further investigations to evaluate these effects further. More specifically, further work should seek to preserve and enhance the protective behaviours whilst eliminating the distractive components, and seek to uncover any nuances in behaviour associated with different sociodemographic groups, most notably young drivers.

Overall, results from our triumvirate of studies are important and timely given the rapid progression of the Automated Vehicles Bill through UK Parliament, which will "set the legal framework for the safe deployment of self-driving vehicles in Great Britain" (DfTa, 2024a; UK Parliament 2023). The insights generated here will be useful in informing future decision-making relating to certain requirements outlined in the bill, for example, ‘transition demands’ (UK Parliament, 2023), including the definition of appropriate transition times and the safe management of situations where users may fail to assume control. In presenting our findings, we recognise that our participants were not driving their own car and that we provided them with a simulated driving experience, albeit framed as authentic journeys. Furthermore, and notwithstanding the longitudinal element to our study design, we were not able to consider longer-term behavioural adaptations (that is, those which take place over several months, or even years, of use). However, by creating authentic and immersive journey experiences and giving participants the agency to behave as they wanted in all three studies, we aimed to preserve important motivational aspects that can be absent in highly controlled experimental studies. Our findings can therefore inform the debate regarding permissible activities at SAE Level 3 conditional driving automation, and support the design of in-vehicle information systems and technology to promote the safety of drivers and passengers, and, indeed, all other road users.

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Appendix A: Questionnaires and Rating Scales

NASA-Task Load Index (NASA-TLX) workload rating

Please provide an answer to the following six questions using the rating scale provided, where 1 = Very Low and 7 = Very High.

Mental demand

1. How mentally demanding was the task?

Very Low	1	2	3	4	5	6	7	Very High

Physical demand

2. How physically demanding was the task?

Very Low	1	2	3	4	5	6	7	Very High

Temporal demand

3. How hurried or rushed was the pace of the task?

Very Low	1	2	3	4	5	6	7	Very High

Performance

4. How successful were you in accomplishing what you were asked to do?

Very Low	1	2	3	4	5	6	7	Very High

Effort

5. How hard did you have to work to accomplish your level of performance?

Very Low	1	2	3	4	5	6	7	Very High

Frustration

6. How insecure, discouraged, irritated, stressed and annoyed were you?

Very Low	1	2	3	4	5	6	7	Very High

Source: Hart & Staveland (1988)

Situational awareness rating technique (SART)

Please provide an answer to the following ten questions using the rating scale provided, where 1 = Low and 7 = High.

Very Low	1	2	3	4	5	6	7	Very High

Instability of situation

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

Very Low	1	2	3	4	5	6	7	Very High

Complexity of situation

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

Very Low	1	2	3	4	5	6	7	Very High

Variability of situation

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

Very Low	1	2	3	4	5	6	7	Very High

Arousal

4. 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)?

Very Low	1	2	3	4	5	6	7	Very High

Concentration and attention

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

Very Low	1	2	3	4	5	6	7	Very High

Division of attention

6. 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)?

Very Low	1	2	3	4	5	6	7	Very High

Spare mental capacity

7. 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)?

Very Low	1	2	3	4	5	6	7	Very High

Information quantity

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

Very Low	1	2	3	4	5	6	7	Very High

Information quality

9. How good was the information you gained during the drive? Was it accessible and usable (high) or difficult to access (low)?

Very Low	1	2	3	4	5	6	7	Very High

Familiarity with situation

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

Very Low	1	2	3	4	5	6	7	Very High

Source: Taylor (2011)

Situational Trust Scale for Automated Driving (STS-AD)

Please indicate your level of agreement with each of the following six statements using the scale provided, where 1 = Strongly disagree and 7 = Strongly agree.

1. I trust the automation in this situation.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

2. I would have performed better than the automated vehicle in this situation.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

3. In this situation, the automated vehicle performs well enough for me to engage in other activities (such as reading).

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

4. The situation was risky.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

5. The automated vehicle made an unsafe judgement in this situation.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

6. The automated vehicle reacted appropriately to the environment.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

Source: Holthausen et al. (2020)

Trust in automation questionnaire

Please indicate your level of agreement with each of the following 28 statements using the scale provided, where 1 = Strongly disagree and 7 = Strongly agree.

1. Automation decreases my problems while driving.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

2. Automation enables me to manage useful activities while driving.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

3. Automation saves time that I would have lost driving manually.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

4. Automation increases road safety.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

5. Automation prevents traffic violations.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

6. Automation supports the driver to detect hazards in time.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

7. Automation contributes to reducing crash risk.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

8. Automation prevents me from detecting hazards.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

9. I drive safer than the automation.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

10. Automation is vulnerable for new hazards like hacker attack and issues with data safety.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

11. To me, new risks that emerge from automation appear to be more serious than the decrease in crash risk due to automated vehicles.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

12. I am suspicious of automation's intent, action or outputs.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

13. I am wary of automation.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

14. Automation's actions will have a harmful or injurious outcome.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

15. I am confident in automation.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

16. Automation provides security.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

17. Automation has integrity.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

18. Automation is dependable.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

19. Automation is reliable.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

20. I can trust automation.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

21. I am familiar with automation.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

22. It is likely that I can use automation.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

23. There is no reason why I should not be able to use automation.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

24. My ability to use automation is dependent on me.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

25. I probably could not operate a vehicle with automation.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

26. I would like to have automation in my car.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

27. I will consider using automation.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

28. I will not use automation in any case.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

Source: Gold et al. (2015)

Technology acceptance questionnaire

Please indicate your level of agreement with each of the following 19 statements using the scale provided, where 1 = Strongly disagree and 7 = Strongly agree.

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 to do what I want it to do.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

7. It is faster to perform 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 have control over using the system.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

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

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

14. 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

15. I find using the system to be enjoyable.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

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

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

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

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

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

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

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

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

Source: Adapted from Venkatesh & Bala (2008) and Hernandez-Ortega (2011) (see Salanitri, 2018)

Post-study questionnaire – driver

Section 1. Please indicate your level of agreement with each of the following 13 statements using the scale provided, where 1 = Completely disagree and 7 = Completely agree.

1. I attempted to maintain awareness of the driving scene while the vehicle was in control.

Completely disagree	1	2	3	4	5	6	7	Completely agree

2. I was fully engrossed in other activities while the vehicle was in control.

Completely disagree	1	2	3	4	5	6	7	Completely agree

3. I was distracted by my passenger during periods of automation.

Completely disagree	1	2	3	4	5	6	7	Completely agree

4. The passenger helped me to decide when to request manual control.

Completely disagree	1	2	3	4	5	6	7	Completely agree

5. The passenger delayed my decision to take over control.

Completely disagree	1	2	3	4	5	6	7	Completely agree

6. The passenger helped me take over control of the car.

Completely disagree	1	2	3	4	5	6	7	Completely agree

7. I was distracted by the passenger during the takeover of control.

Completely disagree	1	2	3	4	5	6	7	Completely agree

8. The presence of a passenger delayed and/or extended the takeover of control.

Completely disagree	1	2	3	4	5	6	7	Completely agree

9. The passenger helped me maintain awareness of the driving scene during periods of automation.

Completely disagree	1	2	3	4	5	6	7	Completely agree

10. I would behave in the same way if no passenger was present.

Completely disagree	1	2	3	4	5	6	7	Completely agree

11. The presence of a passenger improved the takeover of control.

Completely disagree	1	2	3	4	5	6	7	Completely agree

12. The presence of a passenger hindered the takeover of control.

Completely disagree	1	2	3	4	5	6	7	Completely agree

13. I actively involved the passenger during the takeover of control.

Completely disagree	1	2	3	4	5	6	7	Completely agree

Section 2. Please provide written answers to the following questions, providing as much detail as necessary.

1. Briefly describe what you did, as the driver, when required to take over control. Was this successful? Please explain.

Completely disagree	1	2	3	4	5	6	7	Completely agree

2. As the driver, did your actions and behaviour differ between the three drives? If so, how and why?

Completely disagree	1	2	3	4	5	6	7	Completely agree

3. As the driver, did your actions and behaviour differ because of the presence of a passenger? If so, how and why?

Completely disagree	1	2	3	4	5	6	7	Completely agree

4. Briefly describe what the passenger did (if anything), during the takeover of control. Did this help you? Please explain.

Completely disagree	1	2	3	4	5	6	7	Completely agree

5. Did the passenger's actions and behaviour differ between the three drives? If so, how and why?

Completely disagree	1	2	3	4	5	6	7	Completely agree

6. Please provide any further information below.

Completely disagree	1	2	3	4	5	6	7	Completely agree

Note: Section 1. For analysis purpose, items 1, 2R, 3R, 9 and 10R refer to 'during automation'; items 4 and 5R relate to 'decision to take over'; items 6, 7R, 8R, 11, 12R, 13 relate to 'during takeover' (R = reverse-scaled)
Source: Authors' own

Post-study questionnaire – passenger

Section 1. Please indicate your level of agreement with each of the following 13 statements using the scale provided, where 1 = Completely disagree and 7 = Completely agree.

1. I attempted to maintain awareness of the driving scene while the vehicle was in control.

Completely disagree	1	2	3	4	5	6	7	Completely agree

2. I was fully engrossed in other activities while the vehicle was in control.

Completely disagree	1	2	3	4	5	6	7	Completely agree

3. I distracted the driver during periods of automation.

Completely disagree	1	2	3	4	5	6	7	Completely agree

4. I helped the driver to decide when to request manual control.

Completely disagree	1	2	3	4	5	6	7	Completely agree

5. I delayed the driver's decision to take over control.

Completely disagree	1	2	3	4	5	6	7	Completely agree

6. I helped the driver take over control of the car.

Completely disagree	1	2	3	4	5	6	7	Completely agree

7. I distracted the driver during the takeover of control.

Completely disagree	1	2	3	4	5	6	7	Completely agree

8. My presence, as a passenger, delayed and/or extended the takeover of control.

Completely disagree	1	2	3	4	5	6	7	Completely agree

9. I helped the driver maintain awareness of the driving scene during periods of automation.

Completely disagree	1	2	3	4	5	6	7	Completely agree

10. The driver was unaffected by my presence as a passenger.

Completely disagree	1	2	3	4	5	6	7	Completely agree

11. My presence improved the takeover of control.

Completely disagree	1	2	3	4	5	6	7	Completely agree

12. My presence hindered the takeover of control.

Completely disagree	1	2	3	4	5	6	7	Completely agree

13. I was actively involved during the takeover of control.

Completely disagree	1	2	3	4	5	6	7	Completely agree

Section 2. Please provide written answers to the following questions, providing as much detail as necessary.

1. Briefly describe what the driver did when required to take over control. Was this successful? Please explain.

Completely disagree	1	2	3	4	5	6	7	Completely agree

2. Did the driver's actions and behaviour differ between the three drives? If so, how and why?

Completely disagree	1	2	3	4	5	6	7	Completely agree

3. Did the driver's actions and behaviour differ because of the presence of a passenger? If so, how and why?

Completely disagree	1	2	3	4	5	6	7	Completely agree

4. Briefly describe what you did as the passenger (if anything), during the takeover of control. Did this help the driver? Please explain.

Completely disagree	1	2	3	4	5	6	7	Completely agree

5. Did your actions and behaviour differ between the three drives? If so, how and why?

Completely disagree	1	2	3	4	5	6	7	Completely agree

6. Please provide any further information below.

Note: Section 1. For analysis purpose, items 1, 2R, 3R, 9 and 10R refer to 'during automation'; items 4 and 5R relate to 'decision to take over'; items 6, 7R, 8R, 11, 12R, 13 relate to 'during takeover' (R = reverse-scaled)
Source: Authors' own

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RAC Foundation
89–91 Pall Mall
London
SW1Y 5HS

Tel no: 020 7747 3445
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