RAC Foundation

Mobility • Safety • Economy • Environment

Driver Training for Future Automated Vehicles

Introducing CHAT (CHeck, Assess and Takeover)

Emily Shaw, David R. Large, Gary Burnett

University of Nottingham

November 2020

University of Nottingham UK | CHINA | MALAYSIA

RAC Foundation
89–91 Pall Mall
London
SW1Y 5HS

Tel no: 020 7747 3445
www.racfoundation.org

Registered Charity No. 1002705

RAC Foundation

Mobility • Safety • Economy • Environment

Driver Training for Future Automated Vehicles

Introducing CHAT (CHeck, Assess and Takeover)

Emily Shaw, David R. Large, Gary Burnett
University of Nottingham

November 2020

University of Nottingham UK | CHINA | MALAYSIA

About the Author

Emily Shaw is a PhD student with the Human Factors Research Group at the University of Nottingham. Her research is focused on exploring driver behaviour with future automated vehicles in order to inform the design of potential training interventions or in-vehicle Human Machine Interface (HMI) solutions that will support the uptake and maintenance of desired driver behaviours and provide a countermeasure to problems of reduced operation situation awareness and attention.

Dr David R. Large is a Senior Research Fellow with the Human Factors Research Group at the University of Nottingham. Since returning to academia and gaining his PhD in 2013, David has been actively involved in leading and delivering a broad range of industry, UK and EU funded projects, primarily concerning the design, evaluation and acceptance of new and emerging in-vehicle interfaces and technology for both road and rail transport, and the development and application of novel methodologies to enable this work.

Professor Gary Burnett holds a chair in Transport Human Factors within the Faculty of Engineering at the University of Nottingham. He has over 25 years' experience in Human Factors research and development relating to advanced technology within road-based vehicles. His work addresses key safety, usability, and acceptance issues for advanced in-car systems and Human-Machine Interfaces (HMIs), and he is particularly concerned with the role of the human within future highly automated vehicles.

Acknowledgements

The research was conducted as a collaboration between the RAC Foundation and the University of Nottingham. The authors would like to thank Elizabeth Box, Doreen Lam and the other members of the RAC Foundation team for their valuable guidance and support. The authors would also like to thank George Telfer, actor and erstwhile driving instructor, who kindly provided voice-over narration to accompany the behavioural CHAT training.

Disclaimer

Contents

Figures list

Tables list

Foreword

Of the 40 million or so people in the UK with a driving licence few would regard what they do behind the wheel as being akin to the role and responsibilities which weigh on the shoulders of commercial airline pilots, particularly when it comes to aviators' relationship with the automated systems that relieve them of some of the pressures of prolonged flight.

But that could be about to change, because just as auto-pilot for aircraft is commonplace so the self-driving, or at least highly automated, car is coming rapidly down the road.

The truly driverless - go anywhere, anytime - car is probably still years away. What we will encounter first is a hybrid world in which there are certain circumstances where the human is in command and others where the car has control.

In fact, at the time of writing the UK government had recently launched a call for evidence on how automated lane keeping systems (ALKS) might be safely introduced, for the first time allowing for the 'hands-off' situation where it is technology not the driver keeping the vehicle in lane which, combined with adaptive cruise control, leaves the driver to twiddle their thumbs, no longer needing to hold the steering wheel as is the case with existing lane-assist systems. In such circumstances ALKS can be regarded as conditional automation, where the vehicle drives itself (though doesn't choose the route) but humans are expected to intervene upon demand.

It is this handover stage that is potentially fraught with risk. Is the driver ready? Have they checked what's around them? Have they adequately assessed the risks?

What pilots know is that the less likely they are to have to do a task the more they need to train for it. So too with increasingly automated cars, until humans are completely written out of the equation. But are we training drivers adequately for this new world?

The work carried out at the University of Nottingham suggests that drivers who have been trained to understand their new role and responsibilities and provided with a prescribed process – a short and simple checklist – to follow are best placed to resume routine control.

Following checklists is common practice in the aviation and other safety-critical industries; perhaps it will also need to be so in the world of motoring - maybe not today, but the sooner we start thinking about the training we will need to be safe drivers in the future the better prepared we will be when the technology arrives in the showrooms. Just like the driver waiting to take back control of the vehicle it is best to be ready rather than being caught unawares.

Steve Gooding

Director, RAC Foundation

Executive Summary

Automated vehicles are expected to offer many benefits, including improvements in road safety, increased mobility, enhanced driver comfort, and reductions in road congestion. However, fully automated, autonomous vehicles that require no input from a human driver are not likely to populate our roads in the foreseeable future. In the meantime, there is an expectation that we will see greater availability of vehicles offering lower levels of automated control, or those that possess the ability to operate autonomously in certain situations only (Kyriakidis et al., 2019). So-called partially or conditionally automated vehicles (i.e. those in which aspects of the driving task are shared between the human driver and the vehicle) are likely to retain the form factor of current vehicles, looking the same and providing the same primary input controls (e.g. steering wheel, foot pedals and so on). These new vehicles represent a radical change in ideology, completely redefining the role of, and expectations placed upon, the driver; and yet, there appears to be a tacit assumption that current, passive modes of training will suffice, such as providing a user manual.

A previous study conducted by the authors in collaboration with the RAC Foundation (Burnett et al., 2019) explored the types of activities that drivers may wish, or indeed expect, to undertake in these lower-level automated vehicles, and the potential impact that these choices of activities could have when resuming manual driving. One outcome of this research was that it highlighted the importance of new forms of training to ensure that drivers have the awareness and skills with which to operate and interact with automated vehicles in a safe and appropriate manner. This report presents our next study, which investigates driver training for future automated vehicles. The focus here is again on intermediate, level 3 automation, as classified by Society of Automotive Engineers (SAE) (2016) (see Table 2.1 for SAE classification of levels of vehicle automation).

The current work has a strong theoretical grounding in our understanding of the cognitive capabilities and biases of the human driver, as framed by an extensive literature review, and draws in part on experience and literature from the aviation domain. It highlights 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. In particular, the review emphasises the importance of providing, from the outset, clear and consistent learning strategies to foster the development of accurate mental models with which to explain how the system works (including the limits of its capability). In the absence of appropriate mental models, people are likely to create their own models, which may be inaccurate or incomplete (Norman, 1988; Merat et al., 2019). This can lead to situations in which drivers over-rely on the automated system, expecting it to deal with events for which it is neither intended nor capable. The review concludes that to realise the full potential of future, automated vehicles, the training needs of drivers should be viewed with a similar vigour to that which is provided within the field of aviation.

Following this review of the literature, a series of exploratory interviews with ten experienced drivers and expert driving instructors were conducted. The findings of which confirmed the urgent need for improved knowledge and awareness to ensure that all stakeholders accurately understand the potential capabilities and characteristics of future, automated vehicles, and their role within them. Interviewees were not able to articulate any specific, new operational skills that they thought would be required in these future vehicles – proffering the belief that current skills would likely be sufficient. However, there was general consensus regarding the need to improve the behaviour and expectations of drivers as a whole.

Building on the interviews and the literature review, we applied behavioural change theories to develop a proof-of-concept, knowledge-based, behavioural training intervention. This aimed to improve drivers' understanding of vehicle automation, outline their role and responsibilities at level 3 automation, and provide best practice guidance to driving and interacting with such vehicles. As part of this behavioural training intervention, we introduced a standardised operating procedure relating to the transition of control. This was defined by the acronym and mnemonic strategy, "CHAT" (CHeck, Assess, Takeover), which specifically draws attention to the necessary actions, and the order in which they are required, *before* taking over physical control of the vehicle:

- **CHeck**: *first*, check yourself, check for hazards, check all mirrors and check your blind spot
- **Assess**: *next*, assess your position, assess the road, assess the situation and assess the next step
- **Take Over**: *then*, focus on taking over the operational controls of the vehicle

The acronym, 'CHAT', is also semantically aligned with the idea of a two-way conversation (a discussion or 'chat') that must occur between partners in a shared task so as to gain mutual understanding and enable effective collaboration. As such, 'CHAT' also reflects the necessity for shared control and awareness at level 3 automation.

The behavioural (CHAT) training was subsequently evaluated in a between-subjects[2], driving simulator study with 24 participants. Each participant received either Behavioural training, delivered using a self-paced, interactive PowerPoint presentation (narrated by a professional actor), or were given a written user manual ('Operational training'). The latter was based on a user manual provided by a current, commercially available vehicle fitted with automated technology, and thus aimed to emulate current practice.

The study showed that drivers receiving behavioural CHAT:

- Carried out, on average, over 30 additional mirror checks during the 10-minute episode of automated driving and the subsequent transition to manual driving compared to their counterparts in the Operational training group (on average, 47 per person compared to 16.8, respectively).
- Were significantly more likely to notice a potential hazard during the transition to manual driving (in this case, a tailgating car), than those receiving Operational training: in practice, 10 out of 11 drivers in the Behavioural group saw the hazard vehicle, compared to only 3 drivers in the Operational group.

2 A 'between subjects' study design refers to research where different people test each condition, such that each person only experiences one condition. In contrast, in a 'within-subjects' (or repeated-measures) study design, the same person tests all the conditions (Budiu 2018). In this case, one group of participants received the Behavioural training, and another group received the Operational training.

- Were 23.5 seconds quicker, on average, to stop and completely discharge their non-driving related tasks (NDRTs) when provided with 60 seconds' notification to prepare to drive, taking on average 7.3 seconds before first glancing at the road and a further 1.8 seconds to completely stop their NDRT. In contrast, operationally trained participants took 21.3 seconds before making their first glance at the roadway, and a further 11.2 seconds to cease interaction with their NDRT. Consequently, behaviourally trained drivers spent significantly less time sharing their attention between preparing-to-drive and their continued engagement in their NDRT.
- Were demonstrably more careful when preparing to change lanes in anticipation of exiting the dual carriageway, evidenced by them making significantly more mirror checks prior to and during the lane change manoeuvre, and taking significantly longer to prepare (i.e. acquire sufficient situational awareness through on-road and mirror glances) to make the manoeuvre itself (4.3 seconds compared to 2.3 seconds, respectively).

Nevertheless, the additional effort exerted by drivers in the behavioural CHAT group was reflected in higher 'temporal' workload reported amongst this group, which should be expected. Subjective ratings of trust and situation awareness did not differ significantly between groups prior to receiving the training. After the drive, however, participants in the Operational group indicated significantly higher levels of trust-in-automation and greater intention-to-use the automation, whereas ratings made by drivers in the Behavioural group were unchanged. These findings exemplify the problem at hand: without appropriate guidance or training, people may be unaware of the limitations and potential errors in their knowledge (their mental model), and subsequently fail to behave or act appropriately (for example, Operational drivers made fewer mirror checks during automated driving). In the absence of any intervention or event to 'correct' or challenge their knowledge (such as the behavioural training, or a near-miss/accident), their incorrect mental model will be reinforced, potentially leading to even higher expectations – as shown by the increases in trust and intention-to-use amongst the Operational group of drivers.

No specific differences were revealed in the driving performance measures captured during the study. It is suspected that this finding was influenced by the naturalistic nature of the takeover scenario, the fact that no specific technical 'takeover' skills were imparted during the training, and that drivers only attended on a single occasion – in our previous study (Burnett et al., 2019), driving performance notably improved with experience over the course of the week.

The study demonstrates immediate, quantifiable benefits associated with the new, behavioural CHAT training approach, with the greatest positive impact on visual behaviour. In addition, CHAT promotes a standardised operating procedure relating to the transition of control, thereby mitigating against some of the performance issues identified in previous research. As such, CHAT could be integrated into training for new drivers or delivered on a standalone basis to experienced drivers.

Further, ongoing work will seek to:

- validate the CHAT approach, considering factors such as knowledge retention and long-term maintenance of the desired behaviours;
- recruit a more diverse range of participants (in terms of age, driving experience, culture, etc.);
- consider the specific content, timing, and delivery of the behavioural CHAT training; and
- explore the benefits of technological solutions, such as novel, in-vehicle HMIs (human-machine interfaces) to help deliver, support, and maintain these improvements in drivers' behaviour during automated driving and the transfer to manual control.

1. Introduction

Ongoing advancements in technology means that partially, or conditionally, automated vehicles (i.e. those that appear to, or can, operate autonomously in certain situations) are increasingly seen as a viable, and often inevitable, near-future proposition. These future vehicles may allow the driver to relinquish control under predefined conditions but will still require that they maintain an awareness of the road situation and be prepared to resume control when requested or required to do so. This situation could occur if the vehicle exceeds the scope and limits of its automated driving capability, for example, by leaving its so-called operational design domain (ODD).

Previous research conducted in collaboration with the RAC Foundation (Burnett et al., 2019) demonstrated that drivers who spent a week using an automated, SAE level 3 vehicle[2] for their daily commute (in our driving simulator) engaged in a range of immersive, non-driving related tasks (NDRTs) while the vehicle was in control despite their on-going responsibility towards vehicle control and supervision. This indicates high levels of trust and acceptance (confirmed by subjective ratings). As a consequence, when asked to resume manual control, these drivers appeared to be ill-prepared, and their initial takeover performance immediately after control was handed back to them, was subsequently poor,

2 See Table 2.1 for SAE classification of levels of vehicle automation.

demonstrated by high levels of lateral instability and speed variability during the 10 seconds immediately following these scheduled handovers. This is in keeping with the general census regarding the difficulty of resuming active control in a moving vehicle following a period of disengagement from primary control actions (e.g. Merat et al., 2014; Gold et al., 2015a; Zeeb et al., 2016).

Nevertheless, our research also demonstrated that, as a collective cohort, participants' takeover performance (specifically, in terms of their operational control of the vehicle) generally improved over the course of the week, as their experience undertaking this manoeuvre increased. This suggests that drivers actively attempted to improve their physical takeover performance and/or developed coping mechanisms and strategies to overcome the difficulties they experienced on day one. It follows that specific operational takeover skills could potentially be identified and taught to drivers of these future vehicles, and additionally, supported through technological innovations. However, it was also apparent during the former study that the time and effort drivers directed towards maintaining and/or rebuilding awareness of their surroundings and their journey progress and goals (the so-called, tactical and strategic elements of the driving task (Michon, 1985) reduced over the course of the week. Instead, drivers chose to remain engaged with their NDRT for longer each day, apparently increasingly dismissive of the need to re-build their awareness of the driving situation as the week progressed. These behavioural indicators suggest an increase in the level of complacency and confidence that these drivers held regarding their own ability to take control. It may also be indicative of 'satisficing' (Kaber, 2018), whereby drivers select the easiest or most accessible course of action, rather than the optimal one, in order to reduce effort and make the overall experience easier. Fundamentally, these changes in drivers' behaviour are likely to be influenced by their understanding of the capability of the vehicle and the limits of its performance (i.e. their mental model) and their situation awareness. In other words, we believe that during the previous study, drivers were choosing to disregard important driving-related tasks and activities, in favour of remaining engaged with their NDRTs, without a comprehensive understanding of what they really *should* be doing, or attending to – even though specific instructions were provided as part of the study protocol. It is therefore posited that the first and foremost aim of any future driver training programme is to improve drivers' knowledge and awareness, leading to favourable changes in behaviour, rather than necessarily identifying and imparting new and enhanced operational skills *per se* (although this clearly does not negate the absolute need for the latter).

The overall aims of the current programme of work are therefore to:

1. use the academic literature to identify how and why drivers' behaviour may change when interacting with a future level 3 vehicle;
2. gain an understanding from experienced drivers and driving instructors of their current views regarding the potential skills and knowledge that may be required for future automated vehicles; and
3. use the combined findings from (1) and (2) to inform the development of a proof-of-concept behavioural training intervention, which will then be evaluated and validated in a driving simulator study.

In this report, we present our investigation into these key aims. At the outset, we would highlight that this issue could potentially be addressed using both training and/or technological design solutions, and we would argue that the most effective solution would be a combination of both. However, the focus for the current investigation is on the role of driver training in combating the problems arising from familiarisation with new vehicle technologies. That said, it is also worth highlighting that the investigation does not purport to evaluate different training techniques and approaches *per se*, but rather the motivation behind the training – in this case, to encourage a change in behaviour rather than impart technical skills.

2. Literature Review

The development of automated vehicles will fundamentally change the role of the ‘driver’ (Sullivan et al., 2016). Progression towards higher levels of vehicle automation is in motion (Casner et al., 2016; Brown and Laurier, 2017; Kyriakidis et al., 2019). However, until system boundaries no longer exist, the driving task is one which is shared between humans and technology (Brown and Laurier, 2017), and the human driver is required to supervise and intervene when system limits are reached (Victor et al., 2018).

The SAE (2016) categorises vehicle automation into 6 levels of ascending capability. Levels are classified by the extent of system intervention in vehicle control and requirement for the human driver to monitor system performance and resume control of the driving task. SAE level 2 vehicles, available in the current market, provide functionality that automates lateral and longitudinal vehicle controls. However, the human driver remains responsible for monitoring the system and must be ready to take over the driving task when required. Many drivers do not accurately understand the capabilities and characteristics of these level 2 automated systems they are using, or the required level of control and engagement with the driving task (McDonald et al., 2018; Casner and Hutchins, 2019). Clarity and transparency of the role, responsibilities and skills required from the human driver is crucial for successful human-automation interaction. Dislocation of expectations of the key supervisory requirements of the human driver can have dire consequences for performance and safety (Casner and Hutchins, 2019), as already demonstrated with the first, fatal crash of the Tesla Model S vehicle in May 2016 (National Transportation Safety Board, 2017).

Table 2.1: Levels of Vehicle Automation

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

Source: Adapted from Society of Automated Engineers (SAE International, 2016), modified

At SAE level 3, automation capability extends to the monitoring task, allowing drivers to switch their attention towards NDRTs. However, the human driver remains responsible for the vehicle's actions and must be ready to intervene in the event of a system failure or boundary limitation (Large et al., 2019). The role of the driver will change depending on who has control of the driving task. Therefore, drivers will not only need to build up the requisite skill set to effectively interact with the automated system, but they will also require an additional set of skills to be able to smoothly transition between automated and manual driving modes (Gold et al., 2018).

A key challenge in system automation is the inverse relationship between automation and human performance (Banks and Stanton, 2016, 2019). For example, when decision making functions become automated, the driver naturally gives less attention to the driving task. This unintended consequence of automation (Parasuraman et al., 2000) takes the driver 'out of the loop' (OOTL) of control; reducing their level of perception and comprehension of the system state and driving environment and the projection of their future state, a construct termed 'situation awareness' (SA) (Endsley, 2017). Empirical studies investigating transitions from automated to manual control, e.g. (Dogan et al., 2017), have highlighted performance challenges associated with the re-engagement of drivers' cognitive and perceptual-motor controls necessary to effectively takeover the driving task, suggesting that when a system issues a takeover request (TOR), the driver may not be ready to drive. In order to realise the full potential of current and future automated vehicles, drivers therefore need to learn how to operate and interact with them in a safe and appropriate manner (Beggiato et al., 2015).

2.1 Justification for training – lessons from aviation

A common assumption, and often a key selling point, regarding the steady integration of automated systems, is that the more tasks that are delegated to automated control, the easier it will be for the human to operate the system and the less training they subsequently require (Cummings et al., 2019).

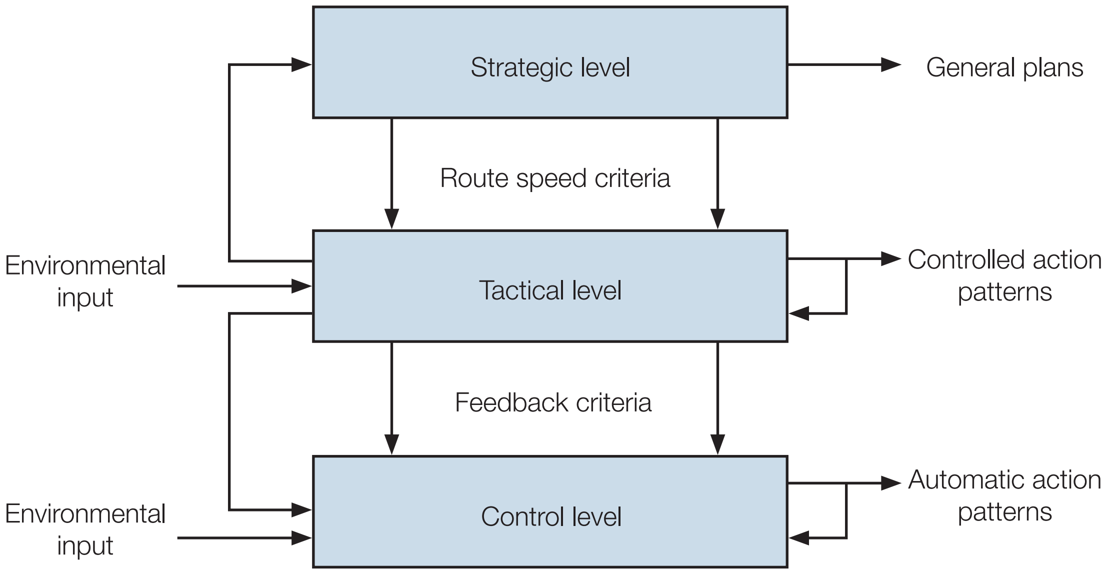
Within the aviation sector, a large body of human factors research (e.g. (Bainbridge, 1982; Sarter and Woods, 1994; Parasuraman and Riley, 1997) demonstrates how the introduction of automation fundamentally changed the flying task and role of the pilot. Research findings highlight the misunderstanding and confusion that automation created for pilots attempting to operate new, complex human-automation system, and the deleterious effects this had on pilot performance and error (Casner and Hutchins, 2019). These findings were subsequently incorporated into the design and delivery of rigorous training programs to provide pilots with a more complete understanding of the effects of automated systems. Even so, reports regarding the recent incidents and fatal crashes involving the Boeing 737 Max (Campbell, 2019) suggest that a contributory factor was a lack of pilot knowledge and understanding of the automated system that had been incorporated into the aircraft. It is alleged that pilots were given minimal provision of computer-based, self-administered training on the 737 Max, which did not include the additional automated system. Consequently, pilots were not equipped with an understanding of the rules or procedures to respond to the system when it failed. Although the pilots were able to use their considerable knowledge and experience to mitigate the impact of the first reported incident of a system fault, there followed two fatal crashes involving failure of the same automated system. This recent example suggests that, even in a sector where there is extensive research to the contrary, there remains a gap in appreciation for how new automation impacts human-automation interactions and shared control of the system, and highlights the importance of updating the mental model of the human agent.

It is noted that in the current driving context, no such training provision is provided for publicly available level 2 vehicles (other than the prerequisite user's operating manual). In light of this and a recent announcement by the USA National Highway Traffic Safety Administration that a special investigation will be launched regarding vehicles with assistance systems following further fatal automation-related incidents involving these vehicles (Shepardson, 2020) (for example, see National Transport Safety Board, 2020; 2019), there would appear to be a need to review the training needs for drivers of automated vehicles with a similar vigour as that provided within the aviation field.

2.2 The changing driving task

The driving task is understood to involve many individual sub-tasks (Banks et al, 2014). Michon's (1985) hierarchical model of the driving task categorises these sub-tasks into three behavioural levels: control (or operational), tactical (or manoeuvring) and strategic (Figure 2.1).

Figure 2.1: Michon's Driving skills hierarchy



Source: Adapted from Michon (1985)

At SAE level 2, automated systems are capable of intervening in control level tasks. Drivers of vehicles fitted with the latest Advanced Driving Assistance systems (ADAS), for example, can potentially enjoy increased comfort and safety as their cognitive resources are freed up through the delegation of menial, primary control actions to features such as active steering (AS) working alongside adaptive cruise control (ACC) (Kircher et al., 2014). As the sophistication of automation increases to level 3, system control capability will extend to tasks at the tactical level. In addition to level 2 capabilities that can control a vehicle's lane position, speed and a set timed headway to a lead vehicle, automated systems will be able to monitor the driving environment, enabling rule-based decisions that allow safe interactions with other vehicles based on the interpretation of the immediate situation (Kircher et al., 2014). However, any vehicle with less than full automation capability still requires the human driver to remain in the control-feedback loop, playing an active role in the driving task (Banks and Stanton, 2019). For example, at level 2, the human driver is required to continuously monitor the system and driving task and be prepared to take over at any point. At level 3, although the human driver has been taken out of the loop of control by design (Merat et al., 2019), the ODD is bounded. Therefore, the driver remains actively responsible for the vehicle and is, consequently, required to be able to take over from the automated system should it be required due to system operational limitations or failures.

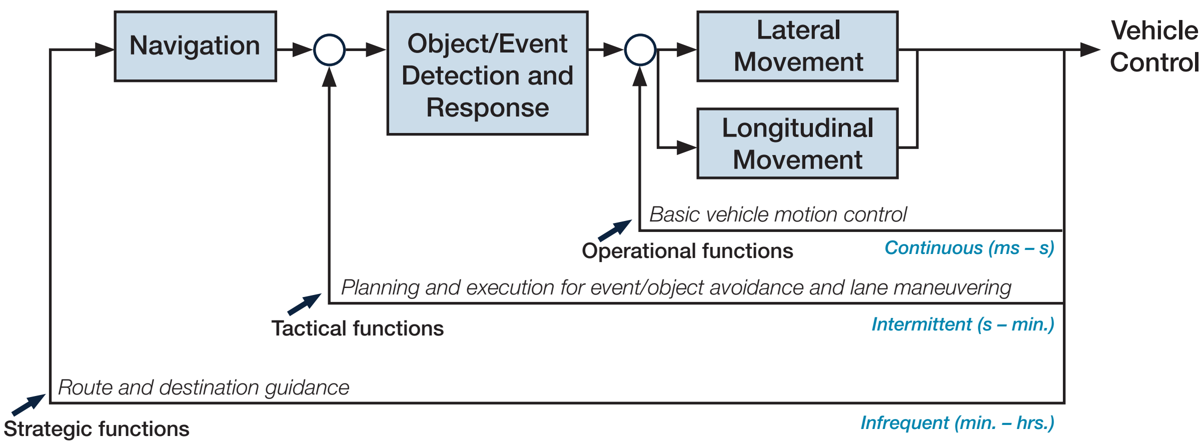
Using automation to control parts of the driving task fundamentally restructures the task as a whole, bringing with it changes to the role and responsibilities of the human driver (Banks et al., 2014; Kircher et al., 2014; Banks and Stanton, 2016). However, the new driver's role has not been formally and specifically outlined within the available automation taxonomies, leaving the skills, knowledge and potential training needs of the human driver in sharing the driving task with automated systems open to interpretation. The role of the driver within an automated vehicle and the challenges related to this changing role is considered to be analogous to that of a pilot in an automated aircraft (Stanton and Marsden, 1996; Casner and Hutchins, 2019). Consequently, the roles of pilot-flying, and pilot-monitoring, as applied in aviation (Casner and Hutchins, 2019), have been transposed to the driving domain at the intermediate stage of automation development, reflecting the changing, rather than diminishing, responsibility of the human driver as they share control of the driving task with automation (Banks and Stanton, 2016; Banks, et al., 2019).

The concept of 'shared control' is often used to reflect the cooperative requirements of the driving task in automated vehicles (Flemisch et al., 2012; Large et al., 2017; Banks et al., 2019). This highlights the critical role that both the automation and the human driver play in the successful completion of the driving task. It draws particular attention to the importance, complexity and challenges of shared situational awareness within a joint cognitive system that is continuously evolving. The shared control approach to the design of automated vehicles relies on the driver's understanding of system capabilities and limitations for effective human-machine cooperation (Large et al., 2017; Banks et al., 2019). Therefore, there is a requirement for both transparency and clarity of the shared driving role (Flemisch et al., 2012) and the identification of training needs and certification (Kyriakidis et al., 2019) that will enable a dynamic balance to be maintained between the control, ability, authority, and responsibility of the actors within the system (Flemisch et al., 2012). Until automation capability requires no human input (i.e. SAE level 5 cars, or SAE level 4 pod-type vehicles in geo-fenced ODDs), the human driver remains a critical agent within the driving task (Banks et al., 2019). It is therefore important to investigate not only how the role of the human driver changes with the introduction of differing levels of automation, but also the dynamic nature of the human driver's role and responsibilities during any one journey, so that necessary training or guidance can be provided through appropriate means (Banks and Stanton, 2016).

2.3 Visual attention and situation monitoring

Driving is primarily a visual task (Merat et al., 2019) and deficiencies in visual attention are widely reported to be responsible for a large proportion of road traffic accidents (e.g. Klauer et al., 2006). Driver inattention can be considered the mismatch between how the driver has allocated their attentional resources (and to what activities) and the resources demanded by activities critical to safe driving, inclusive of any sensory, perceptual, motor and cognitive mechanisms (Lee et al., 2009). For example, so called 'looked, but failed to see' accidents, are attributed to a mismatch between a driver's allocation of attention to a road scene, and their selective (in)attention to a particular feature, such as a cyclist, within their visual array – a phenomenon known as 'inattentional blindness' (Herslund and Jørgensen, 2003). A key task for drivers at all levels of the driving hierarchy is that of situation monitoring – continually processing perceptual information to generate an understanding and prediction of dynamic changes in the driving environment for use in physical vehicle control. It is this coupling of the physical control of the vehicle and the situational monitoring (situation awareness) that has recently been used to clearly define the control loops as mapped onto Michon's (1985) hierarchical model of the driving task, including the different spatiotemporal scales associated with control of subtasks at the operational, tactical and strategic levels (Figure 2.1). For example, continuous monitoring is required for vehicle operations, whereas monitoring relating to tasks at the tactical level varies in response to characteristics of the driving environment (Merat et al., 2019) (see Figure 2.2).

Figure 2.2: Multi-level control in driving, including situation monitoring at each level



Source: Merat et al. (2019)

The associated 'in', 'on' and 'out of the loop' definitions, alongside this model, are useful when thinking about the interrelationship between the driving task, the role of the driver and level of vehicle automation. This is particularly relevant when identifying the impact of increases in automation capability on drivers' perceptual-motor control loop and the resultant implications for informing safe and appropriate skills and behaviours for drivers of these vehicles, and required guidelines for system use. According to these definitions, 'in the loop' is in physical control of the vehicle and monitoring the vehicle, 'out of the loop' (OOTL) is defined as not in physical control of the vehicle and not monitoring the driving situation OR in physical control of the vehicle, but not monitoring the driving situation, and 'on the loop' is not in physical control of the vehicle, but monitoring the driving situation.

A key requirement for drivers of level 2 vehicles is to continually monitor the situation while the vehicle systems are in physical control of the vehicle. Consequently, this level of automation demands the driver remains 'on the loop' during automated periods of driving. However, as is well documented within the literature, a predominant consequence of level 2 automation lies in drivers entering an OOTL state due to challenges associated with this new driving task of passive monitoring. Mitigating strategies should therefore be geared towards supporting drivers in remaining 'on the loop' when using the automated systems. Additionally, vehicle designers need to ensure that drivers are given adequate and correct guidelines to gain accurate understanding of the functionality, capability and limitations of the automation, including the consequences of being OOTL, so that they know how to safely use the system (Carsten and Martens, 2019; Merat et al., 2019). In contrast, the changes in the driving task and driver role at level 3 automation induces OOTL driver state during automated driving, by design. Consequently, a key part of the driver role at this level is the smooth transition in and out of the loops of control in accordance with automated and non-automated driving modes. The reduction in SA and attention at this level of automation is not necessarily unsafe (Carsten and Martens, 2019), as long as the driver is able to calibrate their levels of SA and attention to accurate system reliability. Therefore, in order to ensure safe use of these systems, drivers need to understand what level of SA and attention they should have in relation to different modes of automation and how they need to interact with the system to adjust and tune their SA and attention in a timely manner during dynamic operations.

2.4 Information processing and cognition

Rasmussen's (Rasmussen, 1983) skills-, rules- and knowledge-based behaviour model (SRK), presents a hierarchical taxonomy, similar to Michon's (1985) model of the driving task (Sullivan et al., 2016), which links information processing and cognition to increasing levels of complexity (Cummings, 2014). At the foundational level, skill-based behaviours are sensory motor actions, such as those required for control level driving tasks. Once acquired and mastered with sufficient training, skills become highly automatic, freeing up attentional resources for higher cognitive tasks. At the intermediate level, rule-based behaviours are actions guided by 'if-then' rules, accumulated from previous training and experience and formed through associations between cues and the appropriate action selection (Wickens et al., 2014). Rules are stored either as mental structures, termed 'schemas', or as written procedures. The operator selects the rule by processing input against system state. For example, at the tactical level of the driving task, decisions to give way to or overtake another road user is based on the driver's interpretation of the situation using input monitoring and SA of the traffic environment and automated systems. Issues arise when the human operator does not recognise the correct goal and selects the incorrect procedure. When facing novel situations, operators do not have existing rules to guide action selection and need to work at the knowledge-based level of behaviour. Mental models are built as the operator gains knowledge and experience of the system, creating a set of expectations and conceptual information about the system that can be used to guide the selection and formulation of an action plan for an explicit goal (Cummings, 2014).

For experienced drivers, the actions required to control the moment-to-moment operations of a manual vehicle are predominantly skill-based behaviours – automatic (Kircher et al., 2014; Merat et al., 2019), well-practised, and performed without effort or conscious thought. However, in the context of the automated driving task, automatic performance of these behaviours, based on the mental model of manual driving, may no longer be appropriate. In other words, as with the pilots of Boeing's 737 Max, drivers of these vehicles need to understand the new 'if-then rules' introduced to the driving task through automation, and the perceptual-motor actions or 'skills' they need to apply in the context of automated driving.

Arguably, there is a need to understand how drivers apply skills learnt within the manual driving context to the performance of new tasks required in the automated driving context, such as transitions of control. Exploring how drivers interact with these future vehicles could help to reveal potential issues and inform requirements in relation to driver training or support from interface design to encourage the uptake or maintenance of desired driver behaviour for the automated driving task. Recent work summarising potential consequences of automation linked to OOTL state from the aviation and automation domain (Seppelt and Victor, 2016; Merat et al., 2019) include items such as: passive monitoring, failure to sample some safety critical areas, e.g. rear-view and side mirrors; high trust scores; low SA scores; and inaccurate mental models. As well as providing themes to address with training or interface countermeasures, these items also present options for quantitative and qualitative measures by which to judge driver performance relating to the induction of OOTL driver state during automated driving and the effectiveness of countermeasure strategies (Merat et al., 2019).

2.5 The changing needs of the human driver

Vehicle automation changes the knowledge and understanding the human driver needs in relation to the driving task and operational working of the vehicle (Casner and Hutchins, 2019). Previous technological developments provided general performance improvements to vehicle functions that were already available and managed by the human driver (Sullivan et al., 2016). For example, automatic cruise control (ACC) holds a vehicle's speed as selected by the human driver. This automatic function removes the need for constant driver input to the accelerator pedal, thereby providing the driver with improved control and comfort. However, these improvements do not significantly change the driving task or the role for the driver, who remains in control of operational tasks, such as acceleration and deceleration, as well as managing the vehicle's interaction with objects in the external environment, such as pedestrians and other vehicles, through steering, lane selection, etc. Moreover, any input from the driver to the pedals typically disables the cruise control function.

Automation capability provides the human driver with an array of tools to which they can delegate parts of the driving task. Features such as ADAS, blind spot detection and lane departure warnings play an active role in the overall driving task, controlling tasks at the operational level of driving and supplementing tasks at the tactical level (Casner and Hutchins, 2019). With previous vehicle developments, responsibility for the overall management and accountability of the driving task remained, unambiguously, with the driver. However, in the new human-machine context, the distribution of responsibility requires clarification and reiteration. Within their role, drivers command and control the use of automated features within the driving task. For this to be successful, they need to understand, and subsequently manage, how, when, and why they use them. This level of proactive thinking sets apart the cognitive requirements for drivers of automated vehicles and is facilitated by the appropriate knowledge and understanding of the automated driving task (Casner and Hutchins, 2019). Casner and Huchins (2019) propose that the knowledge required of drivers of automated vehicles is akin to that of pilots using cockpit automation. They refer to Degani and Weiner's (1994) 3Ps of flight deck operations, suggesting that, as with pilots, drivers require:

- *Automation Philosophies* – the need to understand their reasons for using automation;
- *Automation Policies* – the context dependency of when automation should be used; and
- *Standard Operating Procedures* – outline how automation should be used.

Together, these three concepts indicate that there is an additional depth of understanding required by the driver to enable the interaction with automated features and get maximum benefit from their design, above and beyond technical operation. However, there is still a requirement to translate this into the skills, rules and knowledge required by drivers.

2.6 Behavioural adaptations and procedural deviations

Parasuraman et al., (2000) state that automation does not replace human activity, but rather changes it, often in accidental and surprising ways. Research into behavioural adaptations of human drivers interacting with automated vehicles have highlighted a number of issues relating to aspects of performance and safety, similar to those seen when automation was introduced in the aviation domain (Bainbridge, 1982).

Naturalistic studies examining driver experience with level 2 automated vehicles have reproduced evidence of phenomena such as ‘automation bias’, a concept that described pilots’ reduction of risk perception, alongside over-reliance on automated warning systems, due to a lack of understanding regarding the capability and competence of the automated systems being used e.g. (Brown and Laurier, 2017; Endsley, 2017; Banks et al., 2018). Qualitative analysis of driver interaction with these cars has provided anecdotal evidence of increased engagement with non-driving related tasks (NDRTs), as well as reduced situation awareness, and vigilance, impacting upon the ability of the human driver to maintain shared control with the automated system. For example, video analysis of Tesla’s ‘Autopilot’ showed multiple drivers testing the limits of the system and driving for extended periods with no hands on the steering wheel, despite explicit knowledge that the assisted driving provided is not ‘hands-free’ (Banks et al., 2018). In one instance, this lowered risk perception was coupled with ‘mode confusion’, where a driver failed to notice they were driving hands-free in manual mode. Evidence of drivers’ reduced vigilance of the traffic environment and the state of the automated system was shown in drivers failing to notice and correct ‘Autopilot’ errors, such as a misrecognition of exit lane lines. In this example, the autopilot’s misinterpretation was visible to the driver on the dashboard, but the driver did not notice until the vehicle had taken the wrong exit. Interviews with Tesla drivers (Lin et al., 2018), revealed driver understanding of the system’s capability (their ‘mental model’) was often incorrect, resulting, for example, in over reliance on the system and encouraging them to engage with their NDRT rather than monitor the roadway. Although this reported patterned use of trial-and-error demonstrates learning by understanding the car through its behaviour, this has been shown to encourage drivers to deviate from the desired operating procedures of these systems and has important road safety consequences.

At SAE level 3, the extension of automation capability to the monitoring task allows drivers to engage with NDRTs until the operational design domain for the system is reached, or the system fails and the driver needs to re-engage with the driving task. This increase in automation capability changes the way the human-machine system interacts, further impacting the role of the human driver. For example, at level 3 automation, the perspective on driver engagement with NDRTs shifts from one of driver distraction, to task interruption and task switching (Janssen et al., 2019). Transitions of control of the driving task between the automation and driver during dynamic operations introduces an additional set of challenges in relation to driver behavioural adaptation, increasing the potential for procedural deviations that could lead to OOTL issues that negatively impact the safety and effectiveness of the transitions following system takeover requests (TORs).

Research into controlled transitions from automation to manual driving have looked to determine the optimal transition time for drivers to safely and comfortably take over from the driving task, and have proposed between 3-10 seconds, typically based on the mean or median response times observed (Melcher et al., 2015; Merat et al., 2014). More recently, Eriksson and Stanton (2017) highlight the need for adaptive automation – professing that TOR lead times will depend on context and, consequently, suggesting that transition times could extend to over 25 seconds in some situations. Even so, for reasons of experimental control and internal validity, research studies tend to use a pre-defined NDRT that users engage with throughout the period of automation. Although this provides standardisation from which to compare takeover performance across participants, this experimental rigour potentially omits important motivational factors that could have a significant bearing on driver behavioural adaptations. For example, when humans divide their attention between two competing tasks, intervening factors such as prioritisation and motivation will determine time-on-task. During periods of automation control, the human driver may subsequently prioritise their NDRT over interaction with the driving task, regardless of their fall-back responsibility, delaying re-engagement with situation monitoring required to get back in the loop of control.

Our longitudinal study conducted in collaboration with the RAC Foundation (Burnett et al., 2019), was designed to investigate the types of activities naturally undertaken by drivers during periods of automation in SAE level 3 vehicles. The study invited participants to undertake five simulated journeys over consecutive days. The journeys included transitions between manual and automated driving and an extended period in ‘automation mode’. Participants were given free choice about the activities they undertook during automation mode. As the choice of NDRT was unrestricted and uninfluenced, it was possible to investigate any mediating effects of personal motivation on task prioritisation and task switching, and analyse any resulting behavioural adaptations of human drivers, in particular, during the transition from automation to manual driving mode. Findings showed that drivers placed greater emphasis on learning how to effectively re-engage with situation monitoring and physical control at the operational level, whilst neglecting to engage with situation monitoring at the tactical level until after physical control of the vehicle had been transferred, despite explicit instruction to ‘prepare to drive’ as part of the system takeover request (TOR) and exposure to a failure scenario (poor visibility due to fog). Instead, as drivers gained experience and knowledge of the system, they gave priority to their NDRTs. This suggests that, at the point of manual mode engagement, drivers may not be ‘ready’ to carry out tactical level tasks safely and effectively and resume complete control of the driving task. It highlights a need to design training or system design strategies that not only increase driver knowledge of system capability and limitation, but also clearly defines essential operating procedures that guide required driver behaviours, thereby facilitating the safe and effective flow in- and out- of the loop of control and mitigate against procedural deviations that could lead to road traffic accidents or near misses relating to driver inattention.

Research concerning behavioural adaptations echoes previous findings within the aviation domain, where pilot operational deviations were attributed as the leading cause of aviation crashes (Degani and Wiener, 1997). They emphasise that operating procedures form an integral part of the activities required to ensure successful operations in complex human-machine systems. These procedures provide a way to standardise and specify the manner in which the required tasks should be carried out, giving clear instruction to the human operator to ensure tasks are carried out in an optimal, logical, safe and predictable way. A well designed operating procedure should optimise the sequencing of tasks and promote efficient scheduling by the human operator (Degani and Wiener, 1997). In the context of transitions of control at level 3 automation, this procedure should arguably include sequencing tasks associated with getting the human driver 'on-the-loop' of control at the tactical and strategic task levels, before the driver regains physical control of the vehicle. Alongside operating procedures that provide adequate and correct guidance to drivers on how they should be using the system, research findings on behavioural adaptations suggest there is also a need to inform drivers about the effects of automation on their own behaviour and the potential consequences of being OOTL to support safe interactions between the human driver and the automated systems (Carsten and Martens, 2019; Casner and Hutchins, 2019; Merat et al., 2019). The development of strategies focused on supporting the uptake of desired behaviours and mitigating undesirable behavioural deviations, associated with reduced SA and vigilance and increased NDRT use, should consider both user interface design and training interventions to investigate countermeasure solutions that are necessary, sufficient and versatile in order to meet the wide array of requirements from the multiple stakeholders within the automotive field. In particular, interface design solutions are arguably appealing given the costs and complexities involved in rolling out remedial training for experienced drivers. Given that it is not the skills necessarily, but the procedural rules involved with situation monitoring in the automation context, that are novel to this group of drivers, it is suggested that use of an operating procedure that can be built into the design of an HMI would provide a desirable solution.

2.7 Mental models, expectations and trust

Vehicle automation offers novel and complex technology. Research findings highlighting the ways humans interact with these automated vehicles demonstrate the importance of the type, level, and quality of training and knowledge imparted to drivers, who do not yet have an accurate mental model of system functionality and limitations (Beggiato and Krems, 2013; Beggiato et al., 2015; Casner and Hutchins, 2019). Mental models are formed during the learning process and create a set of expectations in relation to what the system contains, how it works and why it works that way (Beggiato and Krems, 2013). Research has shown that incorrect mental models lead drivers to make overly optimistic assumptions about automation capability, influencing how they interact with and manage the system. This, in turn, can lead to 'automation surprises', such as unexpected system responses or failures, which can impact trust and acceptance. For example, a study by Beggiato and Krems (2013) found that the provision of different descriptions of an adaptive cruise control (ACC) system influenced driver mental models and expectations of system functionality. Following simulated drives using ACC, the mental models of all groups converged towards realistic system functionality. However, trust and acceptance scores for the incomplete group showed a steady decline following driver experience of unexpected emergency scenarios. These results highlight the importance of clear and consistent learning strategies to the development of accurate mental models from the outset.

Trust is an important factor in influencing how safely and effectively drivers interact with complex automated vehicle systems (Parasuraman and Riley, 1997). The presence or absence of trust is not dichotomous, it is a dynamic phenomenon that increases or decreases based on the driver's perceptions of how the vehicle system operates and whether their beliefs attached to these perceptions give rise to positive or negative attitudes (Walker et al., 2016). Limited and inconsistent knowledge provided to human drivers about the underlying principles and mechanisms behind automated functions creates uncertainty and variability in the perceptions, expectations, beliefs, and, therefore, trust in the automated system. A lack of formalised training for automated vehicles means that drivers are provided with limited and incomplete knowledge of automated functions (Casner and Hutchins, 2019). The lack of clarity and consistency in drivers' understanding of underlying principles and mechanisms of automated systems creates uncertainty and variability in their mental models and resulting trust, which influences how the driver behaves with the automation (Beggiato and Krems, 2013; Walker et al., 2016). If a driver's trust exceeds the system's capabilities, they are likely to over-trust, and over-rely on the automated systems, something (Parasuraman and Riley, 1997) termed 'automation misuse'. Over-trust results in both risk perception and attention levels being reduced, making drivers susceptible to monitoring failures, slow reaction times and poor reaction quality to critical events (Körber et al., 2018).

Empirical evidence from level 3 driving simulator studies has strengthened the arguments for the provision of formalised training that fosters accurate mental models in drivers (Nylen et al., 2019). For example, Korber et al. (2018) demonstrated the influence of introductory information of system capabilities on trust and behavioural outcomes. Participants provided with 'trust-promoted' information, prior to completing critical and non-critical simulated takeovers, showed a higher number of collisions, deteriorated takeover performance and increased engagement with NDRTs in comparison with the trust-lowered group. These results show the safety implications of creating a sense of 'over-trust' with automated systems and the potential safety benefits of developing appropriately calibrated trust. The authors posit that early training interventions that emphasise how interactions with the dynamic driving environment influence the capability of the system to cope with a situation are required to mitigate the negative effects of automation failure. This idea supports the recommendations from Walker et al. (2016), which finds that to establish trust in vehicle automation that promotes acceptance and successful implementation of the technology, drivers need to be made explicitly aware of what the system is designed to achieve.

These findings highlight how training processes that impart clear and accurate information about the characteristics and capabilities of the automated system from the outset are essential to fully harness the potential safety benefits of this level of automation (Beggiato et al., 2015; Sullivan et al., 2016). However, current training methods for consumers of level 2 autonomous vehicles is often self-directive, passive and inconsistent. According to a recent survey (McDonald et al., 2018), consumer training tends to happen via either: user manuals, where learning effectiveness depends on the user reading, understanding and remembering operational procedures (Casner and Hutchins, 2019); or instructions from sales personnel at car dealerships (Abraham et al., 2017), which have been reported to vary widely in quality depending on personnel training and capability to explain technology to prospective buyers.

2.8 Summary of literature review

The literature identifies clear concerns associated with the introduction of vehicles with automated capabilities onto our public roads without first considering the needs and capabilities of the human driver. Empirical evidence shows that as decision making and control functions are increasingly automated, the driver naturally gives less attention to the driving task. Subsequently, there is an inverse relationship between automation and human performance. However, until vehicles are fully automated, and require no human intervention, the driving task is one that is shared between driver and vehicle. Therefore, to realise the full potential of these future vehicles, *drivers must learn how to operate and interact with automated vehicles in a safe and appropriate manner*. The key points that emerge from the literature (and guide our subsequent activities) are:

- The driving task is one in which the responsibility of the human driver is changing rather than diminishing as they are required to share control of the driving task with the automation.
- Drivers therefore require an additional depth of understanding to enable interaction with automated features and get maximum benefit from their design, above and beyond technical operation.
- Drivers often fail to fully understand the capability and competence of automated systems, and this can result in their over-reliance on the system, a reduction in their situation awareness and vigilance, and encourage engagement in non-driving related tasks and activities (NDRTs).
- At higher levels of automation, system capability allows drivers to switch their attention to NDRTs, inducing an out-of-the-loop (OOTL) state by design. Therefore, it is essential that drivers learn how to interact with these vehicles safely and effectively to be able to smoothly transition in and out of the loop of the driving task.
- Empirical evidence from level 3 driving simulator studies has strengthened the arguments for the provision of formalised training that fosters accurate mental models in drivers, yet no training provision is currently provided to drivers of current, publicly-available level 2 vehicles (other than the prerequisite user's operating manual). The lack of formalised training means that drivers may possess limited and incomplete knowledge of automated functions and inadequate or incorrect

understandings of how and when they should use the system. This can result in drivers relying on the technology in situations for which it was not intended, or potentially switching it off completely, thereby failing to realise any benefit.

- The rising number of automation-related incidents involving vehicles with level 2 functionality suggests that there is a need to review the training needs of drivers of automated vehicles with a similar vigour as that provided within the aviation field, particularly as the level of automation increases.

3. Exploratory Interviews

3.1 Introduction

It is evident from the literature that changes to the driving task precipitated by new, intermediate levels of vehicle automation will place complex, new demands on the human driver. Moreover, human drivers are expected to be ill-equipped to meet these new demands. In contrast, empirical studies show that many drivers are highly willing to engage in immersive, non-driving related tasks and activities (De Winter et al., 2014), even when the vehicle is operating at lower levels of automation – in spite of these new demands. This suggests that drivers were either unaware of their new role and responsibilities in future, automated vehicles, or actively choose to overlook them during these studies. To explore this further and direct our subsequent simulator study, we conducted a series of exploratory interviews with experienced drivers and expert driving instructors. Interview questions were devised to explore aspects of manual driving skills and expectations of future, automated vehicles. Specifically, these aimed to uncover the types of skills and behaviours that people believed would be required by drivers using vehicles at different levels of automation in different situations, for example, during automated driving, or to safely and efficiently resume manual control of a vehicle during a dynamic takeover. The interviews also aimed to uncover different methods and techniques that could potentially be used to impart these new skills or behaviours to drivers.

3.2 Method

Preliminary questions were piloted, and subsequently refined, with experts in the Human Factors Research Group at the University of Nottingham. For the main interview study, ten participants were recruited through personal contacts and recommendations. Participants comprised experienced drivers and ADI-qualified driving instructors. ADI instructors had, on average 14.75 years' experience as a driving instructor and 37.5 years' driving experience. All interviews were conducted face-to-face and were recorded and transcribed.

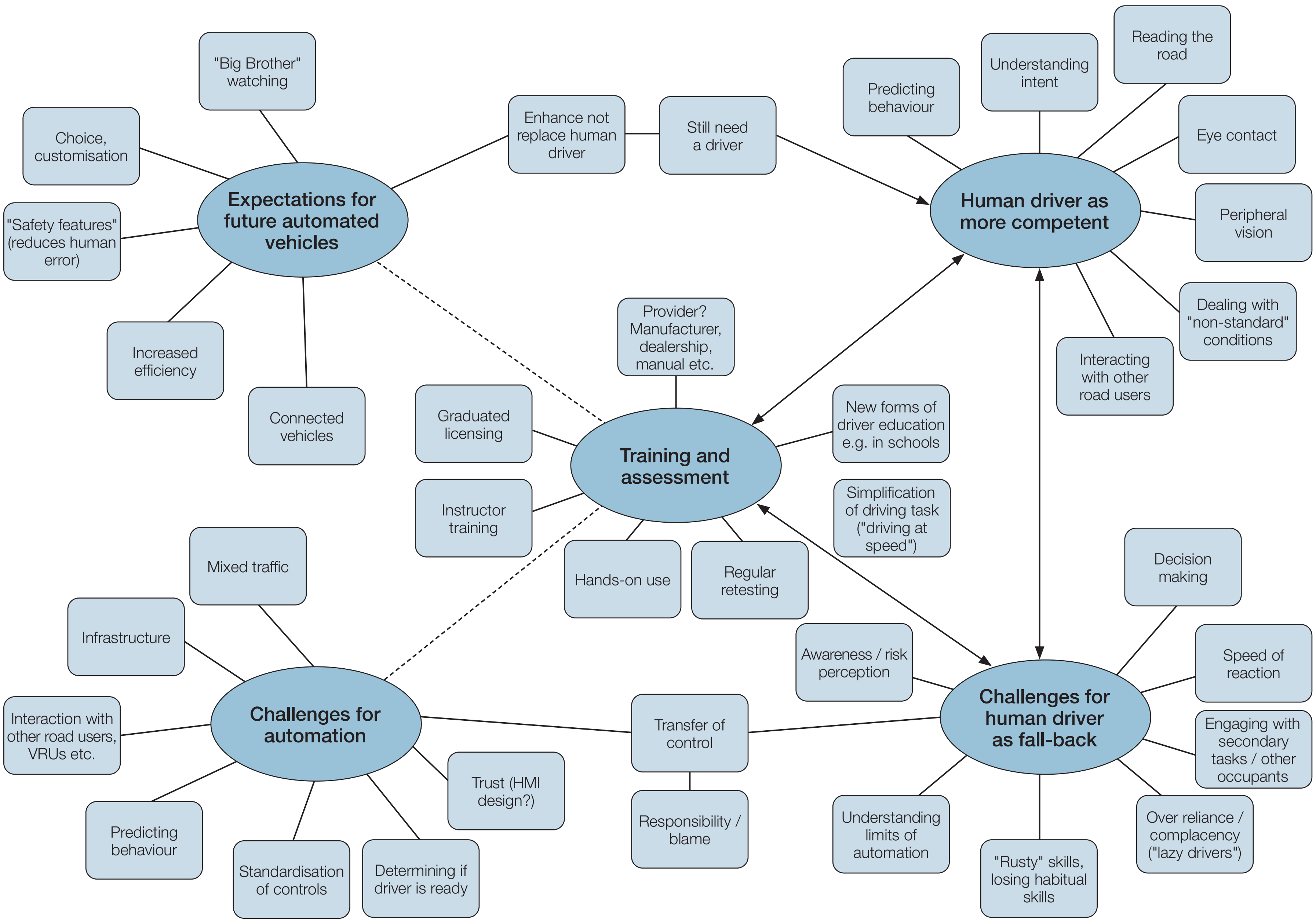
3.3 Interview format and questions

Questions were designed to prompt discussion, with the aim of allowing participants to speak freely about their opinions and experiences. Where appropriate, questions were selected or preceded with, "As a driver…", or, "As a driving instructor…", and probes were used to elicit more specific or in-depth information. The interviews were divided into three sections. After initially asking about their experiences with manual driving (section 1), participants were questioned regarding their knowledge and experiences of using current automated technologies (section 2). As part of this, participants were shown the SAE (2016) classification of levels of vehicle automation (see Table 2.1); this was initially presented to them without further commentary. In section 3, questions were focussed specifically on existing SAE level 3 vehicles, which were described as "mid-range automation", or "partial automation". Full details of the interview questions, with accompanying commentary and follow-up questions (in square parentheses), where appropriate, are in Appendix A.

3.4 Results: thematic analysis

Inductive thematic analysis was undertaken on the transcribed interviews (Braun and Clarke, 2006), by which areas of interest were uncovered, with themes inspired by the research aims. A mind-map showing the emerging themes in shown in Figure 3.1, and commentary regarding each of the themes (sections 3.4.1 to 3.4.4) is provided below.

Figure 3.1: Mind map showing emerging themes



Source: Authors' own

3.4.1 Expectations for future automated vehicles (AVs)

Overall, it was clear that drivers, and indeed, driving instructors, had limited knowledge of automated vehicles (AVs) and AV system functionality:

> *"The vehicles obviously are aware of the situation around them by scanning. How they actually do that and the way that they deal with that particular thing obviously I've got very limited knowledge of."*

This is suspected to be due to the lack of hands on experience of using such systems, but will obviously impact how these people view the technology and their understanding of the skills and knowledge required to operate an AV. Nevertheless, there was a general view that people will become reliant on the technology, *"to tell us what to do."*

For the majority, automation was seen as positive, particularly in terms of safety (*"accidents are caused by human error"*) and efficiency (*"journey times are reduced because we will be doing exactly the same speeds, rather than varying"*). But the technology was generally considered as a separate feature, or an 'add on' to an existing vehicle, rather than AVs being fundamentally different to the manually driven vehicles that are available now. Automated functionality was therefore seen as something that would either support the driver by enhancing their performance or help to overcome their limitations – similar to current technologies operating in isolation, such as anti-lock braking. Moreover, it was suggested that automated features and technology should be optional, and that this would allow drivers to decide whether and when to use it. For example, there was a belief that more experienced drivers may not necessarily need or want to use additional, automated safety features. As such, it was assumed that the driver would still be in control and therefore expected to remain active and attentive. Concerns were subsequently expressed regarding the potential for drivers to become complacent or lazy and over-rely on the technology. Although no specific new (operational) skills were identified, it was felt that higher level 'habitual' skills (relating to situation awareness and tactical elements of the driving task) could be at risk of being lost.

3.4.2 Human driver as more competent

A common theme throughout the interviews was the expectation that there would be many situations in which the human driver would continue to be more capable than an automated vehicle. This included non-standard driving conditions, such as inclement weather and night-time driving.

Human drivers were also seen to be superior in terms of understanding and predicting the behaviour or intent of other road users, interacting with other road users, reading the road, using peripheral vision to gain additional information, and making and interpreting eye contact. Examples of some such comments include:

> *"Your ability to … anticipate what the driver in front is going to do is greater … than the machine might be able to."*

> *"It is all about reading the road ahead in preparation to be able to interpret change in circumstances of what's around you."*

> *"It's about making eye contact and interaction with the driver."*

It was also recognised that things would not change overnight, and therefore there would be a period of mixed traffic on the roads:

> *"Just look at some of vehicles that are on the road now, we've still got vehicles on the road from the 70s, we've still got vehicles on the road from the 50s, we've still got vehicles on the road from prior to that, so we're gonna have to have that ability to interact with them."*

Consequently, it was suggested that, *"Until more than 80% of the actual vehicles on the road are going to be these kind of vehicles we cannot take the human out of the equation."*

3.4.3 Challenges for human driver as fall-back (inc. challenges for automation)

Concerns were expressed regarding the expectation that the human driver would remain vigilant and aware of the driving situation whilst the vehicle was notionally in control. It was suggested that extended use of AVs could lead to over-reliance and complacency (*"lazy drivers"*), taking drivers out of the loop of control (*"I'm worried that the driver will become, erm, less careful, they're not going to be as conscious about what's happening"*), and that this might encourage drivers to engage with other activities (NDRTs). Nevertheless, instructors, in particular, were generally in agreement that no NDRTs would be acceptable in situations of partial-automation (*"not even for short spells"*); examples provided to prompt discussion were using a mobile phone, reading a book, watching a film and sleeping. It was accepted that during periods of automation drivers could *"interact a little bit more with the people inside the vehicle"*, but also that any AV should have the capacity to monitor the driver to ensure that their hands were on the steering wheel and they remained attentive. No specific concerns were expressed regarding drivers potentially becoming bored during periods of automation if no NDRTs were allowed, as they would still *"need to be aware …of the circumstances around [them]"*, and *"concentrate or …pay the correct level of responsibility"*, and this would adequately consume their time and attention.

Despite identifying no new skills, *per se*, instructors recognised that operational skills may become "rusty". However, they did not expect these to be lost, with one drawing an appropriate analogy: *"If you break your leg you don't forget how to walk… your brain knows how to do it, but your co-ordination has gone, your timing has gone"*. In addition, the need for drivers to re-familiarise themselves with the driving situation during a dynamic takeover request was recognised as a potential challenge, both in terms of drivers (re)gaining awareness and perceiving risk, and in that their decision-making and speed of reaction may be degraded after being out of the active control loop for an extended period of time.

In terms of complacency, some instructors made the distinction between new and more experienced drivers, highlighting that drivers with greater experience might be expected to have had experience of driving in a wider variety of contexts (e.g. bad weather, night-time and so on), thereby reducing their potential for complacency. The argument promoted in this regard was that experienced drivers would be aware of the potential challenges presented in inclement conditions, adjust their driving style accordingly, and not rely upon the automation to do so.

3.4.4 Training and assessment

Given the underlying assumption that automation supports the driver and augments the driving task, most interviewees felt that nothing should be required over and above the current, basic driver training to drive cars of increasing levels of automation. The assumption in this regard was that *"if you can drive a full car, you can drive 'half a car"*. It is also interesting to note that here the automated vehicle was referred to as "half a car". Nevertheless, interviewees were in agreement that manual driving skills would remain a pre-requisite for owning and driving an automated vehicle. For instance, as one interviewee put it: *"If there's any chance that they have to be responsible for that vehicle at any time, they need a full licence as though they're driving a fully manual car"*. Another stated that drivers would, *"still [be a] part of the active process of driving a vehicle."*

In terms of learning specific systems or functionality, it was felt that this was solely an operational issue (i.e. learning how to operate that specific function or control), and therefore it was the responsibility of the vehicle manufacturer or dealership to demonstrate these features. One concern which was expressed, however, was with regards to the standardisation of controls, that is the method *"to activate and deactivate and to take over control in an emergency"*. In terms of the dynamic transfer of control, this was not necessarily seen as a problem, although the expectation was that in situations in which the driver would be required to takeover, driver controls should be set appropriately: *"Everything should be set so you just put your hands on… so if you're going round a corner, the wheels should be set at the right [angle]…"*

Even so, there were concerns expressed regarding the current decline of manual driving skills, and a perception that the current driving test was, *"not up to standard"*, and puts, *"too much emphasis… on driving at speed and not enough on the basics of driving"*. More specifically, the concern expressed was that the focus of the current driving test (and therefore, the focus of preparatory lessons) is on optimising the efficiency of the overall journey (*"getting from point A to point B as quickly as possible"*) rather than on the specific skills required to accurately perceive hazards and safely manoeuvre the vehicle.

There were mixed opinions regarding licensing and automated vehicles, with some suggesting that drivers could be licensed based on the level of automation for which they are trained, indicating a graduated licensing scheme, or be required to undertake a probationary period before moving onto the next level. However, most concurred that in any situation where a driver *could* drive (i.e. if primary controls – steering wheel, foot pedals, etc., were still present in the vehicles), they must be fully-trained in manual driving.

Another key point raised was that of responsibility and who to blame if something went wrong – *"at what stage do we say that the responsibility is the car or is it still the human driver? And that's, I think where it'll start to get blurred."*

3.5 Summary of exploratory interviews

The interviews show that, in line with the literature (McDonald et al., 2018; Casner and Hutchins, 2019), experienced drivers, and indeed, expert driving instructors, did not accurately understand the potential capabilities and characteristics of future, automated systems or the required level of control and co-operation within the driving task, as a driver. While this is perhaps not totally unexpected, given the current absence of hands-on experience, and the fact that these new, shared roles and responsibilities are yet to be comprehensively defined, it does highlight the scale of the challenge. This is not least because driving instructors in particular play a vital role in setting the social, moral and cultural contextual boundaries for acceptable behaviour and risk acceptance when driving a car. Subsequently, driving instructors are already potentially playing an influential role in how new drivers view the driving task in relation to future AVs and AV technologies.

It also means that it is difficult to identify or articulate specific operational skills or behaviours that would be required in future driving scenarios from the interviews alone. While there remains a specific need for improved clarity and transparency of the role, responsibilities and skills required by the human driver, findings from the interviews, supported by the literature, point towards the immediate benefit of enhanced knowledge and behavioural training. It is recognised that such training should relate to attention, perception, prediction and interaction, and must be grounded in the cognitive capabilities and biases of the human driver, already discussed in the literature review.

4. Driver Training

4.1 Introduction

There is a clear disconnect between our understanding of the impact of automation on human behaviour and performance, as seen in the literature, and the expectations of future vehicle technologies held by potential users, as revealed through the exploratory interviews. Taken together, findings suggest that the specific new skills associated with different automated driving use-cases may be unclear, difficult to imagine, and yet to be defined. There is nonetheless a need to fundamentally change drivers' knowledge and behaviour to ensure they act appropriately at all stages and levels of vehicle automation. Indeed, it is feasible that some of the key operational skills associated with automated driving may not necessarily be particularly new or novel – and may already feature in an experienced drivers' 'toolbox'. Instead, it is their application and maintenance in the automated driving context that is problematic. As such, a prudent first step would appear to be changing drivers' overall behaviour, rather than identifying and imparting a specific skill, *per se*. However, this clearly does not negate the need to subsequently identify and impart new and enhanced operational skills as our understanding of the role of the human driver, and their capability, within different levels of automation becomes better understood.

Based on an extensive review of the literature and, in particular, the problems associated with SAE level 3 automation, our research focussed on establishing a proof-of-concept relating to a behavioural change training intervention. The behavioural training design was based on the following recommendations, as established from current findings within the literature. Driver behavioural training was primarily focused on:

- Forming adequate and correct mental models of automation, including the *automation policies, principles and procedures* associated with the related level of automation;
- Raising awareness and understanding of the *impact of vehicle automation on driver behaviour* and the *consequences* associated with being out-of-the-loop (OOTL) of control at each level of the driving task; and
- Establishing a *standardised operating procedure* to specify and communicate a clear sequence of tasks required by human drivers to safely and effectively transition in and out of the loop of control during automated and non-automated driving.

The aim of this research, therefore, was to assess the effectiveness of this proof-of-concept behavioural training in comparison to user manual training – the current, typical training solution used for new, commercially-available vehicle technologies. Effectiveness was defined in terms of the driving control loop – that is to say, both the physical control and situation monitoring were considered in terms of driver performance. By including 'driver monitoring performance' in our analysis, the aim is to identify instances of driver 'on' versus 'out' of the loop states to use as a tool to investigate driver behaviour during automated driving, as well as at, and shortly after, the point of transition (Merat et al., 2019).

A secondary aim of seeking to establish 'proof-of-concept' for the behavioural training was to identify areas for consideration in future designs of in-vehicle technological solutions. Therefore, best practice interface design principles were also considered in the training approach and analysis of the study results. Benefits for human machine interface (HMI) design are included within the Discussion section of this report.

4.2 Behavioural change training

4.2.1 Learning approach

Literature in the field of training design advocates that trainees should be active agents in their own learning (Bell and Kozlowski, 2008). Active learning is an effective approach in targeting higher order cognitive abilities. Driver education research has highlighted the importance of addressing areas, such as driver motivation and goals, as well as developing lower level skill-based behaviours (Hatakka et al., 2002; Fylan, 2017). The ability of a learner to recognise how well they are performing and to judge when they are likely to be accurate or when they are likely to make a mistake (known as metacognition (Bell and Kozlowski, 2008), alongside the constructive framing of errors and their consequences, are critical to achieving active learning (Krampell et al., 2020). We therefore looked to behavioural change theories (Fylan, 2017) to target driver motivation to perform desired behaviours, using the following four principles:

- **Shaping Knowledge**: Providing the driver with a better understanding of what causes them to behave in a certain way, and the knowledge of how to perform the target behaviour.
- **Natural Consequences**: Highlighting the consequences of undesirable behaviours, including the social, environmental and emotional consequences, and making these consequences seem more real, for example, by making learners realise that they would regret failing to change their target behaviour.
- **Comparison of Outcomes**: Considering the outcomes of performing desired behaviours, or not, and understanding why the target behaviour is a good thing to do.
- **Antecedents**: Understanding the triggers for the undesirable behaviours, taking practical steps to avoid those triggers, and changing the physical and social environment to make it less likely that drivers will perform these behaviours and more likely they will carry out the desired behaviour.

Applying these principles in the context of level 3 vehicle automation, we devised a behavioural training intervention. The training was designed to be self-administered, with visual lesson content delivered via a PowerPoint presentation and including voiceover instructional/expert commentary. For authenticity, and to reduce any bias associated with the same experimenter narrating the presentation and conducting the study itself, the presentation was narrated by a professional actor. The overall aims of the behavioural training were to:

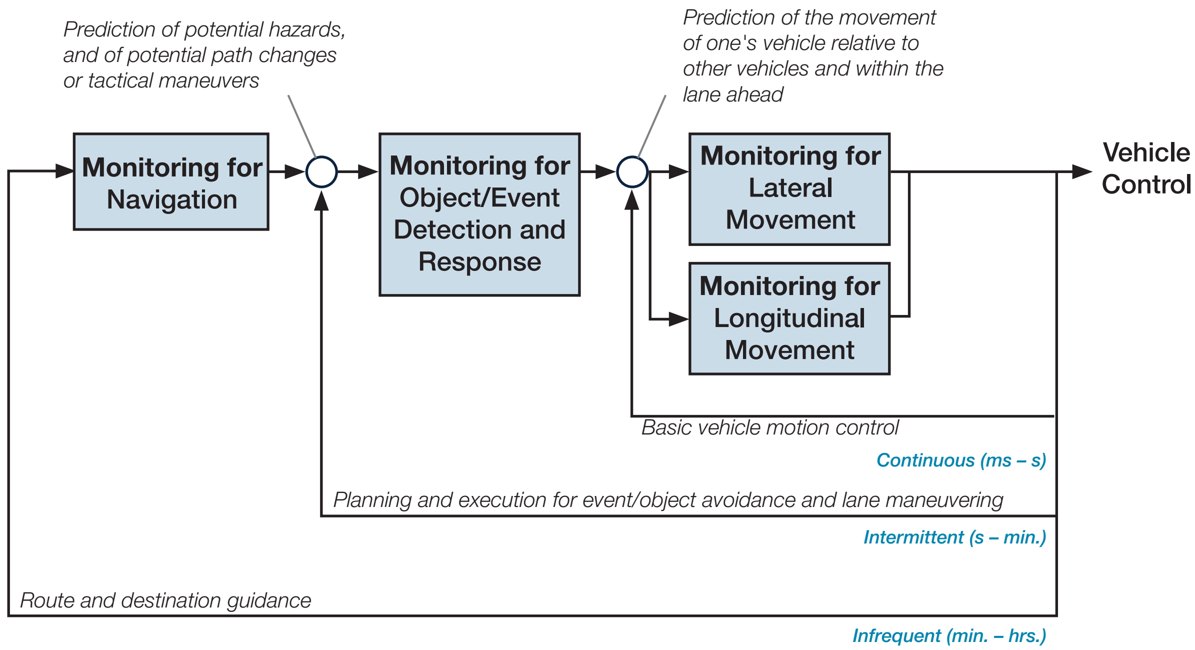
1. improve drivers' understanding of vehicle automation;
2. outline drivers' roles and responsibilities within level 3 automation; and
3. provide best practice guidance for driving, and interacting with a level 3 automated vehicle, including communication of a specific operating procedure.

The behavioural training intervention therefore aligns with Degani and Weiner's (1994) 3Ps of flight deck operations in the aviation domain (i.e. Philosophy, Policy and Procedures), and Casner and Hutchins' (2019) adaptation of them for use in vehicle automation. The aim was to meet the following learning objectives through the intervention:

- Drivers will have a better understanding of Vehicle Automation, including the SAE Levels of Automation and '**Automation Philosophy**': the reasons for/benefits of automation, in particular how vehicle automation 'augments' the driver's role rather than removes it.
- Drivers will have a better understanding of the capabilities and limitations of a level 3 vehicle, understand the concept of 'shared control' and a clear mental model of their role and responsibility as a driver. This will include a focus on an '**Automation Policy**': an understanding of when it is and is not appropriate to use automation.
- Drivers will have a better understanding some of the consequences of vehicle automation on driver behaviour. Drivers will have knowledge and understanding of '**Automation Procedures**': the desired way to engage with a level 3 vehicle. This will focus on the use of non-driving related tasks during automation and awareness of key tactical level controls e.g. monitoring, attention, situation awareness etc., required when interacting with a level 3 automated vehicle.

The behavioural training also focussed on the control, tactical and strategic subtasks of the driving task, with an emphasis on the spatiotemporal elements associated with situation monitoring for each of these levels. The aim of this was to represent the goals of situation monitoring at each level of the driving task in terms of task importance and urgency in relation to the different system states; their role in prediction and decision-making at each level and the potential consequences of neglecting situation monitoring during automated driving (see Figure 4.1).

Figure 4.1: Monitoring inherent to multi-level control in driving



Source: Merat et al. (2019).

- **Control monitoring goals ('Continuous')**: These goals involve controlling basic vehicle operations and managing the vehicle in relation to other vehicles on the road within the lane ahead. This monitoring of lateral and longitudinal control is delegated to the automated systems during automated driving but is required to be resumed by the human driver during and following a transition to manual driving mode.
- **Tactical monitoring goals ('Intermittent')**: These goals involve managing the vehicle in relation to planning and executing events along the journey, including object avoidance. This monitoring should be carried out intermittently by the human driver during automated driving, as good practice, to support the prediction of system limitations and controlled (or emergency) takeovers. Following a takeover request (TOR) and during the transition phase, this monitoring should be conducted with greater frequency and urgency to support the initial takeover and facilitate proactive driver decision making in relation to the planning and execution of the next event/manoeuvre. For example, to plan for a junction exit from a motorway the driver needs to be aware of the vehicles surrounding them on the road, including in their blind spot, ***before*** taking physical control of the vehicle, so

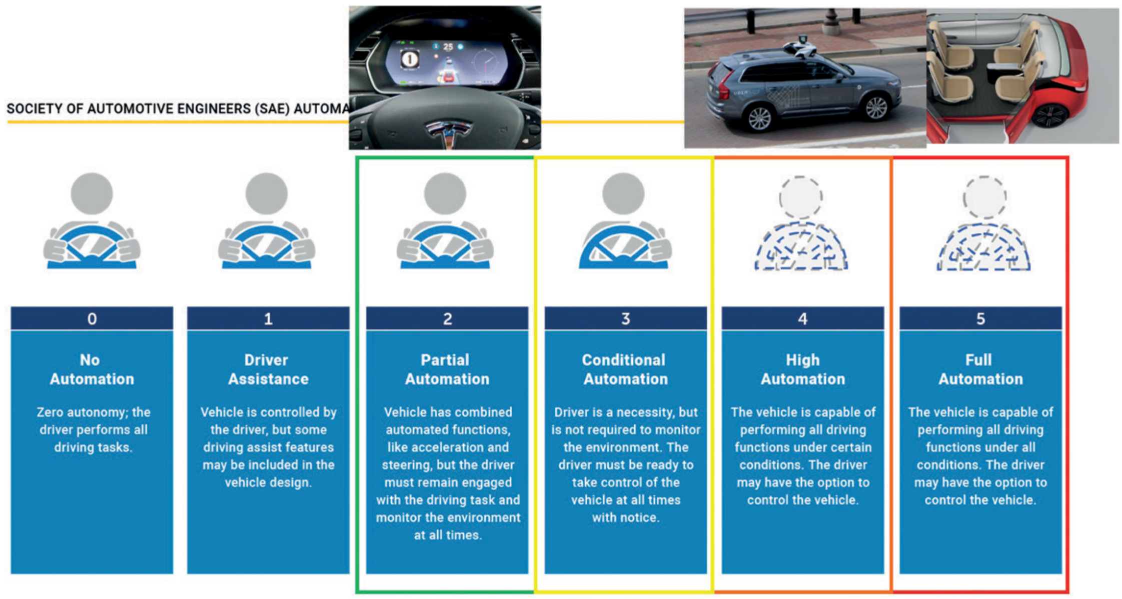
that they can effectively navigate any path changes or manoeuvres. For instance, to avoid surrounding objects and potential hazards in time to safely take their exit.

- **Strategic goals ('Infrequent')**: These goals refer to managing the driving task in relation to the desired destination. It requires infrequent monitoring and attendance to salient and relevant cues in the driving environment associated with navigation. This monitoring should be maintained by the driver through the whole journey, regardless of driving mode, to ensure, for example, that spatial awareness is maintained and that the chartered route is the best, fastest and most appropriate to meet the driver's needs.

4.3 Mental model formation

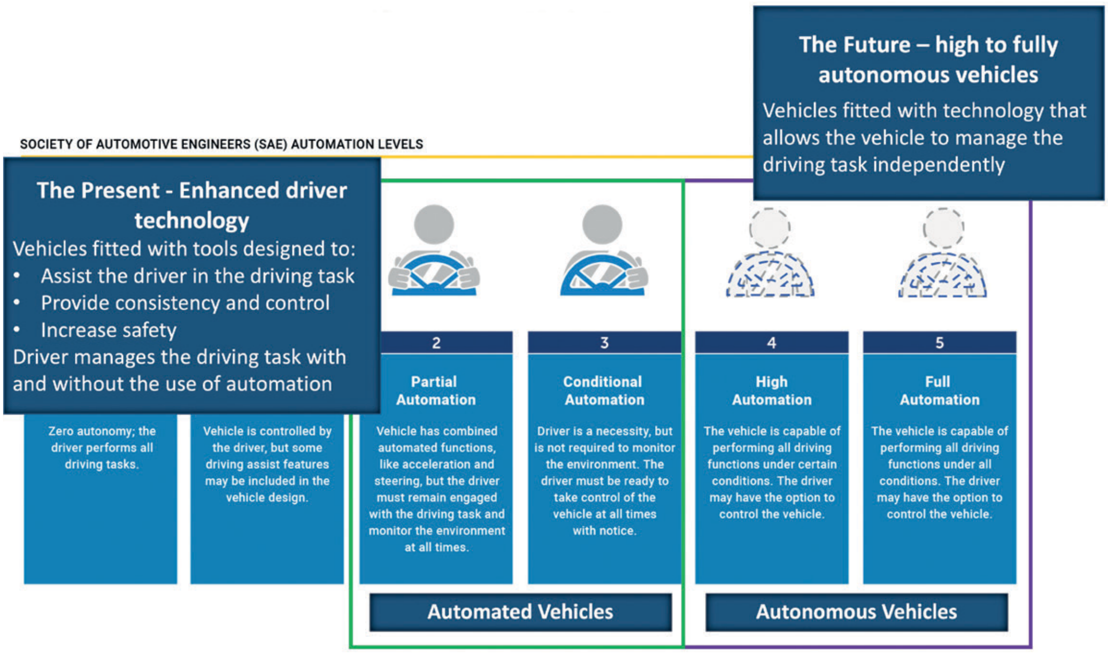
To support the development of an accurate and complete mental model, trainees were given an overview of the SAE Levels of Automation, detailing their roles and responsibilities as the driver at each level (Figure 4.2). In addition, they were provided with a precise explanation of the terms 'Automated' and 'Autonomous' vehicles (Figure 4.3), in the context of commercially-available vehicles and likely future development. Drivers were subsequently given more detailed information relating to SAE level 3 vehicles and their limitations and capabilities (Figure 4.4), and were reminded of the aspects that were controlled by the vehicle during automated driving and those of which the driver needed to retain an awareness.

Figure 4.2: Screenshot captured from training animation delivered in PowerPoint, showing the SAE Levels of Vehicle Automation and the roles and responsibilities of the human driver at each level



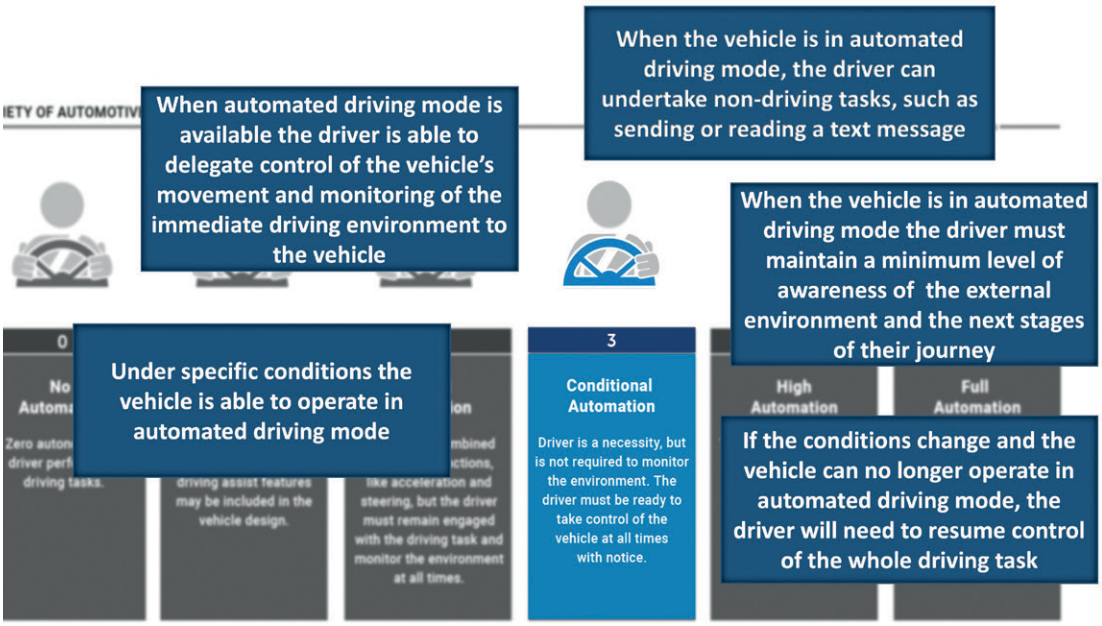
Source: Adapted from Society of Automated Engineers (SAE) International (2016)
Note: dynamic elements and effects (highlights, images, text boxes etc.) were added sequentially as participant moved through presentation.

Figure 4.3: Screenshot captured from training animation delivered in PowerPoint, explaining the definitions of ‘Automated’ and ‘Autonomous’ vehicles



Source Adapted from Society of Automated Engineers (SAE) International (2016)
Note: dynamic elements and effects (highlights, images, text boxes etc.) were added sequentially as participant moved through presentation.

Figure 4.4: Screenshot captured from training animation delivered in PowerPoint explaining SAE Level 3 Automation



Source: Adapted from Society of Automated Engineers (SAE) International (2016)
Note: dynamic elements and effects (highlights, images, text boxes etc.) were added sequentially as participant moved through presentation.

Specifically, drivers were told that they were responsible for the actions of the vehicle during all parts of the journey, but that when they engaged automated driving mode, the vehicle was capable of managing the control level monitoring goals of the driving task, thereby increasing the comfort of the driver. However, drivers were reminded that a level 3 automated vehicle is only able to operate in automated driving mode under certain conditions. These conditions would vary based on the capability of the specific make and model of the vehicle, but could include the following limitations:

- type of road e.g. use of dual carriage way/motorway;
- weather condition; and
- amount of daylight.

Drivers were told that if the vehicle approached a limitation where automated driving mode could no longer perform, it would issue a TOR to the driver, requiring them to take manual control of the vehicle (Figure 4.5). Moreover, they were instructed that although automated driving mode allows the driver to undertake activities that are not related to driving, such as using a mobile phone, it is imperative that they, the driver, maintain an awareness of the tactical and strategic goals for the vehicle so as to:

1. predict when the vehicle might issue a TOR;
2. maintain an awareness of where the vehicle is on the journey and what next steps are required should a TOR be issued; and
3. allow the driver to focus on the short-terms goals when managing the takeover.

Figure 4.5: Screenshot discussing automated driving in relation to Operational Design Domain (ODD) limitations, the role and responsibility of drivers and situation monitoring of tactical and strategic tasks to promote on-the-loop engagement

Source: Authors' own

As the literature has shown, mental models allow people to derive appropriate behaviour for interactions with objects, events and situations, through the provision of explanatory knowledge on the way things work (Norman, 1988). Mental models make learning easier, but if designers or training providers do not offer appropriate mental models, people are likely to create their own, inappropriate ones (Norman, 1988). In the current context, these could lead to the misuse or incorrect use of driving automation (Beggiato and Krems, 2013; Casner and Hutchins, 2019; Merat et al., 2019). Therefore, the first half of the training was designed to encourage the development of accurate, and complete, mental models of vehicle automation and the functionality, limitations and capability of level 3 automated vehicles. This was achieved through the use of appropriate wording, explaining why particular actions are required, as well as what the actions are (Wickens et al., 2014).

Although explanatory knowledge provides meaning and structure that is fundamental to human performance, retrieval of this knowledge from long-term memory stores involve mental resources that are not ideal for tasks necessitating rapid or smooth action (Norman, 1988). Therefore, whilst the development of a good mental model is necessary for the driver to learn appropriate interaction with the vehicle, it is unlikely to be sufficient for supporting the actions required by drivers to calibrate their situation awareness (SA) and attention in a timely manner (Carsten and Martens, 2019). Rote learning of operating procedures and check lists have been successfully used in aviation as a necessary and efficient way to facilitate the fast recall of information by pilots in emergency scenarios (Norman, 1988; Degani and Wiener, 1997). Yet, reliance on arbitrary-knowledge alone makes learning difficult and does not enable the human to apply action in meaningful ways that allow for subtle adjustments to nuanced scenarios, as it does not teach the reasons for the action (Norman, 1988). As such, our behavioural training was designed with the aim of combining the utility and efficiency of a clear, concise operating procedure that could be used to rapidly recall the sequence of actions in a timely manner. This was presented to participants through a meaningful and sensible structure, to simplify and organise the information, supporting them in digesting and understanding the facts, which can aid the memory task. It is anticipated that the procedure could be automatised over time, akin to the 'mirror, signal, manoeuvre' procedure traditionally instilled as part of manual driver training.

The use of HMI design as a way to support desired driver behaviour (as a counter-measure to some of the issues discussed above), and reinforce operating procedures (Carsten and Martens, 2019) form important longer-terms goals for future directions of this research (following on from the proof-of-concept phase). Therefore, our design approach to the operating procedure also took ecological interface design principles (Rasmussen and Vicente, 1989) into consideration and aimed to promote a reflexive response demanded by the dynamic context of driving using rule-based behaviour to structure the application of skill-based behaviour – principally: if- my vehicle issues a TOR, then- I need to follow the 'CHAT' operating procedure (see below).

4.3.1 The ‘CHAT’ operating procedure

The second part of the behavioural training introduced the ‘CHAT’ procedure, a standardised operating procedure designed to motivate and support drivers in remembering and applying explanatory knowledge acquired about level 3 automated vehicles. The aim was to provide drivers with a simple and efficient way of remembering a specific sequence of actions that they must take following a TOR from the system, thereby encouraging the transition to an ‘on the loop state’ before physically resuming manual control of the vehicle.

Semantically, the acronym CHAT aims to represent the verbal or non-verbal communication necessary for effective collaboration on a shared task. This can be likened to the scenario of a manager directing employees through a critical incident; in order to take effective and appropriate action, he/she would first need to communicate with employees on front line operations to acquire all of the relevant information. The letters represent the actions: CHeck (CH-), Assess (-A-) and Takeover (-T). This aims to guide the driver in making the appropriate checks and assessment of their internal and external environments prior to taking over operational control of the vehicle (see Appendix B for a transcript of the script used to describe CHAT during the training). For example, during automated driving, drivers may have adjusted the driver cab, which need to be reset. Additionally, drivers need to check the external environment surrounding the vehicle, including their blind spot and via their mirrors. They will need to assess their position and speed, as well as predicting the movement of other road users in relation to any manoeuvre needed following the takeover. In effect, this procedure is designed to promote an ‘on the loop’ state in the driver during the transition period, allowing the driver to increase their situation monitoring and improve their SA prior to physically taking control of the vehicle. The expectation is that this will ameliorate the transition for drivers from OOTL to in the loop, which will, in turn, support reasoned decision making for tactical or strategic tasks following takeover.

‘CHAT’ is designed in view of several guiding principles (see Wickens et al., 2014) to aid learning, memory and understanding in relation to the application of operating procedure it represents:

- **Standardisation** – the use of CHAT provides a way to standardise this operating procedure across the field of automation (akin to ‘mirror, signal, manoeuvre’ in current driver training).
- **Use of a memory aid** – the use of an acronym constrains the representative action words to the digraph and phonetic sounds: ‘CH’, ‘A’, and ‘T’ to provide recognition opportunity from ‘bottom up’ information (e.g. from an HMI) to aid ‘top down’ recall of information from memory.
- **Use of memorable characteristics**: the semantic association with a request for communication (from the system partner), use of a concrete (rather than abstract) word and no technical jargon; and representation of an organised set of information e.g. the order of the letter sounds represents the required sequence of the operating procedure, the timing of the ‘CHAT’ instruction can also be scheduled via a HMI to promote timely scheduling of the procedure with the driver.

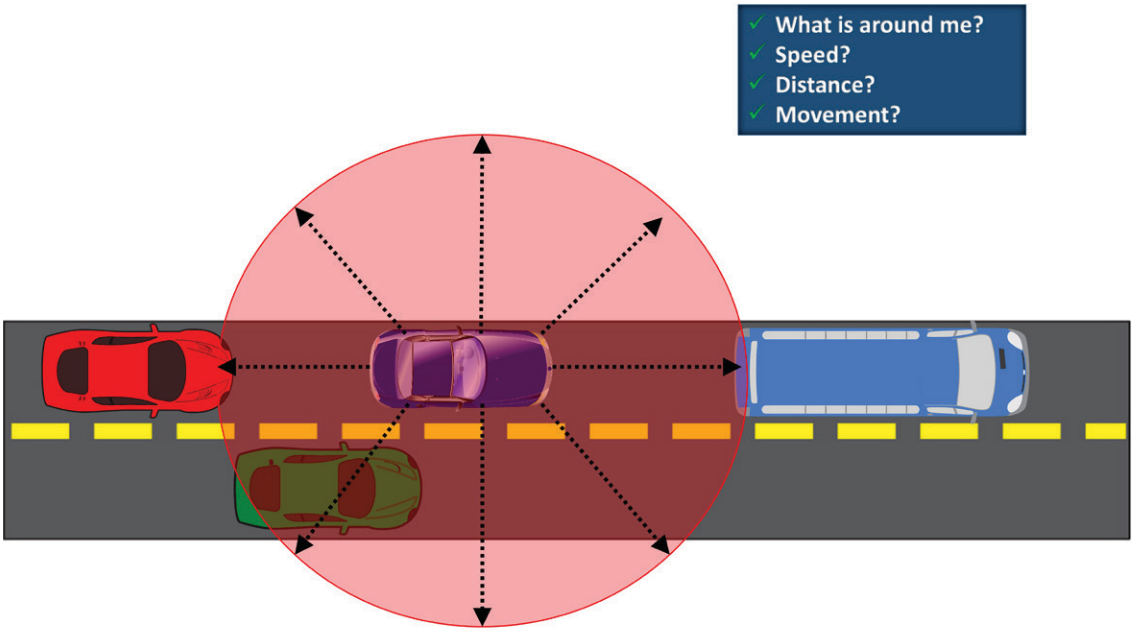
Figure 4.6: Screenshot showing overview of the CHAT procedure

Source: Authors' own

Following an initial explanation of the CHAT procedure, a learning strategy called proactive observation (Castro et al., 2016) was used, combining the approaches of meta-cognition and expert (road) commentary. The aim of this was to motivate trainees to adopt the CHAT behaviours by drawing their attention to potential errors that can be made through inattention. Trainees were presented with a bird's eye view of a takeover scenario (Figure 4.7) and were instructed to actively scan the road scene, applying the principles of the CHAT procedure to establish the 'Checks' and 'Assessments' they would need to make if they were the driver in the 'ego' blue vehicle. Expert commentary then guided them through the task, providing immediate feedback and highlighting the importance and utility of the CHAT procedure. The commentary also indirectly highlighted the consequences of *not* carrying out this procedure ahead of the takeover given spatio-temporal constraints in this example. Specifically, the commentary accompanying the images in Figure 4.7 was scripted to:

1. Draw trainees' attention to the 'ego' blue car (centre of shaded red circle) and ask them to imagine what they would need to do if they were the driver and had just been issued a takeover request.
2. Identify the 'Checks' required in relation to the CHAT procedure, drawing attention to the vehicles in front, behind and in the blue car's blind spot and providing immediate feedback to the trainee.
3. Explain the 'Assess' element of the CHAT procedure, drawing trainees' attention to each of the vehicles surrounding the blue car in turn, building upon the interrelationships between each of them and the movement of the blue 'ego' car. Through this process, emphasis was placed on the necessity of carrying out the CHAT process ***before*** 'Takeover' of the physical control of the vehicle.

Figure 4.7: Interactive slide with use of expert commentary for proactive observation of the CHAT procedure. Blue 'ego' vehicle appears at the centre of shaded red circle



Source: Authors' own

4.3.2 Operational training

To assess the effectiveness of our behavioural change training – compared to current "training", a 'user manual' was also created. This was based on the existing manual provided by a commercially-available vehicle fitted with level 2 automated systems (Advanced Driver Assistance System) (Tesla Company, 2019). The user manual mirrored the style and number of warnings and advisory notices related to engaging with the automated system, but was updated to reflect both driver requirements at level 3 automation and the specific operational features of the simulated vehicle (see: Appendix C). The user manual provided an overview of how the level 3 vehicle worked, detailed the automated features that were fitted in the vehicle ('Autosteer', 'Advanced Cruise Control' and 'Advanced roadway monitoring'), and explained the capabilities and limitations of each feature. There was also a separate section on the limitations of 'Automated driving mode', which detailed numerous warnings relating to the fall-back requirements for the human when the vehicle is in automated driving more. Finally, there was a section on how to operate automated driving mode, which mirrored what the driver would need to do during the experimental drive. The intention in creating the user manual was to provide a baseline (reflecting current practice) against which to evaluate the performance and effectiveness of the behavioural change training. The user manual was subsequently referred to as 'Operational training'.

Figure 4.8: Page taken from the user manual created for 'Operational training' (full details in Appendix C)

Limitations

Many factors can impact the availability of the Automated driving mode within Autocar3, causing this mode to be disabled in certain conditions.

These include (but are not limited to):

- Poor visibility (due to heavy rain, snow, fog, sunlight etc.).
- Damage or obstructions caused by mud, ice, snow, etc.
- Interference or obstruction by object(s), mounted onto the vehicle (such as a bike rack).
- Obstruction caused by applying excessive paint or adhesive products (such as wraps, stickers, rubber coating, etc.) onto the vehicle.
- Narrow or winding roads.
- A damaged or misaligned bumper.
- Interference from other equipment that generates ultrasonic waves.
- Extremely hot or cold temperatures.

Warning: The list above does not represent an exhaustive list of situations where automated driving is not available for use. Never depend on these components to keep you safe. It is the driver's responsibility to stay alert, drive safely, and be ready to take full control of the vehicle at all times.

Source: Authors' own

Table 4.1. Comparison of training approaches

	Behavioural Training	Operational Training
Format	PowerPoint presentation	Printed, written document
Authenticity	Commonly used training approach	Equivalent to current user manual
Content	Behavioural aspects of interacting with the automated system	Functional aspects of interacting with the automated system
Instruction to participant	*"Please work through the slides. Please wait for the audio to finish on each slide and then move onto the next one. The presentation should last for 15 minutes, and I will return after this."*	*"Please read through the information within this document at your own pace. Take your time to read through the information carefully, and I will return in 15 minutes."*
Trainer involvement	None	None
Approach	Self-administered – participant required to move through the presentation at own pace	Self-administered – participant required to read through document at own pace
Duration	15 minutes	15 minutes
Follow-up practice drive	Yes	Yes

Source: Authors' own.

5. Driving Simulator Study

5.1 Overview and Aims

The aim of the driving simulator study was to evaluate and validate the behavioural training intervention through a between-subjects study. It was compared to a more traditional (Operational) approach – effectively a printed user manual, as might be expected with current vehicle technologies. Following the training, participants were asked to undertake a drive in the simulator, which involved an episode of automated driving and a planned takeover request (TOR). Subjective measures of trust, situation awareness and workload were captured after the drive. A post-drive, self-reflective interview was also carried out with participants, while reviewing the split-screen video of the drive. Subsequent quantitative analyses explored drivers' visual behaviour, and their driving performance following the transition of control.

The goals of the behavioural training were to:

1. improve drivers' understanding of vehicle automation;
2. outline drivers' roles and responsibilities with level 3 automation; and
3. provide best practice guidance to driving, and interacting with, a level 3 automated vehicle.

Compared to drivers only provided with the user manual (Operational training), it was hypothesized that drivers receiving Behavioural training would:

1. Be more likely to conduct checks to the internal and external driving environment during the transition from automation to manual mode simulated drive than drivers who received Operational training.
2. Be more likely to carry out activities relating to tactical and strategic level tasks during the automated driving mode than drivers who received Operational training.
3. Perform better in the transition from automated to manual driving than drivers who received Operational training.
4. Perform a manoeuvre more successfully shortly after transition from automation to manual control than drivers who received Operational training.

5.2 Methodology and approach

5.2.1 Experimental drive

The study took place in a medium-fidelity[3], fixed-base driving simulator at the University of Nottingham (Figure 5.1). The simulator comprises a right-hand drive Audi TT car positioned within a curved screen, affording 270 degrees forward and contiguous side view of the driving scene via three overhead high definition projectors, together with rear and side mirror displays. A Thrustmaster T500RS force feedback steering wheel and pedal set are integrated faithfully with the existing Audi primary controls, with the dashboard created using a bespoke application and presented on a 7-inch LCD screen, replacing the original Audi instrument cluster. Four video cameras are strategically located within the vehicle to record participants' behaviour.

3 Fidelity represents the degree to which the simulator replicates reality. Using this definition, simulators are typically labelled as either 'low', 'medium' or 'high' fidelity depending on how closely they represent 'real life'.

Figure 5.1: University of Nottingham Human Factors Research Group Driving Simulator

Source: Authors' own

The simulated driving environment was created using Systems Technology, Inc. STISIM Drive software (version 3) (https://stisimdrive.com/), and was essentially the same as that used during our previous study (Burnett et al., 2019), except for the addition of several exit roads and related signage along the dual carriageway. It was designed to represent a complete journey experience lasting approximately 20 minutes. Participants began in a residential location, which was described to them as their home, then they progressed through a rural setting, and joined a UK two-lane dual carriageway. The dual carriageway supported SAE level 3 automated driving, meaning the driver was able to relinquish the physical primary control actions, i.e. steering, acceleration and braking. Midway along the dual carriageway, participants received a TOR asking them to resume manual control as part of a planned handover. As part of the briefing provided ahead of the experimental drive, participants were instructed that they were required to be in the right-hand lane (lane 2) in order to engage the automation and were given notice that a TOR would occur at some point during the automated drive, and they would then be required to resume control of the vehicle, and prepare to leave the dual carriageway at the next exit. Participants were provided with a brief overview of the timings and HMI display text for the transition and reminded that they had the option to override the 50 second 'Prepare to drive' portion of the transition via a button press, which would move the HMI to the 10 second 'Resume control' countdown. Participants were instructed that, following re-engagement of manual driving, they were to move into the left-hand lane (lane 1) and take the next available exit. This involved negotiating with other road users to find a suitable location to move into lane 1 before exiting the road. All roads involved were populated with moderate to high levels of traffic, authentic road signage, and geo-typical roadside artefacts and terrain. These features served to both increase ecological validity and provide cues within the external driving environment that, if attended to, could be drawn upon by participants during the post-drive interview.

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

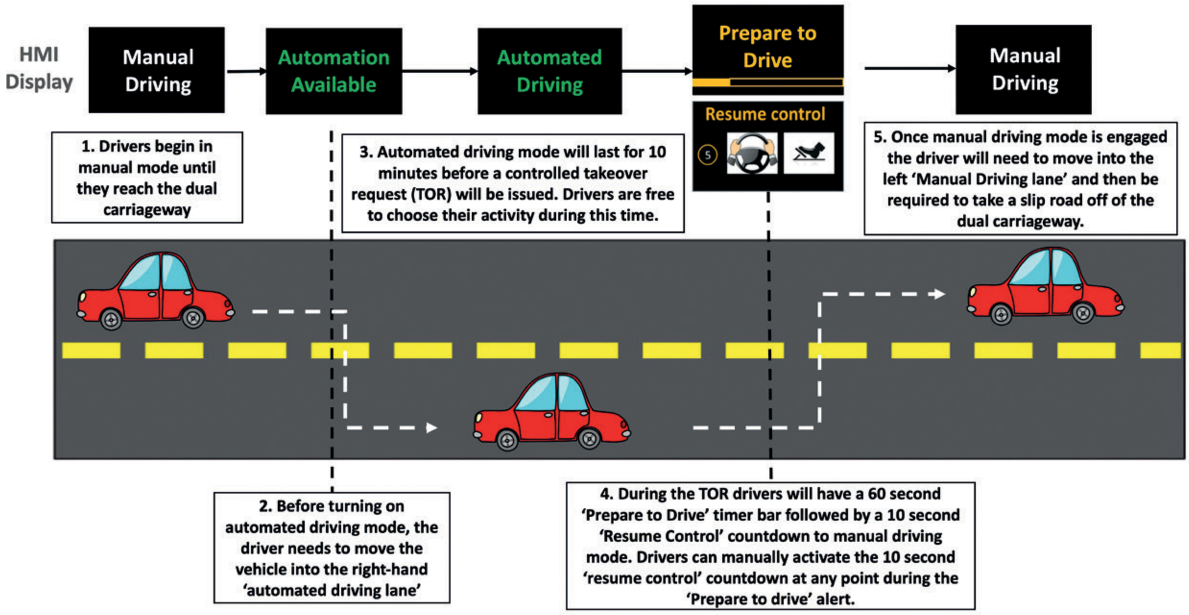
In contrast to our previous study (Burnett et al., 2019), participants only attended on one occasion. This was intended to explore the immediate, measurable impact of the behavioural training, rather than to highlight any changes in behaviour and performance following regular, repeated exposure – factors that were explored during the former study (Burnett et al., 2019).

To support drivers, a rudimentary HMI was installed in the centre console of the vehicle. This provided basic system feedback throughout the drive, delivered via an interactive PowerPoint presentation controlled remotely by the researcher. System feedback included information, such as whether automation was available, the status of the automated control, and guidance during the handover. Feedback was provided both visually (in the form of text-based messages and images) and audibly (by tones and spoken messages). Participants were alerted of any updates to the information presented using a tone. All participants received the same information and notifications during the study.

5.2.2 Planned take-over request (TOR)

Participants began by driving manually, i.e. they were responsible for all primary control actions. SAE level 3 automated control was made available to drivers only when they joined the dual carriageway, which occurred approximately 5 minutes into the journey. Participants were notified of automation availability by means of an audio-visual text-based message presented on the in-vehicle HMI, with accompanying spoken audio. They engaged the automation via a button press and were only able to engage the automation once they had move into the right-hand (automation) lane (lane 2). Participants were told that during periods of automation, they were permitted to engage in NDRTs as they saw fit – no restrictions were applied other than making drivers aware at the start of the study that they would be required to resume manual control and leave the dual carriageway at the next exit, and would be given 60 seconds' warning to prepare themselves. In practice, the planned takeover request was issued approximately 10 minutes into the automated driving mode. This occurred via an audio-visual 'Prepare to drive' alert on the HMI display. This alert was displayed for 60 seconds, with the remaining time indicated as a countdown timer bar on the HMI display. At the end of 60 seconds, the driver received a further audio-visual alert on the HMI to 'Resume control'; this included a 10 second count down, following, which manual driving mode resumed. The driver was able to manually activate the 10 second 'Resume control' countdown at any point during the 'Prepare to drive' notification period. Once manual driving mode had been resumed, the driver was required to move into lane 1 and then take the next exit road, which is where the drive terminated. Figure 5.2 provides an overview of the experimental drive and HMI displays.

Figure 5.2: Schematic showing experimental drive and associated HMI displays



Source: Authors' own

5.2.3 Participants

Twenty-five participants were recruited to take part in the study (20 male, 5 female; mean age: 35 years; range: 21-59 years). All participants were experienced drivers, and were required to hold more than three years of driving experience, and drive regularly (at least 2 to 3 days a week), including experience of dual carriageway or motorway driving (in practice, participants' mean number of years driving was 14, and their annual mileage ranged from 5,680-26,000). Participants primarily comprised employees and postgraduate students at the University of Nottingham and were recruited by means of advertisements placed around the University of Nottingham campus and sent via email. In practice, one of the participants displayed some atypical behaviours (they later admitted to "playing with" the driving simulator), and their data and responses were subsequently removed prior to analysis. This resulted in approximately half the participants (n=11) receiving Behavioural training and the remaining participants (n=13) provided with Operational training prior to driving in the simulator. Participants were in attendance for approximately one hour and were reimbursed with £10 in shopping vouchers as compensation for taking part. The study procedure was approved by the Faculty of Engineering's Ethics Review Committee.

5.2.4 Training

Prior to completing the simulated drive, all participants completed a self-directed training session. Participants in the Behavioural group completed training in the form of a PowerPoint presentation with audio commentary voiced by a professional actor. Participants in the Operational group were provided with a document based on a user-manual for a commercially available vehicle fitted with level 2 automated systems (Advanced Driver

Assistance System). The user manual training mirrored the style and number of warnings and advisory notices related to engaging with the automated system but was updated to reflect both driver requirements at level 3 automation and the operational features of the simulated vehicle. Both groups were given 15 minutes to complete the training.

In addition, prior to completing the experimental drive, all participants took part in a ‘test drive’ scenario, lasting around 5 minutes. This allowed drivers to practice the vehicle controls, including a transition to and from automated driving and gain knowledge of the HMI display and other key features for the drive. Evidence from the previous study (Burnett et al., 2019) showed that drivers significantly improved their lateral and longitudinal performance at the point of transition to manual mode between the first and second drives. Therefore, this test drive served to allow drivers the chance to practice the operational skills involved in the transition and offer an opportunity to validate previous behavioural adaptations (Shaw et al., 2020) during the transition period. No other vehicles were present in the test drive scenario. Drivers began in manual mode on a dual carriageway and practiced the following manoeuvres:

- changing lanes;
- engaging automation;
- receiving and responding to a takeover request; and
- transitioning from ‘Automated Driving’ mode to ‘Manual Driving’ mode.

5.2.5 Measures

Prior to taking part in the driver training, participants completed the Total Trust in Automation Questionnaire (TTAQ) (Gold et al., 2015b). Following the training, participants were asked to complete a 5-point subjective ratings scale questionnaire adapted from a classroom engagement study (Wang et al., 2014), to evaluate the training (Training Evaluation Questionnaire, TEQ). After completion of the experimental drive, the participant repeated completion of the Total Trust in Automation questionnaire (TTAQ) (Gold et al., 2015b); the Situational Awareness Rating technique (SART) scale (Taylor, 2017) and the NASA-TLX workload questionnaire (Hart and Staveland, 1988) (see Appendices for further details of questionnaires used).

Driving performance measures were captured by the STISIM simulation software. These were used to calculate key driving performance indicators associated with the takeover of control, including longitudinal and lateral acceleration, standard deviation of lane position and steering reversal rate, aiming to identify the smoothness of the resumption of control and lane change manoeuvre. In addition, the minimum time to collision (TTC) was determined to provide an indication of how close participants were to other vehicles in their immediate surroundings.

Behaviour Observation Research Interactive Software (BORIS) (Version 7.4.7) (Friard and Gamba, 2016) was used to create an ethogram used to code driver behaviours during the experimental drive. Frame-by-frame coding of behavioural observations was conducted from the split-screen video recordings of the experimental drive; cameras were positioned so that the internal and external environment could be observed (see Figure 5.3 for examples).

Observations were analysed to explore and compare behaviour between the Behavioural and Operational groups during: automated driving mode; the transition period, defined as between the TOR and the point that manual driving mode re-engaged; and during the lane change manoeuvre after drivers had resumed manual control. Behavioural measures included (list not exhaustive) eye glance direction and frequency (to mirrors, external and internal sources), engagement with NDRT, hands on/off wheel, and feet or body adjustments.

Figure 5.3: Example of split-screen video recordings used for analysis, showing participant engaged in NDRT during automation (top) and following the request to resume manual control (bottom)

Source: Authors' own

5.3 Results and Analysis

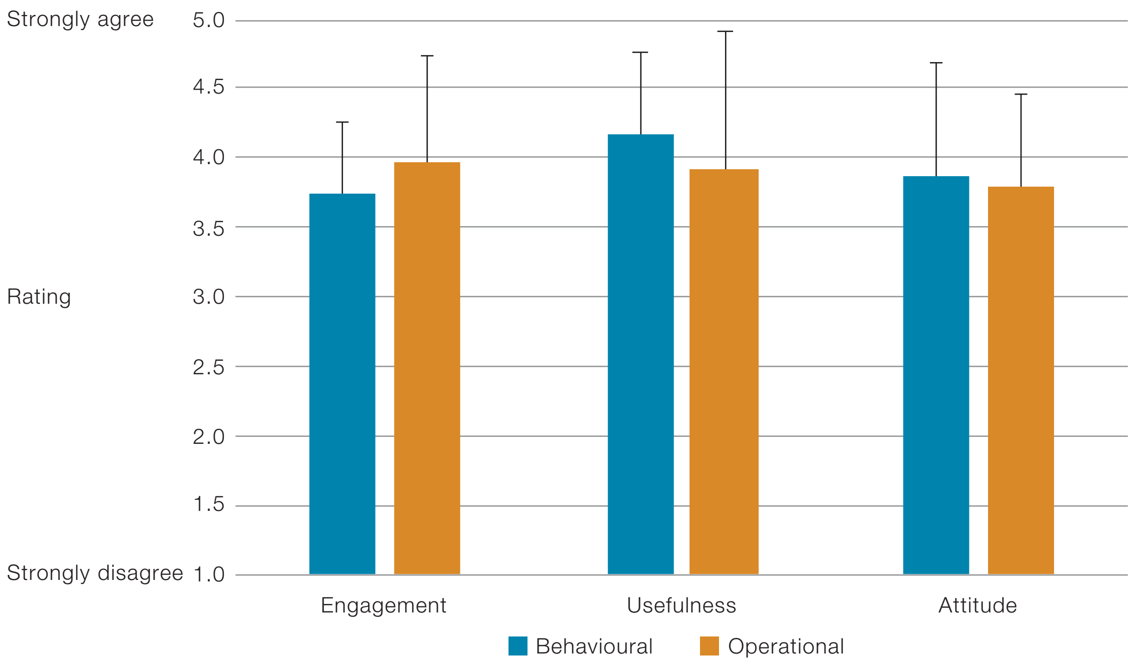
Differences in results between drivers receiving Behavioural training and those receiving Operational training were tested for statistical significance using *t*-tests and Fisher's exact test. Further explanation of these standardised tests can be found in Appendix H. Statistical significance is reported at $p < .05$.

5.3.1 Subjective Measures

Training Evaluation

Participants were asked to rate the training they had received (Behavioural or Operational) using the training evaluation questionnaire (TEQ) adapted from Wang et al. (2014). Ratings were captured using 5-point Likert scales, where 1 indicates strongly disagree, and 5 indicates strongly agree. Individual scales were subsequently grouped into engagement, usefulness and attitude for analysis, in line with previous applications (Lawson et al., 2019). Ratings were generally high (above the scale mid-point) for all attributes and amongst both cohorts (Figure 5.4). Notably, there were no significant differences between ratings made by drivers in the Behavioural and the Operational groups, suggesting that both approaches were comparable from the perspective of the participants' experiences.

Figure 5.4: Results from Training Evaluation Questionnaire (TEQ) showing engagement, usefulness and attitude ratings. Aggregated ratings scaled to match original scale values and increments to ease interpretation. Error bars show standard deviations



Source: Authors' own

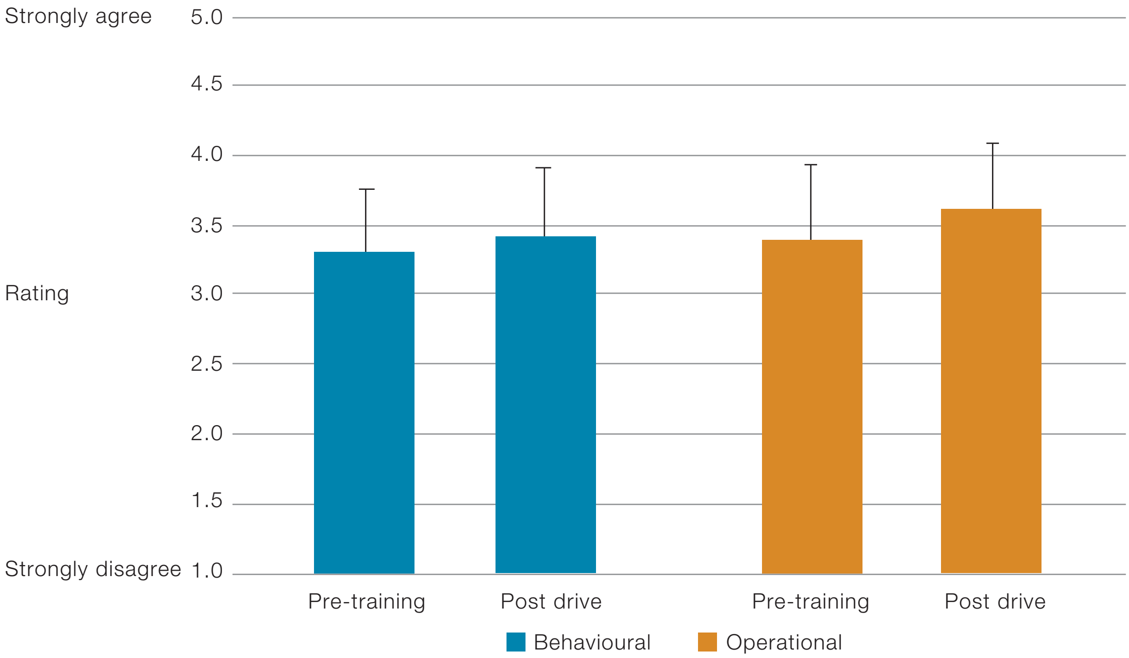
Trust

The total trust in automation questionnaire (TTAQ) (Gold et al., 2015b) comprises five sub-scales relating to: the discharge of the driver due to automation, safety gains, safety hazards, trust in automation, and intention to use. Again, ratings were captured using 5-point Likert scales, where 1 indicates strongly disagree, and 5 indicates strongly agree. Total trust was calculated as the cumulative score (i.e. the summation of all subscales). Participants were asked to complete the TTAQ before training and then immediately after driving.

Pre-training ratings were comparable between groups (Behavioural and Operational) for total trust and all subscales. However, by comparing ratings made before and after driving, it is evident that there was a significant increase in total trust (TTAQ) within the Operational group (p = .02) (Figure 5.5). Upon closer inspection, drivers in the Operational group indicated a greater intention to use automation after the experience (p = .03) and higher trust in automation (subscale) (p = .003).

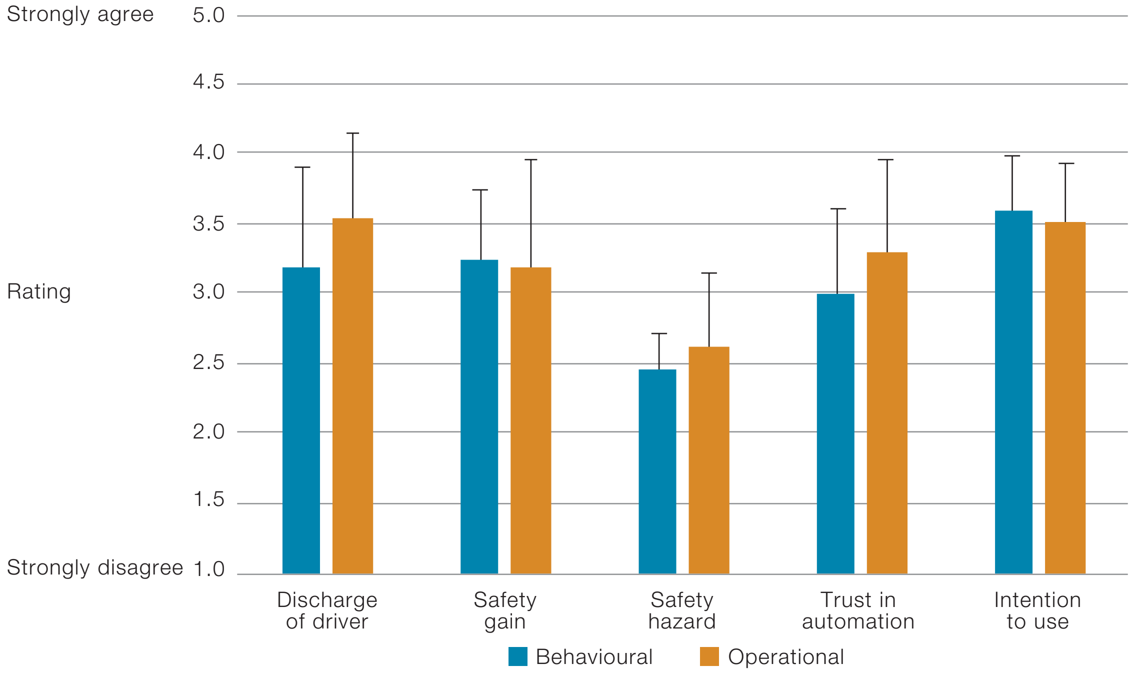
There were no significant differences between pre and post ratings made by drivers in the Behavioural group (Figure 5.6, Figure 5.7).

Figure 5.5: Total Trust (TTAQ) ratings. Aggregated ratings scaled to match original scale values and increments to ease interpretation. Error bars show standard deviations



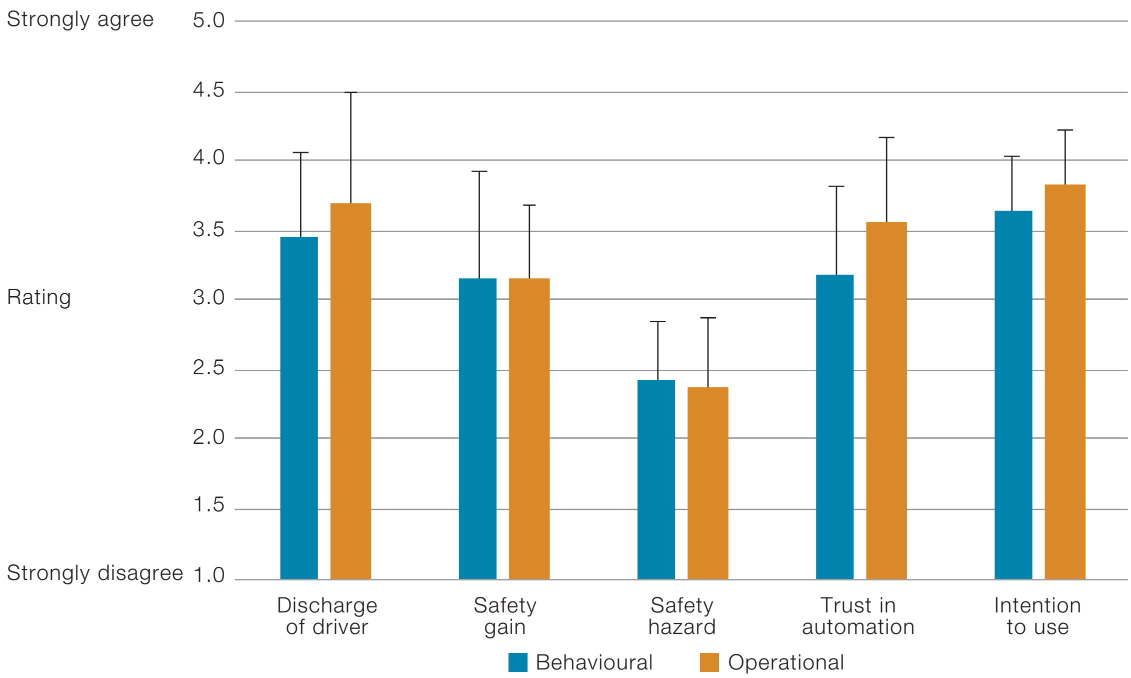
Source: Authors' own

Figure 5.6: Pre-training trust ratings showing all subscales. Aggregated ratings scaled to match original scale values and increments to ease interpretation. Error bars show standard deviations



Source: Authors' own

Figure 5.7: Post-drive trust ratings showing all subscales. Aggregated ratings scaled to match original scale values and increments to ease interpretation. Error bars show standard deviations

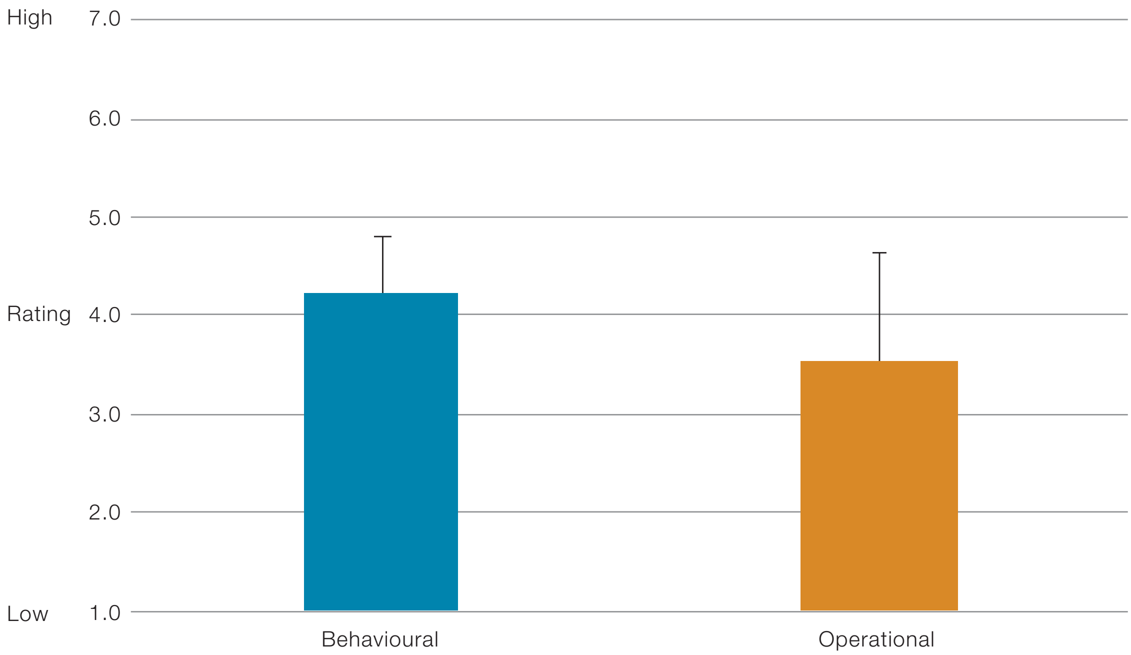


Source: Authors' own

Situation awareness

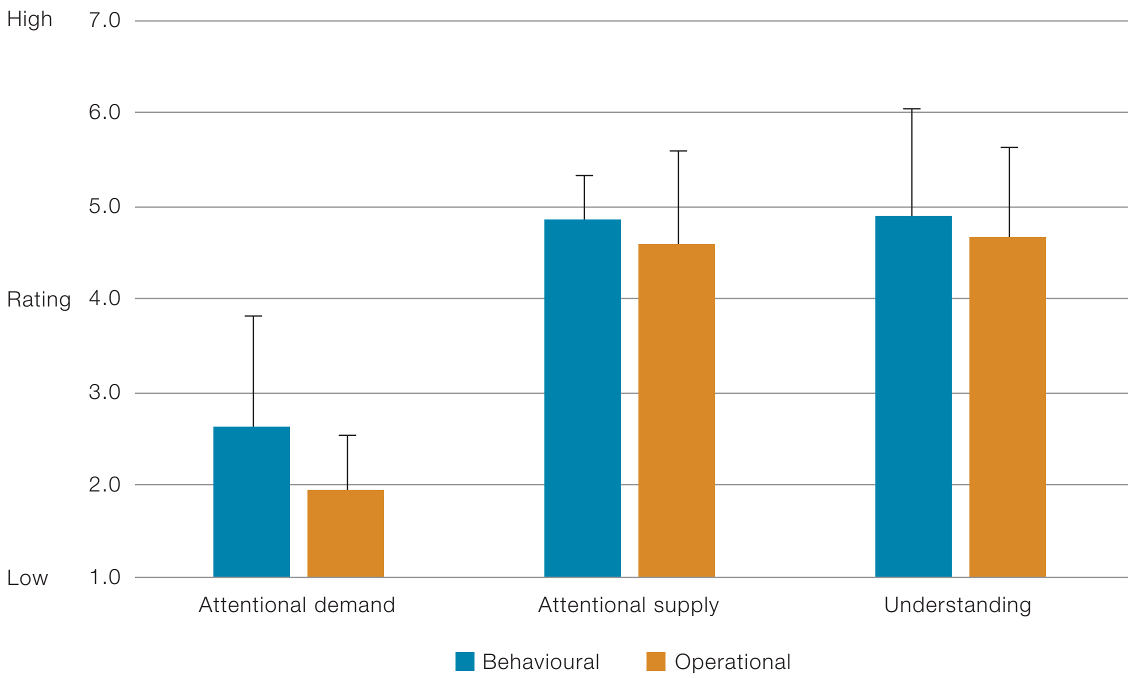
The Situational Awareness Rating Scale (SART) (Taylor, 2017) explores respondents' perception of the attentional demand, attentional supply, and their understanding of the situation. Ratings are made using 7-point Likert scales, captured post-drive, where 1 is labelled 'low', and 5 labelled 'high'. Although ratings made by drivers in the Behavioural group were generally higher based on the responses captured during the study, the differences between groups were not statistically significant (p = .097) (Figure 5.8). There were no significant differences between groups for any of the subscales (Figure 5.9).

Figure 5.8: Situation Awareness (SART) ratings. Aggregated ratings scaled to match original scale values and increments to ease interpretation. Error bars show standard deviations



Source: Authors' own

Figure 5.9: Situational Awareness (SA) ratings showing all subscales. Aggregated ratings scaled to match original scale values and increments to ease interpretation. Error bars show standard deviations

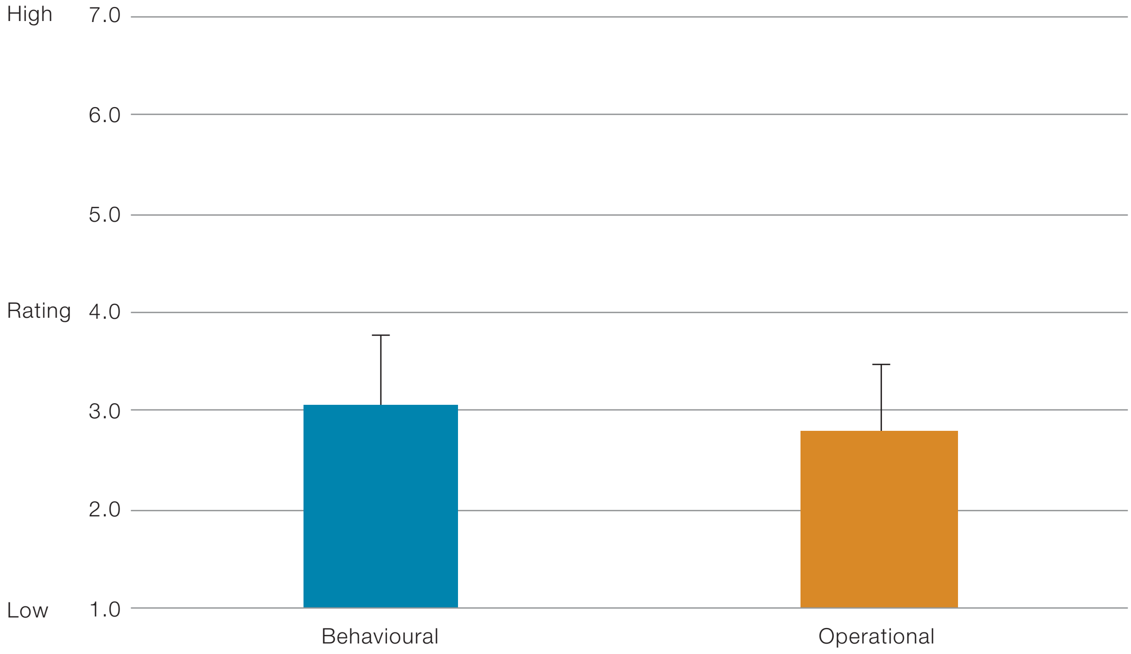


Source: Authors' own

Workload

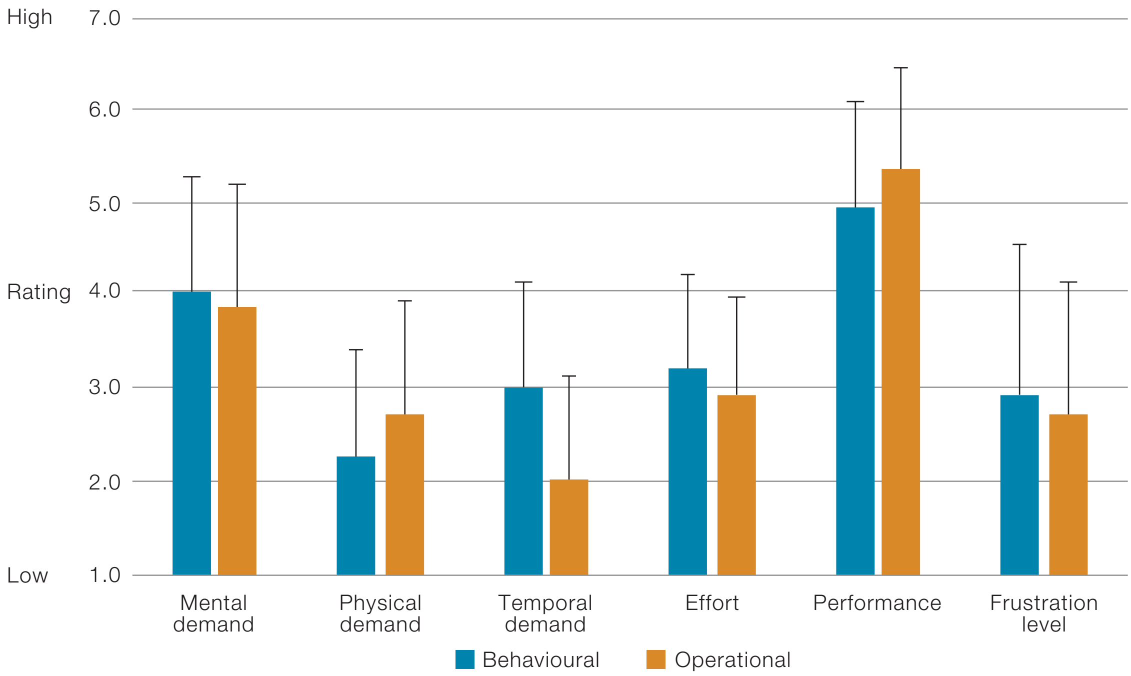
The NASA-TLX workload index (Hart and Staveland, 1988) is a multi-dimensional scale exploring mental demand, physical demand, temporal demand, effort, performance and frustration levels. Ratings were made using 7-point Likert scales, where a rating of 1 represents low workload, and seven, high. Although Total Workload (the numerical summation of all subscales, with ratings for performance reverse-scored) was statistically comparable between groups (Figure 5.10), those receiving Behavioural training indicated significantly higher temporal demand (p = .048) (Figure 5.11), suggesting they felt greater time pressure due to the pace at which the tasks or task elements occurred, compared to drivers in the Operational group.

Figure 5.10: Total Workload (NASA-TLX) ratings. Aggregated ratings scaled to match original scale values and increments to ease interpretation. Error bars show standard deviations



Source: Authors' own

Figure 5.11: Workload ratings showing all subscales. Mean values. Error bars show standard deviations



Source: Authors' own

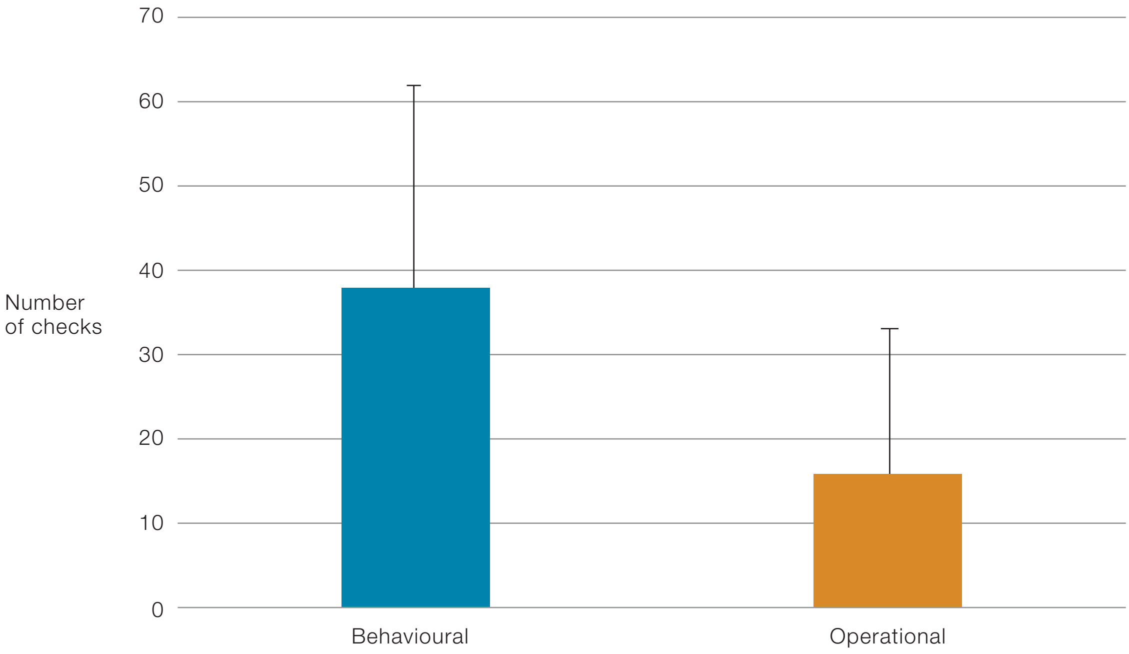
5.3.2 Visual behaviour

A key aim of the study was to change drivers' behaviour, not just their opinions. We would therefore expect to find a significant difference between cohorts (Behavioural versus Operational) with regards to their visual behaviour (e.g. number and frequency of glances at mirrors) during automated driving and following the resumption of manual control. In particular, we anticipated the Behavioural training cohort to demonstrate situation monitoring behaviours during the transition period that would suggest they were in an 'on the loop' state prior to taking back physical control of the vehicle, and this would have a knock effect on their situation monitoring behaviours following transition to manual control.

Glances to mirrors

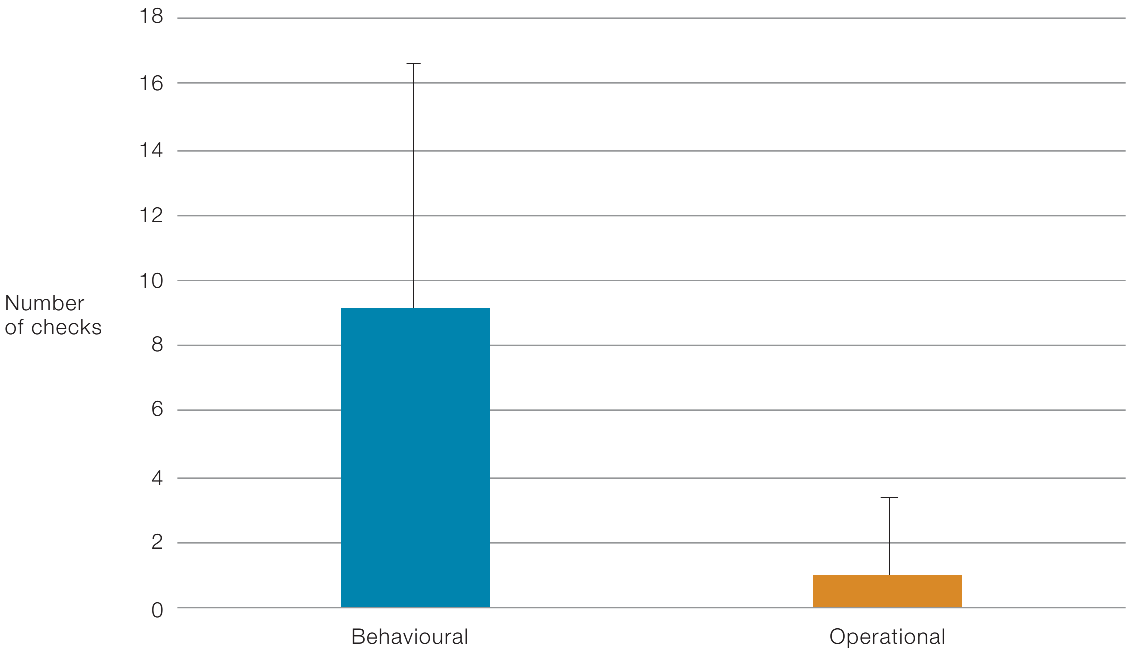
The number of mirror checks were determined for all participants during the entire drive, i.e. during automated driving, when preparing to take over control, during the transition of control and after resuming manual driving. These provide an indication of the extent to which drivers attempted to remain engaged with the driving task, rebuild their awareness when asked to resume control, and the caution they applied during manual driving. The data show that drivers who received Behavioural training carried out significantly more mirror checks than those receiving Operational training during both automated driving and the transition to manual driving ($p = .010$ and $p < .005$, respectively) (Figure 5.12 and Figure 5.13, respectively). On average, drivers in the Behavioural group made 37.8 mirror checks during the 10-minute automated driving and 9.2 during the transition period, compared to 15.8 and 1.0, respectively, by drivers in the Operational group. In addition, drivers were statistically more likely to make at least one glance during the transition of control in the Behavioural group ($p = .005$).

Figure 5.12: Mean number of mirror checks made during automated driving. Includes glances to left, right and rear-view mirrors. Error bars show standard deviations



Source: Authors' own

Figure 5.13: Mean number of mirror checks from prepare-to-drive notification (PTD) to manual driving. Includes glances to left, right and rear-view mirrors. Error bars show standard deviations

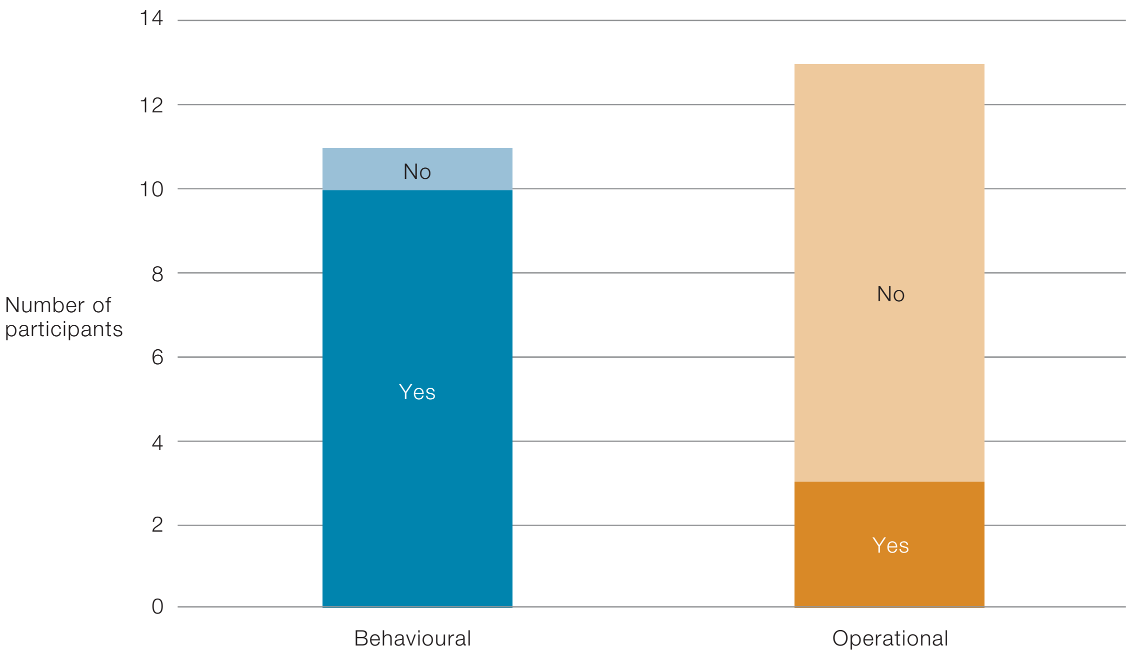


Source: Authors' own

Awareness of the hazard car

As part of the experimental design, a car joined lane two behind the participant's vehicle simultaneously to the 'prepare-to-drive' TOR. The car sped up and remained close to the rear of the participant's vehicle, effectively, tailgating it. The behaviour of the car was designed to replicate that of an irate driver wanting to overtake, i.e. abnormal behaviour that might be expected to draw attention and would normally be identified as dangerous or hazardous. The hazard car was plainly visible in the rear-view and side mirrors during the entire prepare-to-drive period (60 s). At the point drivers resumed manual control, the hazard vehicle slowed and effectively disappeared from immediate sight. The intention in introducing the vehicle was to present another potential hazard to drivers during the takeover, but specifically one that required the use of their mirrors. Analysis of participants' glance behaviour shows that significantly more drivers in the Behavioural group (10 out of 11 drivers) saw the hazard vehicle (p = .002), compared to drivers in the Operational group (only 3 of the 13 drivers) (Figure 5.14).

Figure 5.14: Number of participants who saw the tailgating, hazard car during the prepare-to-drive (PTD) period. 'Yes' indicates that participant saw the car, and vice versa



Source: Authors' own

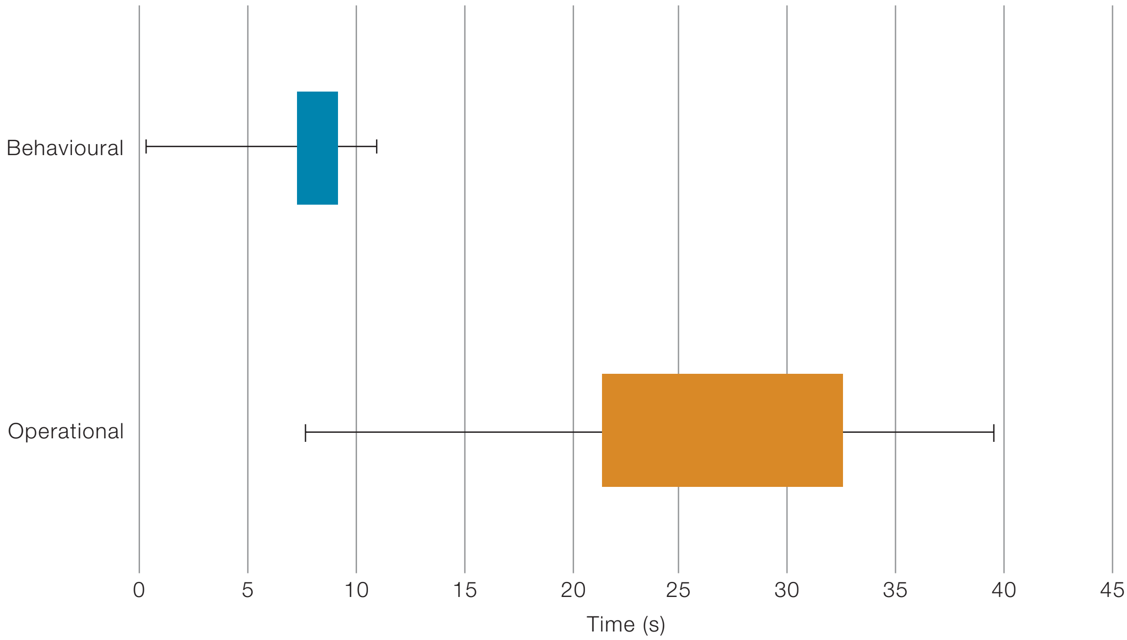
Shared attention

Although mirror checks suggest that drivers are actively attempting to remain engaged with, or to re-establish their engagement with, the driving scene, the manner in which these were distributed, particularly during the 60-second transition/hand-over period, shows the relative importance with which drivers considered the driving task and their NDRTs. In other words, a glance to a mirror immediately after a takeover request (TOR) has been issued, should indeed be welcomed, as it suggests that the driver recognises the need to see what's around them in preparation to resume control. However, if they immediately revert their attention back to their NDRT after this preliminary mirror check, it suggests that they have not fully disengaged with their NDRT and are subsequently not fully re-engaged with the driving task. Instead, such behaviour suggests these drivers are choosing to share their attention between both activities. In practice, drivers must discharge their NDRT as well as re-engage with driving before taking over control.

To explore this further, we observed the timing of the first driving-related glance (i.e. to a mirror or the forward road scene) immediately after the TOR was issued. We then identified any subsequent glances that were associated with their NDRT, and in particular, the final NDRT-related glance. This reveals a period of shared attention – from drivers' first attempt to re-engage with the driving scene (e.g. attempting to rebuild their situation awareness) to their last interaction with their NDRT. Again, this is an area where we believe Behavioural change training will benefit drivers in that they will be encouraged to discharge their NDRT both earlier and more expeditiously during the transition period, thereby providing more time to re-familiarise themselves with driving. In other words, during the study, we would expect an earlier, shorter period of shared attention amongst drivers receiving the Behavioural training, compared to those receiving the Operational training.

Indeed, the data show that Behaviourally-trained drivers spent significantly less time sharing their attention during the prepare-to-drive notification period than Operational participants ($p < .005$) (Figure 5.15). On average, the former participants spent 1.8 seconds between their first glance to the road and their final engagement with or glance at their NDRT, compared to 11.2 seconds for the latter. Moreover, the time to the first mirror check following the PTD was also significantly different between groups ($p < .005$), with Behavioural participants taking on average 7.3 seconds before making their first glance at the road, whereas Operational participants took 21.3 seconds. Even so, it is worth highlighting that some drivers – in both groups – were not engaged with their NDRT at the time the TOR was issued. Five of these were in the Behavioural group, and three in the Operational group.

Figure 5.15: Initiation and duration of shared attention during prepare-to-drive (PTD) showing first driving-related glance (left end of solid bar) to final NDRT-related glance (right end of bar). Mean values with standard deviation error bars



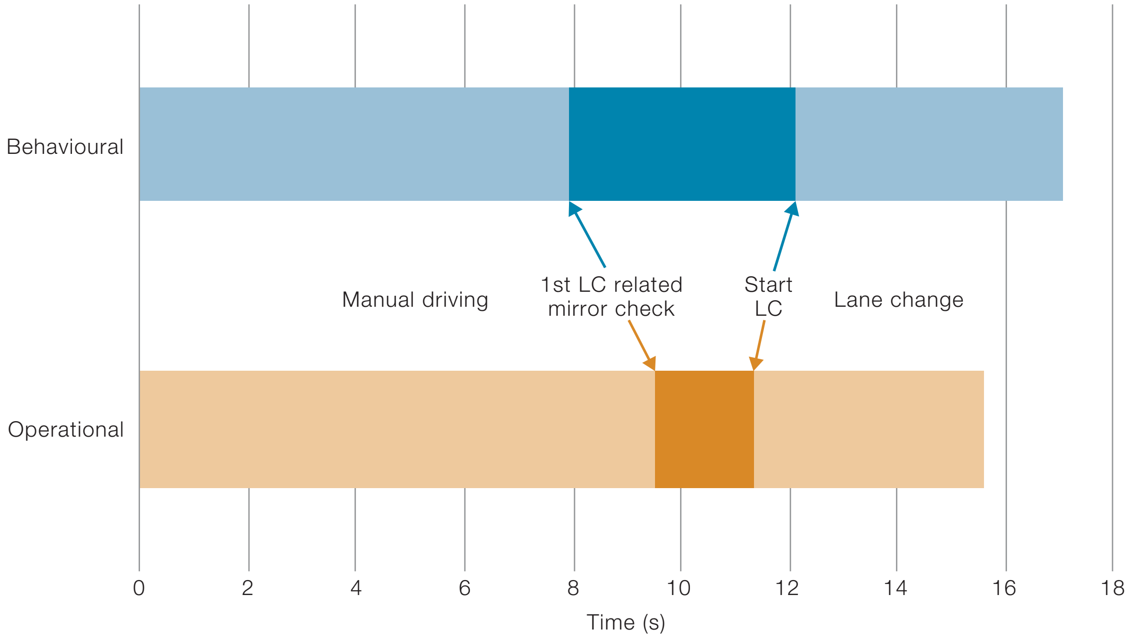
Source: Authors' own

Visual behaviour after resuming manual driving

Drivers' visual behaviour remains important after resuming manual control, not least due to the fact that, in the current study, they were required to move into lane one – meaning they needed to negotiate with other road users already present in lane one – and then exit the dual carriageway. All mirror checks were subsequently identified from the resumption of manual driving. These were categorised as either glances associated with rebuilding situation awareness (SA), or were specifically attributed to the lane change manoeuvre (LC). The latter were defined as those which immediately preceded physical actions associated with manoeuvring their vehicle, based on our expert evaluation of the videos. These actions included repositioning hands on the steering wheel (for example, to activate the indicator), or beginning to turn the steering wheel to guide the vehicle into lane one. From these actions, a lane-change timeline was identified, and this was subsequently cross-referenced with the vehicle performance data captured by the STISIM simulation software.

It is noteworthy that, on average, the time from resuming manual control to the first LC mirror check (i.e. immediately preceding the commencement of the LC manoeuvre) was the same (i.e. there was no statistical difference) for drivers in both groups (p = .74). However, the delay before the lane change was physically enacted following the final confirmatory LC mirror check (effectively, the time taken to begin to make the LC manoeuvre after deciding to do so) differed between groups (p = .02), with drivers in the Behavioural group taking significantly longer than Operational drivers (mean times: 4.3 seconds and 2.2 seconds, respectively), suggesting greater caution amongst the former drivers. Nevertheless, there was no significant difference in the time taken to physically manoeuvre the vehicle from lane two to lane one once this action was started (p = .36) (Figure 5.16). In addition, drivers who received Behavioural training made significantly more mirror checks prior to and during the lane change manoeuvre (p < .005 and p = .012). These drivers were also significantly more likely to make multiple glances to their mirrors during the lane change manoeuvre itself (p = .016).

Figure 5.16: Time to contemplate and undertake lane-change (LC) manoeuvre (mean values). Time zero represents the start of manual driving



Source: Authors' own

5.3.3 Driving performance

A key factor in any study investigating the transfer of control from automated to manual driving is drivers' manual driving performance immediately following the takeover. This was indeed an important consideration in our previous RAC Foundation study (Burnett et al., 2019), which revealed that lateral control (lane swerving, in particular) was poor during the 10 seconds immediately after resuming control – although, this notably improved following repeated, daily exposure during the week. This suggests that specific operational 'takeover' skills could potentially be identified and taught or supported through technological interventions. In contrast, the behaviour of participants (who took part in the former study) during periods of automation and the transition of control arguably deteriorated over the week, i.e. they dedicated increasing time to NDRTs rather than attempting to remain engaged with the driving task during automated driving, or rebuilding their awareness when asked to resume control, suggesting complacency and/or satisficing. Such behavioural changes are clearly undesirable and are likely to have long-term implications, resulting in the inappropriate allocation of trust and over-reliance.

During the current study, we are therefore focussing on changing drivers' behaviour by improving their knowledge and awareness (for example, by completing and/or correcting their mental model). The expectation is that these drivers will subsequently act more appropriately during automation and when asked to resume control. However, it is also anticipated that this should improve their driving behaviour and performance immediately following the transfer of control. We therefore captured driving performance data from the STISIM simulation software, and selected key driving performance metrics employed in similar research to explore the rate of change of longitudinal and lateral behaviour, i.e. longitudinal and lateral acceleration, standard deviation of lane position and steering reversal rate, aiming to identify the smoothness of the resumption of control and lane change manoeuvre. In addition, we calculated the minimum time to collision (TTC) to provide an indication of how close participants were to vehicles in their immediate surroundings.

Longitudinal and lateral acceleration were calculated in 1-second time intervals following the resumption of control. The data suggests no apparent difference between the Behavioural and Operational groups (p = .48 and .24, respectively, when averaged across the entire 10 seconds). Comparing each 1-second interval between groups, there is some evidence of statistical differences at t=2s and t=6s (p = .048 and p = .011, respectively), with data suggesting that drivers in the Operational group demonstrated higher longitudinal and lateral variability (respectively), although in isolation, these two differences are largely inconclusive.

In addition, there is no evidence of any statistical differences between groups for standard deviation of lane position (SDLP) over the 10 seconds following the takeover of control (p = .56), or the minimum time to collision (effectively, the distance between the participant's car and other vehicles on the road) (p = .95). Steering reversal rate is also comparable between groups (p = .90).

5.3.4 Non-Driving related tasks (NDRT)

As with our previous study (Burnett et al., 2019), drivers were able to select and bring with them their own non-driving related tasks and activities (NDRTs) and engage with these as they desired – and believed appropriate – during automation. Moreover, no restrictions were applied to the type of tasks and activities that drivers could undertake. Whilst this approach arguably fails to provide standardisation from which to compare driver takeover performance, it nevertheless increases the ecological validity of the experience and participants' behaviour, not least because it is expected to evoke important motivational factors that could have a significant bearing on drivers' engagement (or lack of) with the driving task. Although the type and range of different NDRTs were not formally analysed as part of this study, general observations made by the researcher suggest that the range of NDRTs were similar to those seen during our former study, with drivers predominantly using mobile phones, tablet computers and laptops, and bringing with them books and printed papers to read during automation.

5.4 Summary of results

Table 5.1: Summary of results from subjective measures

Category	Measure	Result
Training Evaluation Questionnaire (TEQ)	• Engagement • Usefulness • Attitude	• No significant differences between Behavioural and Operational training
Total Trust in Automation Questionnaire (TTAQ)	• Total Trust (TTAQ)	• No significant differences between groups pre-training • Ratings significantly higher post drive for Operational group (*p* = .02)
	• Trust in Automation • Intention to Use • Discharge of the Driver • Safety Gains • Safety Hazards	• Significant increase in Trust in Automation for Operational group (*p* = .003) • Significant increase in Intention to Use for Operational group (*p* = .03) • No significant differences in Discharge of the Driver, Safety Gains or Safety Hazards
Situation Awareness (SART)	• Attentional Demand • Attentional Supply • Understanding Situation	• No significant differences between groups
Workload (NASA-TLX)	• Mental demand • Physical demand • Temporal demand • Effort • Performance • Frustration level	• Higher Temporal Demand for Behavioural group (*p* = .048)

Source: Authors' own

Table 5.2: Summary of results from objective measures

Category	Measure	Result
Visual behaviour	Glances to mirrors/roadway during automated driving and prepare-to-drive (PTD)	• Significantly more mirror checks during automated driving and during PTD by Behavioural group (p = .010 and p < .005). • Statistically more drivers in Behavioural group made at least one mirror glance during transition of control (p = .005) • Significantly shorter time to first glance at mirror/roadway during PTD (p < .005) for Behavioural group • Behavioural group statistically more likely to see the tailgating blue car (p = .002)
	Shared attention during PTD (driving / NDRT)	• Behavioural group spent significantly less time sharing their attention between driving and NDRT during PTD (p < .005)
	Glances to mirrors/roadway during manual driving and lane change manoeuvre (LCM)	• Behavioural group undertook significantly more mirror checks before starting LCM (p < .005) • Behavioural group undertook significantly more mirror checks during LCM (p = .012) • Behavioural group significantly more likely to make multiple mirror checks during LCM itself (p = .016)
Driving behaviour	Lane change manoeuvre	• Behavioural group took significantly longer to begin lane change following the final confirmatory mirror check (p = .020) • No significant difference in the time taken to physically change lanes (p = .36)
Driving performance	Manual Driving	*No significant differences between groups identified for:* • Lateral and longitudinal acceleration (p = .48 and p = .24, respectively) • Standard deviation of lane position (p = .56) • Steering reversal rate (p = .90) • Minimum time to collision (p = .95)

Source: Authors' own

6. Discussion

Our previous report: How will drivers interact with the vehicles of the future? (Burnett et al., 2019), investigated the nature and range of secondary tasks that drivers may undertake during periods of automation, i.e. at SAE levels 3 and 4 (SAE, 2016), and the manner in which these may impact their ability to resume manual control if and when required or desired (Large et al., 2019; Shaw et al., 2020). In addition, some strategies were considered to help re-engage the driver and re-build their situation awareness prior to handing-over control (White et al., 2019). It is evident from this work, and indeed, from current literature (De Winter et al., 2014; Merat et al., 2014; Kyriakidis et al., 2019), that new forms of driving afforded by higher levels of vehicle automation will place new demands on drivers. 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 in SAE level 3 or 4 vehicles. Ultimately, it is predicted that drivers (or vehicle 'users') will become passive observers when SAE level 5 is reached in vehicle automation (Banks, Plant and Stanton, 2019). Moreover, for vehicles capable of delivering different levels of automation, most likely, SAE level 3 or 4 functionality, the driver may be required to assume different roles within the same journey, and to move between different states at short notice.

A major concern is that the different driver roles are likely to require fundamentally different types of skills. In SAE level 3 or 4 vehicles, for example, factors such as maintaining an awareness of the functionalities and operational limits of the vehicle, knowing who is in control at any time (i.e. the driver or the automated vehicle), and anticipating potential situations requiring manual intervention, are all important. Thus, drivers of these future vehicles will need to be proficient in 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 (Burnett et al., 2019), nor are these skills called upon during manual driving, or indeed, taught during current driver training. Nevertheless, it is expected that drivers of future vehicles will also need 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 partially automated vehicles are likely to retain the same form factor as current vehicles on the road (i.e. 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, training providers, car dealerships, etc., and therefore the need for additional training above and beyond the current, prerequisite 'user manual' may not be immediately apparent.

In practice, these new, shared roles and responsibilities are yet to be comprehensively defined and mapped out. However, whilst the literature review highlighted many theoretical areas of human behaviour and performance that require attention, current, experienced drivers (and indeed, driving instructors) appear to lack the wherewithal to articulate exactly what kinds of new skills might be required and how they may feature in future driver training, or indeed, on the road. Coupled with this is the fact that, when given the opportunity to experience a 'future level 3 automated vehicle', participants in our previous study immediately placed high levels of trust in the vehicle and engaged in immersive secondary tasks and activities during automated driving mode, despite their ongoing responsibilities towards vehicle monitoring and control (Burnett et al., 2019). Unsurprisingly, this had a major impact on their ability to resume manual control when prompted to do so. Even for drivers experiencing current SAE level 2 automated driving features on the road, there is increasing evidence of unfavourable behavioural adaptations. Specifically, such drivers can be seen relying on the technology in situations for which it was not designed or intended, and changing their own behaviour as a consequence of its use (Brown and Laurier, 2017; Banks et al., 2018; Lin et al., 2018).

However, rather than concluding that these drivers are actively choosing to *disregard* their role and responsibilities, we believe that such behaviour is indicative of drivers *not knowing* or *understanding* their role and responsibilities. This may be because they lack an awareness of the limits of the technology's capability, for example. Consequently, there is a fundamental need to first inform drivers and moderate their expectations and subsequent behaviour, to prepare them for the uptake of, yet, undefined, new skills.

6.1 CHAT ('CHeck', 'Assess', 'Takeover')

The CHAT procedure used as part of our Behavioural training was developed using a combination of design principles informed by the implications of long-term memory on learning. Moreover, the design of this training tool had at its core the importance of meaning and structure in the efficient application of skills-based knowledge to the nuanced and dynamic driving context. Drawing upon the learning strategy of 'proactive observation' (Castro et al., 2016), the aim was to highlight the importance of improving SA in preparing to drive following a takeover request (TOR). It was designed to draw the trainee's attention to the number of events and (typically automatic) actions relevant to making proactive and reasoned decisions that are required ***before*** taking over physical control of the vehicle to enable safe and effective driving. The CHAT procedure gave trainees a template for how to actively scan a takeover scenario for relevant objects or events, and expert commentary to guide their attention and provide immediate feedback to the task. In this way, the learning approach and procedural design aimed to motivate the driver in the uptake of desired behaviours, and that this would facilitate them in being 'on-the-loop' during transitions of control.

The CHAT acronym was designed to attend to a number of principles relating to supporting learning, memory and understanding (Wickens et al., 2014). This included the semantic association with our understanding of the importance of communication in collaborative partnerships. The selection of the word 'chat' was intended to inspire and reflect the process of conversation that facilitates mutual understanding, and efficient and effective collaboration and decision making when working towards a shared goal.

The aim of the simulator study was to compare the new, behavioural CHAT training with a more traditional approach. We are mindful that it may appear to the reader that those receiving the CHAT behavioural training received a far more immersive and engaging experience compared to those receiving Operational training, and that it is therefore unfair to make a direct comparison. We believe that the reason for this apparent disparity (should the reader be of this opinion) is because we have gone to some length to explain the underlying rationale and motivation for the new Behavioural training, provided comprehensive theoretical grounding to frame this approach, and included full details of how the participant was guided through the content. In contrast, the Operational training is rather disparagingly introduced as a 'user manual'. It is therefore important to recognise that in practice, the training experience provided as part of the simulator study was designed to be comparable between both groups. It is also worth highlighting the following points to support our approach:

- **Authenticity**. The Operational training is a true reflection of the level of detail and approach offered by current user manuals for automated systems. In practice, it is expected that a lot of new users will not read their user manual in great detail, if at all. During the study, however, we provided dedicated time and specific instruction to read through the manual in detail and followed this with a test drive scenario to re-enforce the learning.
- **Content**. The Behavioural training did not include any functional details about how to use the system, typically found in user manuals. This cohort *only* learnt how to use the automated system via the test drive scenario, and did not have sight of any

details regarding the functionality of individual features such as autosteer/ACC. In other words, they were only provided with information on the overarching limitations and what this meant for their interaction with the vehicle, not with specific details on how the system operated. Behavioural training also focused on the wider context of automation to aid understanding, i.e. 'automation policy' and 'automation principles', which was absent within the functional approach of a user manual.

- **Timing and Trainer Involvement**. Both approaches lasted the same amount of time and neither involved face-to-face interaction with a trainer, albeit Behavioural training made use of expert commentary to aid delivery. Even so, this still relied on the motivation and understanding of the learner to self-administer the training (i.e. they were required to select and playback episodes and move through the presentation at their own pace).
- **Training Assessment**. All participants were asked to evaluate their training experience using a questionnaire adapted from a classroom engagement study by Wang et al., (2014). Results from the training evaluation questionnaire show that there were no significant differences between groups in terms of engagement, usefulness and attitude. This indicates that both approaches were comparable from the perspective of the participants' experiences.

6.2 Subjective ratings

Whereas trust ratings were comparable between groups at the start of the study, the subjective data shows that participants who received Operational training expressed higher trust-in-automation and higher intention to use SAE-level 3 automation after their experience, and felt their situation awareness (SA) was as good as those receiving Behavioural training. In contrast, those in the Behavioural group felt greater time pressure (temporal workload) associated with the demands of the task (maintaining awareness, sharing control, keeping on or in-the-loop etc.), and indicated no differences in their trust and intention to use the automation after the drive.

On face value, the outcomes associated with the Operational group may seem to be more favourable – after all, it is important that people trust future technologies and intend to use them. Moreover, lowering the workload may, on initial inspection, appear desirable. However, the concern is that at intermediate levels of automation, the driving task is shared, and the driver therefore retains responsibilities and has specific tasks to undertake, even when the vehicle is notionally in control. Consequently, trust must be appropriate to avoid the driver over-trusting or over-relying on the technology. Moreover, achieving the right level of workload – commensurate with the task at hand (i.e. not removing it completely), is not only favourable, but also a prerequisite to help drivers remain alert and maintain awareness (Young and Stanton, 2007), and is also expected to support the accurate calibration of trust. We therefore posit that drivers in the Operational group may be forming opinions and making decisions based on limited knowledge or poorly constructed mental models, leading to overly optimistic assumptions about the capability of the automation, and unsubstantiated judgements about the level of trust they should place in the system. Such factors have already been highlighted as possible deleterious consequences of vehicle automation (Seppelt and Victor, 2016; Kyriakidis et al., 2019). These are exactly the elements that the Behavioural training aimed to address. Indeed, trust ratings made by drivers in the Behavioural group were unchanged after the experience.

6.3 Visual behaviour

During the study, drivers provided subjective ratings of their SA using the situation awareness rating technique (SART) (Taylor, 2017). However, it can be difficult to guarantee that the SART scale items have been interpreted and applied correctly, particularly in the context of simulated driving, and there is an inevitable delay before responses are collected. In contrast, 'freeze-probe' techniques, such as the Situation Awareness Global Assessment Technique (SAGAT) (Endsley, 1988), provide the opportunity to question participants at the point of criticality. However, these may still be unreliable and subject to bias in certain contexts. For example, obscuring the road scene and asking participants to recall precise details of the type and location of all other road users, etc., fails to acknowledge the dynamic nature of the driving task, and the relative levels of risk presented by different road users. For instance, a driver might be expected to direct greater attention towards a vehicle displaying unusual behaviour (e.g. unexpected braking, swerving or tailgating their own vehicle) and subsequently reduce the relative level of attention they direct towards other apparently 'safer' drivers. As such, when asked, they may be able to provide a precise estimation of the location of the former, but not necessarily the latter road users. To overcome some of these limitations, researchers look to other surrogate measures of SA–in particular, those that show the driver is making an active attempt to engage with the driver scene and key elements within it. In this context, eye movements, such as glances to mirrors, have been shown to be one of the most perspicuous activities (De Winter et al., 2019). Mirror checks are considered essential for safe driving and help drivers to maintain (or rebuild) SA (Li and Busso, 2013). This is particularly the case in the context of automated driving, whereby drivers may be engaged in NDRTs: checking their mirror, or the roadway, demonstrates a clear and deliberate attempt to disengage from these activities (if only, temporarily) and rebuild their awareness of, or to remain engaged with, key elements in their surroundings during automated driving.

The results and analysis show that drivers in the Behavioural group made significantly more mirror checks during automated driving and when asked to prepare-to-drive than those who received Operational training. In practice, drivers receiving Behavioural training carried out over 30 additional mirror checks compared to those receiving Operational training (on average, 47 per person compared to 16.8, respectively) – even during the short journey. They were also more likely to see the tailgating hazard car, which appeared at the same time as the takeover request was issued – ten out of the eleven drivers (over 90%) in the Behavioural group saw the hazard car, compared to only three of the thirteen drivers (23%) in the

Operational group. Given that four drivers in the Operational group made at least one glance to their rear-view mirror during the transition of control, it can be assumed that one of these drivers looked in their mirror but failed to notice the hazard car – 'look-but-failed-to-see' errors have been highlighted as a major cause of road traffic incidents, particularly involving more vulnerable road users, such a cyclists and motorcyclists (Herslund and Jørgensen, 2003). This detail was confirmed in the post-study interview and provides further support for the provision of a specific operating procedure, such as CHAT, to encourage conscious processing of the checks and assessments drivers must do at this point in the drive.

One of the notable problems highlighted in our previous study was that drivers remained actively engaged with their NDRTs after receiving the TOR instead of preparing to drive. Moreover, the amount of time they continued to remain engaged with NDRTs increased over the week, with drivers choosing to continue with these activities for longer each day, even during the prepare-to-drive period. It was also noted that these drivers tended to make an initial, perfunctory glance to the road, when asked to prepare to drive, but then immediately returned their attention to their NDRT, choosing to prioritise this instead. In the current study, we therefore explored this as a period of shared attention. This period was defined as the time from the driver's first attempt to re-engage with the driving scene, indicated by their first driving-related glance (e.g. to a mirror or the forward road scene) immediately after the TOR was issued, until their final NDRT-related glance or interaction. These timings were taken directly from the videos. It is interesting to note that drivers receiving Behavioural training demonstrated an earlier, shorter period of shared attention, compared to those receiving Operational training. On average, drivers in the CHAT group started to re-familiarise themselves with the driving scene (i.e. start of shared attention), 14 seconds earlier and had completely discharged their non-driving related activities 23.5 seconds sooner, than Operational drivers. This naturally provides more time to enable drivers to re-familiarise themselves with driving.

During the current study, we also recognised that mirror glances made following the takeover of manual control served two purposes. First, these were used to build SA (allowing drivers to contemplate changing lanes), and then subsequently to maintain awareness during the lane change manoeuvre itself. In other words, drivers typically made several mirror glances after resuming manual control. These were initially used to build awareness of their surroundings but did not necessarily precipitate the action of changing lanes. When we believe the driver had confirmed that it was safe to change lanes (based on our expert analysis of the video and driving performance data), mirror checks were thereafter employed to maintain awareness during the manoeuvre itself. It is therefore interesting to note that drivers receiving Behavioural training made significantly more mirror checks after resuming manual driving, but *before* starting the lane change, and more mirror checks during the lane-change manoeuvre itself, even though, arguably, they were already in possession of greater awareness of their surroundings (given the higher number of mirror checks during automated driving) than drivers in the Operational group. Although, this may reflect and require additional workload and effort, it also indicates a more cautious approach – one which we would argue is more appropriate given that drivers may have been 'out of the loop' with respect to the driving task for an extended period of time.

6.3.1 Out-of-the-Loop, On-the-Loop and In-the-Loop

Attendance to an NDRT (including thought, i.e. 'mind not on driving') during automated driving induces an OOTL driver state (Merat et al., 2019). It could be argued that without appropriate training or HMI support to improve SA in a timely way, that there is a residual impact on driver SA and vigilance well after explicit shared control has visibly ceased. For example, the lack of mirror glances conducted by drivers from the Operational group during the transition period demonstrated a failure to observe safety critical areas of the roadway. This, in turn, negatively impacted their visual search and selective attention performance in perceiving the tail-gating car and putting them at increased risk of inattentional blindness (Mack and Rock, 1998), as evidenced by the driver who 'looked but failed to see' the hazard car even though they had actually looked in the mirror. In other words, during the transition phase from automated to manual driving, drivers in the Operational training group could be said to be 'on the loop' in relation to the innermost loop in Merat et al.'s (2019) multi-level control in driving model, but remained 'out of the loop' at both the middle and outermost loops (see Figure 2.2). In contrast, those drivers receiving Behavioural training could be said to be 'on the loop' (for all loops) during the transition, actively monitoring the driving situation and attending to multiple on-road regions, which resulted in a greater number of mirror glances in relation to the basic vehicle motion control and during the planning and execution of the lane change manoeuvre.

6.4 Driving performance

Following the handover of control, participants had been instructed to move into lane 1 and exit the dual carriageway. Given the presence of other road users in lane 1, this meant that they were required to find a suitable space between vehicles already travelling in lane 1 and move safely into this before leaving the road. However, the other road users in lane 1 were not necessarily in exactly the same positions relative to the ego vehicle for each participant – not least because drivers could choose to curtail the 60 seconds prepare-to-drive notification and resume manual control sooner, if so desired. Consequently, there was no 'perfect', predefined manoeuvre with which to compare driver groups. It is therefore difficult to draw robust conclusions from the driving performance data. Moreover, in the chosen scenario, which was specifically selected to ensure drivers were required to make the type of manoeuvre that might be expected following the transition of control, behaviour may be interpreted in different ways. For example, a swift move into lane may be due to the fact that the driver already had good awareness of their surroundings and were confident that it was safe to change lanes immediately; equally, it could be because the driver *thought* it was safe to change lanes, but in fact it is not, i.e. it is precisely their lack of awareness that has precipitated the manoeuvre. Consequently, it is not possible to draw absolute comparisons between groups in the current study. Therefore, the lack of significant differences in driving performance measures is not of particular concern here. We believe that it is simply symptomatic of the nature of the driving task, immediately following the handover of control, and an artefact of the naturalistic design of the scenario. Moreover, no specific technical takeover skills were imparted during the training, and drivers were only in attendance on a single occasion. Nevertheless, it is suspected that different results and driving performance may be observed in a different post-takeover scenario, although caution should be applied in the selection of a post-automation scenario. For example, other related work has often employed a hazard situation immediately after the transition of control, such as a braking vehicle ahead. Drivers' response to a potential collision event such as this is often reflexive, typified by sudden, emergency braking (Zeeb et al., 2016; Gold et al., 2018): while they may therefore be successful in avoiding the hazard, it does not necessarily indicate that they are fully prepared to control their vehicle and engage with other road users.

6.5 Benefits of CHAT

6.5.1 Human-Machine interface (HMI) design

In joint cognitive systems (i.e. where the human and 'intelligent' machine each play a role in a shared task), such as driving automated vehicles, both the human and the system need to collaborate to deliver safe and comfortable driving. The main means of communication between the vehicle and human to facilitate this partnership is the human-machine interface (HMI). A key role of the HMI is to help the human driver understand what is expected of them in terms of monitoring and active interventions (Carsten and Martens, 2019). As system design affordances (i.e. the qualities or properties that define how something should be used) can lead to misuse or incorrect interactions with vehicle automation (Merat et al., 2019), so the HMI plays an important role in supporting appropriate driver behaviour. Following ecological design principles (Rasmussen and Vicente, 1989), the goal of an HMI should be to support the efficient, rapid and accurate recall of desired skill-based behaviours and avoid the need for drivers to employ reflective interpretation of information that could slow down required responses in time-critical scenarios. The CHAT procedure was designed with these key points in mind. It presents a potential design template for use in HMI design that has the potential to provide an effective countermeasure to human performance problems relating to OOTL driver state induced by automated driving at level 3 automation and exists in a format preferable to decision tools or remedial skills training (Carsten and Martens, 2019).

6.5.2 Standardisation and versatility

In addition to its proven effectiveness at motivating behavioural change in situational monitoring, the concept of CHAT has further applied benefits in relation to standardisation and versatility that make it an attractive concept for further development. First, the CHAT concept provides an opportunity for a standardised approach to an, arguably, essential operating procedure relating to transitions of control in level 3 automated vehicles and is independent of differences in system design. Its distinctive and memorable design and succinct format make it practical for use either within HMI solutions, or, if vehicle manufacturers are averse to using the concept within their designs for aesthetic reasons, it can be applied within public safety or marketing campaigns (similar to the 'THINK!' road safety campaign (Transport, 2020). Repetitive use, facilitated by either of these approaches, should aid learning. In this case, the CHAT procedure moved from declarative to procedural knowledge and encouraged transfer of training (Krampell et al., 2020). The use of CHAT within HMI design offers a way to improve SA and attention in a timely way as communication via the HMI can promote efficient scheduling of situation monitoring tasks with the driver, a key goal in procedural design (Degani and Wiener, 1997). Additionally, the explanatory training related to CHAT and the guiding philosophies of automation principles, policies and procedures is versatile enough to be either integrated into training for new drivers or delivered on a stand-alone basis to experienced drivers at point of sale or hire of a level 3 automated vehicle.

6.6 Summary and limitations

Overall, results suggest that behavioural 'CHAT' training had a positive influence on tactical level task performance during automated driving and following a transition to manual driving. It is also possible to infer that the early engagement in re-building SA demonstrated by drivers in the Behavioural group led to more informed and measured decision making in relation to the lane change manoeuvre. However, caution must be used when interpreting the success of these results. First, the effect on knowledge retention and maintenance of desired behaviour has not been tested within the present study. Second, success of any proposed driver training intervention will depend on the willingness and compliance of drivers to complete it and the relevant bodies to facilitate, finance and regulate its development and management. These challenges make a valid case to investigate ways of integrating the key concepts used in this Behavioural training intervention into a technological design solution. In particular, as the training intervention did not aim to introduce any new skills, but rather apply those that experienced drivers will already have, it is envisaged that these would represent a specific operating procedure to support the new automated driving context.

It is also worth recognising that the results as presented relate to the specific set of controlled conditions to which participants were exposed. The most significant factor being that the study took place within a medium-fidelity driving simulator. To address such concerns, we ensured that the experience was as realistic as possible, given our expert understanding and expectations of future vehicle capabilities, and we applied a naturalistic approach as far as was practicable – for example, participants could select their own NDRTs and choose when to disengage automated driving following the TOR. Nevertheless, there remains unavoidable, inherent limitations associated with research conducted in a driving simulator, relating to factors such as the fidelity of the experience, the absence of risk from harm if a collision occurs, and so on (Caird and Horrey, 2011). For these reasons, caution should be applied when drawing absolute conclusions and relating these to on-the-road behaviour. However, we are confident of the *relative* validity of our study findings, and the *absolute* value and potential benefits of behavioural change motivators, such as CHAT. We would also remind readers that it remains an inevitable necessity to use simulated experiences and approaches to explore future technologies, particularly where these are simply not yet available (or legal to use on the roads) or may present an unnecessarily high risk to participants.

7. Conclusions

Future vehicles are expected to be capable of delivering intermediate levels of automation that may allow the driver to relinquish control under certain, predefined conditions. However, these vehicles are likely to retain the same form factor as current vehicles on the road, and as such, they may not present an obvious step change in development. Drivers, as well as those responsible for delivering driver training– and indeed, those who manufacture and sell these vehicles– may therefore be forgiven for assuming that no new skills are required to use them. Current, passive modes of training, such as providing a user manual, may also appear to be acceptable. To date, the introduction of standalone driver support technologies, such as cruise control, have not fundamentally changed the role of the driver. However, the advent of intermediate levels of automation means that the driving task will become one that is shared between the driver and the vehicle, and this completely changes the ideology of what makes a 'driver' and a 'car', and the interrelationship and interactions between them. One key challenge in this relationship is ensuring that drivers possess the knowledge and skills to operate and interact with partially automated vehicles in a safe and appropriate manner. It is therefore important that drivers understand the capability and competence of the automated system being used.

Building on an extensive literature review and informed by interviews conducted with experienced drivers and expert driving instructors, we applied behavioural change theories to develop a proof-of-concept, behavioural training intervention. This took the form of a specific operating procedure (CHAT) to be applied during the transition of control and was tested in a between-subjects driving simulator study to demonstrate its immediate and tangible benefits. Interestingly, drivers who had not received the Behavioural training ('the Operational group') judged aspects of their own behaviour and performance favourably, as evidenced by high ratings of trust, the belief that they were equally well-informed about the driving scenario (i.e. the same level of situational awareness (SA)), low ratings of workload, and the fact that they remained engaged with their NDRTs for much longer. Given our previous work, and based on observations and findings from the current study, we would argue that, the mental model of these drivers was likely to have been incorrect from the start, and therefore the approach they took and the judgements they made were applied on an ad-hoc basis. This may in fact be adequate in some situations, and their performance during the transition of control may even be deemed "good enough" during the study, though clearly not optimal. On the road, however, this may not be the case. The concern is that because of their lack of knowledge and awareness, these drivers may make overly optimistic assumptions about the capability of the automation, leading to unacceptable or dangerous behaviour. Moreover, for these drivers, their mental model will arguably only be updated or corrected by chance, for example, if they were directly involved in a hazardous situation.

The behavioural training developed for this report specifically addresses these points, aiming to ensure that drivers are aware of what they should or could be doing to help prepare themselves to take over control following a period of automated driving. It also encourages drivers to remain engaged with the tactical and strategic elements of the driving task during periods of automation and the transition of control, and avoid focussing solely on the operational or control tasks during the takeover. It is therefore notable that ratings for trust and intention to use did not increase after the experience amongst those who received behavioural training.

The improvements in visual behaviour are abundantly clear. Drivers in the Behavioural group were more likely to conduct checks to the internal and external driving environment during the transition from automation to manual mode than drivers who received the Operational training. They were also more likely to demonstrate positive visual behaviours relating to tactical and strategic level tasks during the automated driving mode than their counterparts. They were arguably therefore better prepared to successfully perform a manoeuvre shortly after transition from automation to manual control than drivers who had received the Operational training.

Nevertheless, it is recognised that the effect on knowledge retention and maintenance of desired behaviour is yet to be tested. Moreover, as already highlighted, the success of any proposed driver training intervention will depend on a number of interrelated factors. These factors are outside the scope of the current study. The next phase in this research will focus on using the novel CHAT procedure to inform the design and development of a human machine interface to support the uptake and, importantly, the maintenance of the desired driver behaviours.

The research team intends to extend these research findings by seeking to validate the CHAT approach and develop it further, for example, by recruiting a more diverse range of participants (in terms of age, driving experience, culture and so on). In addition, there is a need to explore whether formal training is necessary for experienced drivers, or if the introduction of the CHAT principles into manufacturer guidance and in-vehicle technological solutions is sufficient to mitigate against the performance issues identified by previous research. CHAT may, therefore, present an opportunity to improve driver safety at level 3 automation without the need for formal training interventions or graduated licences, reducing disruption to the roll out of such vehicles without compromising on safety.

References

Abraham, H., Lee, C., Brady, S., Fitzgerald, C., Mehler, B., Reimer, B., & Coughlin, J. F. (2017). Autonomous Vehicles and Alternatives to Driving: Trust, Preferences, and Effects of Age Learning to Use Technology View project. *Transportation Research Board 96th Annual Meeting*, (January). Available at: https://www.researchgate.net/publication/319269855.

Bainbridge, L. (1982). Ironies of Automation. *IFAC Proceedings Volumes*. Elsevier, 15(6):129–135.

Banks, V. A., Eriksson, A., O'Donoghue, J., & Stanton, N. A. (2018). Is partially automated driving a bad idea? Observations from an on-road study. *Applied Ergonomics*. Elsevier, 68:138–145.

Banks, V. A., Plant, K. L. and Stanton, N. A. (2019). Driving aviation forward; contrasting driving automation and aviation automation. *Theoretical Issues in Ergonomics Science*. Taylor & Francis, 20(3):250–264.

Banks, V. A. and Stanton, N. A. (2016). Keep the driver in control: Automating automobiles of the future. *Applied Ergonomics*. Elsevier Ltd, 53:389–395.

Banks, V. A. and Stanton, N. A. (2019). Analysis of driver roles: modelling the changing role of the driver in automated driving systems using EAST. *Theoretical Issues in Ergonomics Science*. Taylor & Francis, 20(3):284–300.

Banks, V. A., Stanton, N. A. & Harvey, C. (2014) Sub-systems on the road to vehicle automation: Hands and feet free but not "mind" free driving. *Safety Science*. Elsevier, 62:505–514.

Beggiato, M., Pereira, M., Petzoldt, T., Krems, J., (2015). Learning and development of trust, acceptance and the mental model of ACC. A longitudinal on-road study. *Transportation Research Part F: Traffic Psychology and Behaviour*. Elsevier Ltd, 35:75–84.

Beggiato, M. & Krems, J. F. (2013). The evolution of mental model, trust and acceptance of adaptive cruise control in relation to initial information. *Transportation Research Part F: Traffic Psychology and Behaviour*. Elsevier Ltd, 18:47–57.

Bell, B. S. & Kozlowski, S. W. J. (2008). Active Learning: Effects of Core Training Design Elements on Self-Regulatory Processes, Learning, and Adaptability Regulatory Processes, Learning, and Adaptability. *Journal of Applied Psychology*. 93(2):296.

Braun, V. & Clarke, V. (2006). Using thematic analysis in psychology', Qualitative Research in Psychology, 3(2):77–101.

Brown, B. & Laurier, E. (2017). The Trouble with Autopilots, in Proceedings of the 2017 CHI *Conference on Human Factors in Computing Systems*, CHI, 17. New York, New York, USA: ACM Press:416–429.

Budiu, R. (2018). Between-Subjects vs. Within Subjects Study Design. Available at: https://www.nngroup.com/articles/between-within-subjects/ (Accessed 18 August 2020).

Burnett, G., Large, D. R. & Salanitri, D. (2019). *How will drivers interact with vehicles of the future?* RAC Foundation, London

Caird, J. K., & Horrey, W. J. (2011). Twelve practical and useful questions about driving simulation. In D. L. Fisher, M. Rizzo, J. K. Caird, & J. D. Lee (Eds). *Handbook of driving simulation for engineering, medicine, and psychology* 5:1-5,18. Boca Raton, FL: CRC Press.

Campbell Darryl (2019). The many human errors that brought down the Boeing 737 Max– The Verge, Vox Media. Available at: https://www.theverge.com/2019/5/2/18518176/boeing-737-max-crash-problems-human-error-mcas-faa (Accessed: 18 September 2019).

Carsten, O. & Martens, M. H. (2019). How can humans understand their automated cars? HMI principles, problems and solutions, *Cognition, Technology and Work*. Springer London, 21(1):3–20.

Casner, S. M. & Hutchins, E. L. (2019). What Do We Tell the Drivers? Toward Minimum Driver Training Standards for Partially Automated Cars. *Journal of Cognitive Engineering and Decision Making*. 13(2):55–66.

Casner, S. M., Hutchins, E. L. & Norman, D. (2016). The challenges of partially automated driving. *Communications of the ACM*, 59(5):70–77.

Castro, C., Ventsislavova, P., Pena-Suarez, E., Gugliotta, A., Garcia-Fernandez, P., Eisman, E., & Crundall, D. (2016). Proactive Listening to a Training Commentary improves hazard prediction. *Safety Science*. Elsevier, 82: 144–154.

Cummings, M., Huang, L., Zhu, H., Finkelstein, D., & Wei, R. (2019). The Impact of Increasing Autonomy on Training Requirements in a UAV Supervisory Control Task. *Journal of Cognitive Engineering and Decision Making*. Sage CA: Los Angeles, CA. 295-309.

Cummings, M. M. (2014). Man versus Machine or Man + Machine? *IEEE Intelligent Systems*, 29(5):62–69.

De Winter, J.C., Eisma, Y.B., Cabrall, C.D.D., Hancock, P.A. & Stanton, N.A., (2019). Situation awareness based on eye movements in relation to the task environment. *Cognition, Technology & Work*, 21(1):99-111.

De Winter, J.C., Happee, R., Martens, M.H., & Stanton, N.A. (2014). Effects of adaptive cruise control and highly automated driving on workload and situation awareness: A review of the empirical evidence. *Transportation Research Part F: Traffic Psychology and Behaviour*. Elsevier Ltd, 27(PB):196–217.

Degani, A.; Weiner, E. (1994). Philosophy, policies, procedures, and practices in *Aviation Psychology in Practice*. Brookfield; VT: Ashgate Publishing Co.

Degani, A. & Wiener, E. L. (1997). Procedures in complex systems: the airline cockpit. *IEEE Transactions on Systems, Man, and Cybernetics–Part A: Systems and Humans*, 27(3):302–312.

Dogan, E., Rahal, M. C., Deborne, R., Delhomme, P., Kemeny, A., & Perrin, J. (2017). Transition of control in a partially automated vehicle: Effects of anticipation and non-driving-related task involvement. *Transportation Research Part F: Traffic Psychology and Behaviour*. Elsevier Ltd, 46:205–215.

Endsley, M. R. (2017). From Here to Autonomy: Lessons Learned from Human-Automation Research. *Human Factors*, 59(1):5–27.

Endsley, M. R. (1988). Situation awareness global assessment technique (SAGAT). *Proceedings of the IEEE 1988 National Aerospace and Electronics Conference*. IEEE: 789–795.

Eriksson, A. & Stanton, N.A., (2017). Takeover time in highly automated vehicles: noncritical transitions to and from manual control. *Human Factors*, 59(4):689-705.

Flemisch, F. et al. (2012). Towards a dynamic balance between humans and automation: Authority, ability, responsibility and control in shared and cooperative control situations. *Cognition, Technology and Work*, 14(1):3–18.

Friard, O. & Gamba, M. (2016). BORIS: a free, versatile open-source event-logging software for video/audio coding and live observations. *Methods in Ecology and Evolution. British Ecological Society*, 7(11):1325–1330.

Fylan, F. (2017). *Using Behaviour Change Techniques: Guidance for the road safety community*. London.

Gold, C., Berisha, I. & Bengler, K. (2015a). Utilization of Drivetime – Performing Non-Driving Related Tasks While Driving Highly Automated. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*. Human Factors an Ergonomics Society Inc., 59(1):1666–1670.

Gold, C., Körber, M., Hohenberger, C., Lechner, D. and Bengler, K. (2015b). Trust in automation –Before and after the experience of take-over scenarios in a highly automated vehicle. *Procedia Manufacturing*, 3:3025-3032.

Gold, C., Happee, R. & Bengler, K. (2018). Modeling takeover performance in level 3 conditionally automated vehicles. *Accident Analysis and Prevention*. Elsevier, 116(April 2017):3–13.

Hart, S. G. & Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research. *Advances in Psychology*. North-Holland, 52(C):139–183.

Hatakka, M. et al. (2002). From control of the vehicle to personal self-control; broadening the perspectives to driver education. *Transportation Research Part F: Traffic Psychology and Behaviour*. Elsevier Ltd, 5(3):201–215.

Herslund, M. B. & Jørgensen, N. O. (2003). Looked-but-failed-to-see-errors in traffic. *Accident Analysis and Prevention*. Elsevier Ltd, 35(6):885–891.

Janssen, C. P., Iqbal, S. T., Kun, A. L. & Donker, S.F. (2019). Interrupted by my car? Implications of interruption and interleaving research for automated vehicles. *International Journal of Human-Computer Studies*. Academic Press, 130:221–233.

Kaber, D. B. (2018). Issues in Human–Automation Interaction Modeling: Presumptive Aspects of Frameworks of Types and Levels of Automation. *Journal of Cognitive Engineering and Decision Making*. SAGE Publications, Sage CA: Los Angeles, CA, 12(1) 7–24.

Kircher, K., Larsson, A. & Hultgren, J. A. (2014). Tactical driving behavior with different levels of automation. *IEEE Transactions on Intelligent Transportation Systems*. IEEE, 15(1):158–167.

Klauer, S. G., Dingus, T.A., Neale, V.L., Sudweeks, J.D., & Ramsey, D.J. (2006). *The Impact of Driver Inattention on Near-Crash/Crash Risk: An Analysis Using the 100-Car Naturalistic Driving Study Data*. United States. National Highway Traffic Safety Administration. Available at: https://vtechworks.lib.vt.edu/handle/10919/55090 (Accessed: 26 June 2020).

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

Krampell, M., Solís-Marcos, I. & Hjälmdahl, M. (2020). Driving automation state-of-mind: Using training to instigate rapid mental model development. *Applied Ergonomics*, 83(October 2019).

Kyriakidis, M., De Winter, J.C., Stanton, N., Bellet, T., Van Arem, B., Brookhuis, Martens, M.H., Bengler, K., Andersson, J., Merat, N., & Reed, N. (2019). A human factors perspective on automated driving. *Theoretical Issues in Ergonomics Science*. Taylor & Francis, 20(3):223–249.

Large, D.R., Banks, V., Burnett, G. (2017). Literature Review: Human-Automation Coordination, Communication and Shared Control. Nottingham.

Large, D.R., Burnett, G., Salanitri, D., Lawson, A., Box, E. (2019). A Longitudinal Simulator Study to Explore Drivers. Behaviour in Level 3 Automated Vehicles in *Automotive User Interfaces and Interactive Vehicular Applications* (AutoUI2019). Utrecht, Netherlands.

Lawson, G., Shaw, E., Roper, T., Nilsson, T., Bajorunaite, L., & Batool, A. (2019). *Immersive virtual worlds: Multi-sensory virtual environments for health and safety training*. Available at: http://arxiv.org/abs/1910.04697 (Accessed: 26 June 2020).

Lee, J., Young, K. & Regan, M. (2009). Defining driver distraction. In Regan, M., Lee, J., & Young, K. (eds) *Driver Distraction: Theory, Effects, and Mitigation*. Boca Raton: CRC:31–40.

Li, N. & Busso, C. (2013). Driver Mirror-Checking Action Detection Using Multi-Modal Signals. In *Proceedings of 6th Biennial Workshop in Digital Signal Processing for in-vehicle Systems and Safety*, 101-108.

Lin, R., Ma, L. & Zhang, W. (2018). An interview study exploring Tesla drivers' behavioural adaptation. *Applied Ergonomics*. Elsevier, 72 (December):37–47.

Mack, A. & Rock, I. (1998). Inattentional Blindness: Perception without attention', in Wright, R. D. (ed.) *Visual attention*. Oxford University Press: 55–76.

McDonald, A; Carney, C.; McGehee, D. V. (2018). *Vehicle Owners' Experiences with and Reactions to Advanced Driver Assistance Systems*. Washington, DC. Available at: https://aaafoundation.org/vehicle-owners-experiences-reactions-advanced-driver-assistance-systems/.

Melcher, V., Rauh, S. Deiderichs, F., Widlroither, H., & Bauer, W. (2015). Takeover Requests for Automated Driving. *Procedia Manufacturing*, 3:2867–2873.

Merat, N., Jamson, A.H., Lai, F.C., Daly, M., & Carsten, O.M. (2014). Transition to manual: Driver behaviour when resuming control from a highly automated vehicle. T*ransportation Research Part F: Traffic Psychology and Behaviour*. Elsevier Ltd, 27(PB):274–282.

Merat, N., Seppalt, B., Louw, T., Engstrom, J., Lee, J.D., Johansson, E., Green, C.A., Katazaki, S., Monk, C., Itoh, M., & McGeehee, D. (2019). The "Out-of-the-Loop" concept in automated driving: proposed definition, measures and implications. *Cognition, Technology and Work*. Springer London, 21(1):87–98.

Michon, J. A. (1985). A Critical View of Driver Behaviour Models: What Do We Know, What Should We Do? *Human Behaviour and Traffic Safety*. Edited by R. Evans, Leonard; Schwing. Boston, MA: Springer.

National Transportation Safety Board (2020). *Final Reports for 2 Advanced Driver Assistance System Crash Investigations* Published. [Press Release]. 19 March. Available at: https://www.ntsb.gov/news/press-release/Pages/NR20200319.aspx. (Accessed: 29/07/2020).

National Transportation Safety Board (2019). *Collision Between Vehicle Controlled by Developmental Automated Driving System and Pedestrian*. Available at: https://www.ntsb.gov/investigations/AccidentReports/Reports/HAR1903.pdf (Accessed: 29/07/2020)

National Transportation Safety Board (2017). Collision Between a Car Operating with Automated Vehicle Control Systems and a Tractor-Semitrailer Truck, *Highway Accident Report*. Available at: https://www.ntsb.gov/investigations/AccidentReports/Reports/HAR1702.pdf. (Accessed: 25/04/2019

Norman, D. A. (1988). *The Psychology of Everyday Things*. Basic books. New York.

Nylen, A. B., Reyes, M.L., Roe, C.A., & McGeehee, D.V. (2019). Impacts on Driver Perceptions in Initial Exposure to ADAS Technologies. *Transportation Research Record*: Journal of the Transportation Research Board:354-360.

Parasuraman, R. & Riley, V. (1997). Humans and Automation: Use, Misuse, Disuse, Abuse. *Human Factors: The Journal of the Human Factors and Ergonomics Society*. SAGE PublicationsSage CA: Los Angeles, CA, 39(2):230–253.

Parasuraman, R., Sheridan, T. B. & Wickens, C. D. (2000). A model for types and levels of human interaction with automation–Syst ems, Man and Cybernetics, Part A, *IEEE Transactions on. IEEE Transactions on Systems, Man, and Cybernetics–Part A: Systems and Humans*, 30(3):1–12.

Rasmussen, J. (1983). Skills, rules, and knowledge; signals, signs, and symbols, and other distinctions in human performance models. *IEEE Transactions on Systems, Man, and Cybernetics, SMC*, 13(3):257–266.

Rasmussen, J. & Vicente, K. J. (1989). Coping with human errors through system design: implications for ecological interface design. *International Journal of Man-Machine Studies. Academic Press*, 31(5):517–534.

Sarter, N. B. & Woods, D. D. (1994). Pilot Interaction With Cockpit Automation II: An Experimental Study of Pilots' Model and Awareness of the Flight Management System. *The International Journal of Aviation Psychology*. Lawrence Erlbaum Associates, Inc., 4(1):1–28.

Seppelt, B. D. & Victor, T. W. (2016). Potential Solutions to Human Factors Challenges in Road Vehicle Automation. *Springer, Cham*:131–148.

Shaw, E., Large, D. R. & Burnett, G. (2020). Towards Future Driver Training: Analysing Human Behaviour in Level 3 Automated Cars. In Charles, Rebecca; Golightly, D. (ed.) *Contemporary Ergonomics & Human Factors*: 59–66.

Shepardson, D. (2020). NHTSA opens probe into fatal Tesla crash in Indiana. Automotive news. Available at: https://www.autonews.com/regulation-safety/nhtsa-opens-probe-fatal-tesla-crash-indiana. (Accessed: 27/07/2020).

Society of Automotive Engineers (SAE) (2016). J3016A: Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles. Available at: https://www.sae.org/standards/content/j3016_201609/ (Accessed: 6 August 2019).

Stanton, N. A. & Marsden, P. (1996). From fly-by-wire to drive-by-wire: Safety implications of automation in vehicles. *Safety Science*. Elsevier, 24(1):35–49.

Sullivan, J. M. et al. (2016). Literature Review of Behavioral Adaptations to Advanced Driver Assistance Systems. Available at: https://trid.trb.org/view/1445984 (Accessed: 9 July 2019).

Taylor, R.M., (2017). Situational awareness rating technique (SART): The development of a tool for aircrew systems design. In *Situation Awareness*, 111-128. Routledge.

Tesla Company (2019). *Model S Owner's Manual*, 208.

Transport, D. for (2020). *THINK! – Road safety*. Crown copyright. Available at: https://www.think.gov.uk/ (Accessed: 26 June 2020).

Victor, T. W. et al. (2018). Automation Expectation Mismatch: Incorrect Prediction Despite Eyes on Threat and Hands on Wheel. *Human Factors*, 60(8):1095–1116.

Walker, G. H., Stanton, N. A. & Salmon, P. (2016). Trust in vehicle technology. *International Journal of Vehicle Design*, 70(2):157.

Wang, Z., Bergin, C. & Bergin, D. A. (2014). Measuring engagement in fourth to twelfth grade classrooms: The classroom engagement inventory. *School Psychology Quarterly*. American Psychological Association Inc., 29(4):517–535.

White, H., Large, D. R., Salanitri, D., Burnett, G., Lawson, A., Box, E. (2019). Rebuilding Drivers' Situation Awareness During Takeover Requests in Level 3 Automated Cars. *Ergonomics & Human Factors*, Stratford-upon-Avon, UK.

Wickens, C. D., Lee, J.D., Liu, Y., Gorden-Becker, S. (2014). *An Introduction to Human Factors Engineering* (2nd Edition). Essex: Pearson Education Limited.

Young, M. S. & Stanton, N. A. (2007). What's skill got to do with it? *Vehicle automation and driver mental workload. Ergonomics*. Taylor & Francis, 50(8):1324–1339.

Zeeb, K., Buchner, A. & Schrauf, M. (2016). Is takeover time all that matters? The impact of visual-cognitive load on driver takeover quality after conditionally automated driving. *Accident Analysis and Prevention*. Elsevier Ltd, 92:230–239.

Appendices

A. Exploratory Interview Questions

B. Excerpt from Behavioural Training Describing CHAT Procedure

C. Operational Training Manual

D. Training Evaluation Questionnaire (TEQ)

E. Total Trust in Automation Questionnaire (TTAQ)

F. Situation Awareness Rating Technique (SART)

G. Workload Scale (NASA-TLX)

H. Statistical Testing

Appendix A: Exploratory Interview Questions

Part 1: Manual Driving

- Briefly, what do you think are the key skills and knowledge required by drivers of manual cars?
- As a **driving instructor**, how do you maintain attention of the road situation when supervising a pupil? [Are there any specific techniques you use?]
- If you need to take over control of the vehicle at any time, how would you do this? Talk me through the steps you would take (physical actions, how to determine when you need to do so, what do you say, etc.).

Part 2: Current Understanding of Automated Vehicle Technologies

- What is your understanding of **vehicle automation**? [Have you heard of it? What do you think it does?]
- What is your understanding of an **autonomous vehicle**? [How do you think this differs from 'vehicle automation'?]
- What is your understanding of **partial automation/partially automated vehicles**?
- How do you feel about automation/automated vehicles? [Have you seen any reports in press, e.g. Tesla AutoPilot?]
  - What do you think the benefits will be?
  - What concerns do you have?
- What are your expectations from future cars with automation?
  - What do you think cars will be able to do in the future?
- How could you imagine the driving task would change as more and more automation comes in?
  - How do you think vehicle automation will change… (select as appropriate)
    - the way your car operates?
    - the way you drive your car?
    - the way you instruct new drivers?
    - the way drivers are licensed?

Here are some typical automated features of vehicles currently available on the market. Have you heard of them? Do you know what they does? Do you use them?

    - Forward collision warning
    - Automatic emergency braking
    - Parking assist
    - Lane departure warning
    - Lane keeping assist
    - Blind spot warning
    - Rear cross-traffic warning
    - Adaptive cruise control

- Have any of these operated/activated unexpectedly, or startled you?
    - If so, did you seek information regarding why your vehicle behaved as it did? [If so, how did you do this – on-board system, web search, manual, dealership…?]

- Do you think specific training (knowledge/skills) should be provided for any of these features?
    - If yes, which ones/why?
    - And, how could that training be provided?

- As a **DRIVER**, do you think any of these features have/will change the way you drive or interact with your car? If so, how?
    - Would you look for them when buying a new car? / be willing to pay a premium for them?

- As a **DRIVING INSTRUCTOR**, do you discuss these features (and vehicle automation more generally) with students during lessons?
    - What do you say about them? [Positives or negatives?]

- There are 5 different levels of automation defined by the Society of Automotive Engineers. These are:
    - Level 0 – no automation
    - Level 1 – driver assistance
    - Level 2 – partial automation
    - Level 3 – conditional automation
    - Level 4 – high automation
    - Level 5 – full automation
- What do you think are the key skills and knowledge that will be required at each level?
- Should drivers be trained / licensed differently for each level?

Part 3: Future Vehicles–Issues, Skills and Training

For the questions in the second half of the interview, we will be focusing specifically on vehicles that sit in the mid-range of automation ('partial automation') – vehicles, which have a level of automation, whereby the system can control the execution of steering, acceleration/deceleration and monitoring of the driving environment, but where the human driver may be required to take over from the vehicle either in the event of an emergency or where the driving mode falls outside the boundary of system capability.

- What would you say the role and responsibility of the driver is at this level of automation?
- Should drivers in these vehicles be allowed to undertake secondary activities – unrelated to driving, when the vehicle is in control? [For example, using their phone, reading, sleeping?]
- As part of the driving task with vehicles at this level of automation, there may be a requirement to transfer control, whereby the driver would be required to takeover from the vehicle while the vehicle is moving.
  - What do you think the key challenges would be in taking over control in this situation?
  - Talk me through how you imagine this would happen? What steps would take place?
  - What **NEW** skills or knowledge do you think will be needed in order to take over from the vehicle? [Consider that it is moving while you're doing it?]
  - What training do you think **EXISTING drivers** would need to safely carry out this manoeuvre?
    - What do you think is the best way to deliver and assess this training?
  - What training do you think **NEW drivers** would need to safely carry out this manoeuvre?
  - What do you think is the best way to deliver and assess this training?
  - How do you think their training for future 'partially automated' vehicles would differ from driver training now in a manual car?
- What (other) new situations or issues could you see happening when using this level of automation?
- What other knowledge/skills do you think **EXISTING** or **NEW** drivers would need before driving vehicles equipped with this technology?
  - For each of these, what do you think is the best way to deliver and assess this training?
- Do you foresee any differences between **YOUNGER** and **OLDER** drivers acquiring these new skills/responding to training? [younger people may be more tech-savvy?]
- Do you think there are any skills **EXISTING drivers** would lose when using vehicles with this level of automation? Does this matter?
- Should there be ongoing (repeated/regular) training and assessment associated with the introduction of vehicles with higher levels of automation? [If so, what/how?]
- Should new forms of licensing be introduced, for example, that depend on the level of automation that the vehicle offers?

Appendix B: Excerpt from Behavioural Training Describing CHAT Procedure

"CHAT stands for ***Check 360, Assess, Takeover***.

Check 360 represents the checks you should make all around you both inside and outside the vehicle to make sure you are ready to drive.

Check yourself – are you ready to drive? Are you feeling tired? Your first priority action, must be to put non-driving tasks, such as your phone or tablet down, out of the way and in a safe place where they cannot distract you. You may need to re-set your seat if you have moved it during automated driving mode, check you can safely reach the pedals, and switch off any internal lights. Make sure you are comfortable to drive. Once you are in in the right position for driving you need to turn your attention to the road. You will need check all around you,

Check for hazards,

Check all the mirrors, and

Check your blind spot. Look to see where the vehicles and other road users are all around you. How busy is the road, are there vehicles in front of you, behind you, to the right or left of you, in your blind spot? It is important for you to know what else is on the road with you before you take over control of the vehicle movements.

Assess represents the essential assessment you need to carry out to be able to make decisions to maintain safe driving movements once you have taken over control of the full driving task.

You must ***assess*** your position,

the road,

the situation,

and the next steps you might need to take, both in the immediate situation and the journey.

Look to see where you are in comparison to the vehicles around you. Assess how fast the vehicles around you are going, whether they are approaching or moving away from you. Where are you on the road? Is it single or multi-lane? What vehicles are you approaching and will you need to take action such as braking or changing lanes to avoid a collision? What are the road conditions like? Are there are any bends in the road that you will need to navigate safely, is the speed limit about to change, is the road wet, is it foggy. These things will all affect how you drive and your decisions, for example, to drive slower than you would if the conditions were clear. What are the next steps you need to take along your route? Are you approaching a junction or a roundabout? You need to think about things like, which direction you will need to need to turn, which lane you need to be in, which exit you need to take.

Once you have checked and assessed all around you to re-engage with the monitoring aspect of the driving task you will be ready to takeover control of the vehicle's movements."

Appendix C: Operational Training Manual

Autocar3: Automated Driving User Manual

How It Works

Your Autocar3 includes the following automated driving components that actively monitor the surrounding roadway:

1. A camera is mounted above the rear license plate.
2. Ultrasonic sensors are located in the front and rear bumpers.
3. A camera is mounted in each door pillar.
4. Three cameras are mounted to the windshield above the rear view mirror.
5. A camera is mounted to each front fender.
6. Radar is mounted behind the front bumper on the side of the vehicle.

Autocar3 is also equipped with high precision electronically-assisted braking and steering systems.

Features

Automated driving operates by simultaneously engaging the following features. It is designed to reduce driver workload and allow the use of non-driving activities:

- Autosteer
- Advanced cruise control
- Advanced roadway monitoring

Automated driving mode is a hands-free feature. When engaged, automated driving mode does not require you to hold the steering wheel, allowing you to engage in tasks and activities not related to driving, such as the use of mobile phones. However, when manual driving mode is engaged you must hold the steering wheel at all times and all traffic legislation regarding the use of non-driving activities applies as usual to manual vehicles.

As automated driving is not available in all circumstances, Autocar3 requires that you are ready to respond to a takeover request from the vehicle and remain prepared to resume full manual control of the vehicle at any time.

Autosteer

Automated driving mode intelligently centres Autocar3 in its driving lane when cruising at a set speed. Using the vehicle's camera(s), the radar sensor, and the ultrasonic sensors, automated driving mode detects lane markings and the presence of vehicles and objects for assisting you in steering Autocar3.

> Warning: Autosteer is intended for use only on dual carriageways and motorways with a fully attentive driver. When using Autosteer, be mindful of road conditions. Do not use Autosteer on residential streets, in construction zones, or in areas where bicyclists or pedestrians may be present. Always be prepared to respond to a takeover request from the vehicle. It is the driver's responsibility to be in control of Autocar3 at all times. Failure to follow these instructions could cause damage, serious injury or death.

Advanced Cruise Control

With Autocar3's automated driving mode, the forward looking cameras and the radar sensor are designed to determine when there is a vehicle in front of you in the same lane. If the area in front of Autocar3 is clear, automated driving maintains a set driving speed. When a vehicle is detected, automated driving mode is designed to slow down Autcar3 as needed to maintain a selected time-based distance from the vehicle in front, up to the set speed. When cruising behind a detected vehicle, Advanced Cruise Control accelerates and decelerates Autocar3 as needed to maintain a following distance, up to the set speed.

Automated driving also adjusts the cruising speed when entering and exiting curves.

Note: When automated driving is actively slowing down Autocar3 to maintain the selected distance from the vehicle ahead, brake lights turn on to alert other road users that you are slowing down.

> Warning: Automated driving may occasionally cause Autocar3 to brake when not required or when you are not expecting it. This can be caused by closely following a vehicle ahead, detecting vehicles or objects in adjacent lanes (especially on curves), etc.

> Warning: Automated driving mode cannot operate in all circumstances. Always be ready to respond to a takeover request from you vehicle and be prepared to take over full manual control. Depending on automated driving in all circumstances can result in serious injury or death.

Advanced Roadway Monitoring

Automated driving has the capability to monitor the roadway and automatically apply the brakes when needed. Automated driving is primarily intended for driving on dry, straight roads, such as dual carriageways and motorways. It should not be used on town or city streets. Automated driving is designed for your driving comfort and convenience, it is not able to operate on all roadways and in all circumstances. It is your responsibility to stay alert, drive safely, and be ready to respond to a takeover request from your vehicle at all times. Always be prepared to take full manual control of the vehicle, in the event that the vehicle gives notice that automated driving needs to disable and you are required to resume manual control of the vehicle. Failure to do so can result in serious injury or death.

Warning: Automated driving cannot be used on residential streets or on roads where traffic conditions are constantly changing.

Warning: Automated driving cannot be used on winding roads with sharp curves, on icy or slippery road surfaces, or when weather conditions (such as heavy rain, snow, fog, etc.) make it inappropriate to drive at a consistent speed.

When automated driving is engaged and the vehicle approaches a condition where automated driving will no longer available for use, the vehicle will issue advanced notice for you to resume full, manual control of the vehicle.

Limitations

Many factors can impact the availability of the Automated driving mode within Autocar3, causing this mode to be disabled in certain conditions.

These include (but are not limited to):

- Poor visibility (due to heavy rain, snow, fog, sunlight etc.).
- Damage or obstructions caused by mud, ice, snow, etc.
- Interference or obstruction by object(s), mounted onto the vehicle (such as a bike rack).
- Obstruction caused by applying excessive paint or adhesive products (such as wraps, stickers, rubber coating, etc.) onto the vehicle.
- Narrow or winding roads.
- A damaged or misaligned bumper.
- Interference from other equipment that generates ultrasonic waves.
- Extremely hot or cold temperatures.

Warning: The list above does not represent an exhaustive list of situations where automated driving is not available for use. Never depend on these components to keep you safe. It is the driver's responsibility to stay alert, drive safely, and be ready to take full control of the vehicle at all times.

Engaging Automated Driving mode

You must ensure you are in the correct lane for automated driving before activating automated driving mode.

To use Automated driving, you must be driving at least 30 mph.

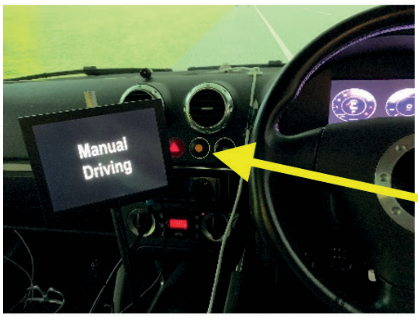
All alerts and information in relation to the driving modes and takeover requests will be displayed on the in-vehicle display screen, which is located in the area on the diagram below:

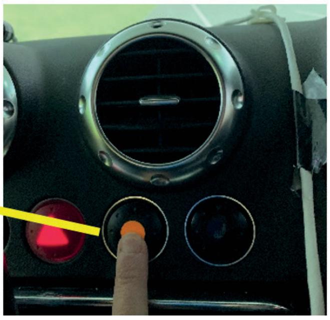
When the vehicle is in manual driving mode, the in-vehicle display screen will show the following visual alert:

When automated driving is available the in-vehicle display screen will show the following visual alert with accompanying 'AUTOMATED DRIVING AVAILABLE' audio alert.

Note: when this is alert is shown on the in-vehicle display screen, automated driving is available but is not actively controlling your vehicle movement until you activate it.

To activate automated driving mode push the orange button located above the radio as shown below:





When automated mode is engaged, the in-vehicle display will show the following visual alert with accompanying 'AUTOMATED DRIVING ENGAGED' audio alert.

Takeover Requests and Resuming Manual Driving mode

If Autocar3 approaches a situation where automated driving will no longer be available, the vehicle will request that you takeover full manual control of the vehicle via audio-visual alerts on the in-vehicle display screen. You will receive a takeover request 60 seconds ahead of automated driving being disengaged. This time is for you to prepare to resume full manual driving mode of the vehicle. The following series of alerts will proceed when Autocar3 issues a takeover request:

When the takeover request is initiated, the in-vehicle display will show the following visual alert with accompanying 'PREPARE TO DRIVE' audio alert. This alert will be displayed for 50 seconds, an orange timer bar is displayed towards the base of the screen to give a visual indication of the countdown. 50 seconds is reached once the bar reaches the other side of the screen:

When 50 seconds has passed, the in-vehicle display will show the following visual alert and will show number counting down from 10 to 1. An audio alert will sound as the display appears, then again at numbers 3, 2 and 1.

The alert will be displayed for 10 seconds. At the end of these 10 seconds, automated driving mode will dis-engage and the display will switch to read Manual Driving mode to signal the point of manual mode engagement. Manual mode engagement will be accompanied by a longer audio alert sound and the visual display ‘Manual driving’.

Note: When automated driving is dis-engaged, regenerative braking slows down Autocar3 in the same way as when you move your foot off the accelerator when driving without Advanced Cruise Control, until it becomes stationary.

Warning: Automated driving mode may issue a takeover request, in the following situations:

- Weather changes that are predicted to cause poor visibility (due to heavy rain, snow, fog, etc.).
- Daylight changes that are predicted to cause poor visibility.
- Approaching narrow, winding or residential roads.
- Approaching minimum sensor thresholds for extremely hot or cold temperatures.

Warning: The list above does not represent an exhaustive list of situations that may interfere with proper operation of automated driving mode.

When automated driving is unavailable or cancels, Autocar3 no longer centres the vehicle, drives consistently at a set speed, maintains a specified distance from the vehicle ahead or monitors the roadway. It is the driver’s responsibility to be in control of Autocar3 at all times.

Use of non-driving tasks

Automated driving mode is a hands-free feature. When engaged, automated driving mode does not require you to hold the steering wheel, allowing you to engage in tasks and activities not related to driving, such as the use of mobile phones. However, when manual driving mode is engaged you must hold the steering wheel at all times and all traffic legislation regarding the use of non-driving activities applies as usual to manual vehicles.

The use of non-driving activities is permitted during automated driving mode, but normal traffic legislation for manual vehicles applies when the vehicle is in manual driving mode. It is your responsibility to stay alert, drive safely, and be ready to respond to a takeover request from your vehicle at all times.

Appendix D: Training Evaluation Questionnaire (TEQ)

Instruction: Please tick the box that best represents how much you agree with each of the statements below, where 1= strongly disagree and 5 = strongly agree

Statement	**1 (Strongly disagree)**	**2**	**3**	**4**	**5 (strongly agree)**
I felt interested					
I felt bored					
I paid attention to the things I needed to remember					
I formed new questions in my mind as I participated in the training					
I did not want to stop at the end of the training					
I asked myself questions as I went along to make sure the training made sense to me					
I was 'zoned out' and not really thinking during the training					
I let my mind wander during the training					
The skills I learned during the training will be helpful in knowing what to do in real-life					
I would want to undertake this type of training again					
I better understand the importance of knowledge about automated vehicles after completing this training					
I take training requirements for automated vehicles more seriously after completing this training					

(Adapted from Wang, Bergin and Bergin, 2014)

Appendix E: Total Trust in Automation Questionnaire (TTAQ)

Instruction: Please tick the box that best represents how much you agree with each of the statements below, where 1= strongly disagree and 5 = strongly agree

Statement	**1 (Strongly disagree)**	**2**	**3**	**4**	**5 (strongly agree)**
Automated driving mode decreases my problems while driving					
Automated driving enables me to manage useful activities while driving.					
The system saves time that I would have lost driving manually					
The system increases road safety					
The system prevents traffic violations					
The system supports the driver to detect hazards in time					
The system contributes to reduce crash risk					
The system distracts from detecting hazards in time					
I drive safer than the vehicle in automated driving mode					
Automated driving is vulnerable for new hazards like hacker attack and issues with data safety					
To me new risks that emerge from automated vehicles appear to be more serious than the decrease in crash risk due to automated vehicles					
The system is deceptive					
The system behaves in an underhanded manner					
I am suspicious of the system's intent action or outputs					

Statement	1 (Strongly disagree)	2	3	4	5 (strongly agree)
I am wary of the system					
The system's actions will have a harmful or injurious outcome					
I am confident in the system					
The system provides security					
The system has integrity					
The system in dependable					
The system is reliable					
I can trust the system					
I am familiar with the system					
It is likely that I can use the system					
There is no reason why I should not be able to use it					
Whether I can use an automated vehicle mode is dependent on me					
I probably could not operate an automated vehicle					
I would like to have this system in my car					
I will consider the use of the system					
I will not use the system in any case					

(Gold et al., 2015b)

Appendix F: Situation Awareness Rating Technique (SART)

Instruction: Please circle as appropriate on the scales for each question

Instability of situation

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

Low	1	2	3	4	5	6	7	**High**

Complexity of situation

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

Low	1	2	3	4	5	6	7	**High**

Variability of situation

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

Low	1	2	3	4	5	6	7	**High**

Arousal

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

Low	1	2	3	4	5	6	7	**High**

Concentration and attention

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

Low	1	2	3	4	5	6	7	High

Division of attention

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

Low	1	2	3	4	5	6	7	High

Spare Mental capacity

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

Low	1	2	3	4	5	6	7	High

Information quantity

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

Low	1	2	3	4	5	6	7	High

Information quality

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

Low	1	2	3	4	5	6	7	High

Familiarity with situation

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

Low	1	2	3	4	5	6	7	High

(Taylor, 2017)

Appendix G: Workload Scale (NASA-TLX)

Instruction: Please circle as appropriate on the scales for each question

Mental demand

How much mental activity was required to perform the driving task? (thinking, deciding, calculating, remembering, looking, searching ….?)

Low	1	2	3	4	5	6	7	**High**

Physical demand

How much physical activity was required to perform the driving task?

Low	1	2	3	4	5	6	7	**High**

Temporal demand

How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred?

Low	1	2	3	4	5	6	7	**High**

Effort

How hard did you have to work (mentally and physically) to accomplish your level of performance in the driving task?

Low	1	2	3	4	5	6	7	**High**

Performance

How satisfied were you with your performance?

Low	1	2	3	4	5	6	7	**High**

Frustration level

How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent do you feel about the driving task?

Low	1	2	3	4	5	6	7	**High**

(Adapted from Hart and Staveland, 1988)

Appendix H: Statistical Testing

The key goal of our training was to improve the behaviour of drivers during automated driving, and after they resumed manual control, particularly with respect to their ongoing responsibility towards driving. We therefore employed a range of measures aiming to evaluate what drivers thought about their own behaviour, using recognised subjective ratings scales exploring trust, situation awareness and workload, and explored how this translated into tangible benefits. The study employed a limited number of participants (n=24), from whom we can make comparisons and identify potential trends in their data (descriptive results). However, in order that we can apply our findings to the wider population, and make predictions and recommendations, we employ statistical tests (inferential statistics) in line with common practice. In other words, descriptive results may suggest a difference between the two groups (for example, if presented visually on a graph), but further analysis is required (inferential statistics) to confirm that this difference is actually significant (i.e. likely to apply to a wider population), and not caused by random effects.

During the study, we are looking to explore whether attitudes, behaviour and performance differed between the group of drivers receiving Behavioural training and those receiving operational training. To do this, we vary independent variables (here, the provision of either Behavioural or Operational training), and examine their effect on dependent variables (for example, the number of mirror checks). Given the “between-subjects” experimental design (i.e. participants were assigned to one of two different conditions, with each participant experiencing only one of the conditions), we have utilised two simple, statistical tests during the analysis – the *t*-test and Fisher’s exact test. The *t*-test is a commonly employed test to determine if there is a significant difference between the means of two groups. Essentially, a *t*-test allows us to compare the average values of the two data sets and determine if they came from the same population. In the above examples, if we were to take a sample of drivers (the Behavioural group) and another sample of drivers (the Operational group), we would not expect them to have the same means and standard deviations, *if* the Behavioural training has had an effect. Fisher’s exact test is used to analyse categorical data that result from classifying behaviour in two different ways. It is used to examine the significance of the association (contingency) between the two kinds of classification. So, in our study, one criterion of classification might be whether drivers made one or fewer glances during a specific time, and the other could be whether drivers made multiple glances.

For both tests, statistical significance is typically determined and reported using *p*-values. The *p*-value, or probability value, is the probability of obtaining test results at least as extreme as the results actually observed, assuming that there are no differences. In other words, the probability that the results are due to random variability. By convention, statistical significance is declared if the *p*-value is less than .05, that is, a probability of less than 5% that results are due to randomness, or alternatively, less than 5% risk of concluding that a difference exists when there is actually no difference.

RAC Foundation

Mobility • Safety • Economy • Environment

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

Registered Charity No. 1002705

Designed and printed by
The Javelin Partnership Ltd
Tel: 0118 907 3494

Produced on paper from a managed
sustainable source which is FSC certified
as containing 50% recycled waste.