# **Towards Future Driver Training: Analysing Human Behaviour in Level 3 Automated Cars**

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## ABSTRACT

Automation capability of future Level 3 vehicles will extend to tactical as well as control levels of the driving task. However, if systems fail or boundary limitations are exceeded the human driver must be ready to take over control of the vehicle. Behavioural adaptations of drivers when interacting with automated vehicles, highlight an inverse relationship between automation and human performance, often attributed to complacency. This study investigated behavioural adaptations of drivers during transitions to manual control in a level 3 automated vehicle. An extensive existing data set from a recent longitudinal study was re-analysed. 49 drivers undertook a series of 5 simulated drives in a level 3 automated vehicle. The study's design allowed the investigation of driver interactions with driver-led non-driving related tasks (NDRTs) and changes in driver behaviour with experience. Frame-by-frame video analysis showed driver behavioural adaptations to improve performance of control level tasks, complacency effects on tactical level tasks, and evidence of cognitive heuristics to allow prioritisation of NDRTs during the transition. Findings highlight the importance of clearly defining concepts, such as complacency, to accurately identify and interpret patterns of behaviour, to select appropriate mitigation strategies within system design or driver training.

## **KEYWORDS**

Automated driving, Behavioural adaptation, Transitions of control

## Introduction

Progression towards fully autonomous driving is steady. However, until system boundaries no longer exist, the driving task is one which is shared between humans and technology (Brown and Laurier, 2017). The Society of Automotive Engineers (SAE, 2016) categorises vehicle automation into 6 levels of ascending capability. Levels are classified by the extent of system intervention in vehicle control of the driving task and the requirement of the human driver to monitor system performance and resume control of the driving task where necessary (White et al, 2019). Michon's (1985) hierarchical driving model categorises the driving tasks into three behavioural levels: control, tactical and strategic. At SAE level 2, automated systems are capable of taking over control level tasks, for example, 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 if required. At level 3, automation capability extends to tactical level tasks (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 (White et al. 2019).

A key challenge in system automation is the inverse relationship between automation and human performance. For example, as decision making functions are automated, the driver gives less attention to the driving task. This unintended consequence of automation takes the driver 'out of the

loop' of control; reducing the driver's level of perception and comprehension of the system state and driving environment and the projection of their future state, a construct termed 'situation awareness' (Endsley, 2017). This can be seen in the behavioural adaptations evidenced in recent naturalistic studies analysing the experiences of drivers operating the Tesla Model S, level 2 vehicle (e.g. Banks et al., 2018; Brown and Laurier, 2019; Endsley, 2017). Qualitative analysis provided anecdotal evidence of increased engagement with NDRTS, and reduced situation awareness, and vigilance, impacting the ability of the human driver to maintain shared control with the automated system.

At 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. At this point the system will issue a takeover request (TOR) to the driver to re-engage with the driving task. Empirical studies investigating automation to manual transitions have highlighted performance challenges impacting the ability of human drivers to effectively take over the driving task. Research has focused on determining the optimal TOR timing for drivers to safely and comfortably take over from the automation (e.g. Melcher et al., 2015). However, for reasons of experimental control, these studies tend to use a standard NDRT that drivers engage with during the simulated automation mode. Although this provides standardisation from which to compare driver take-over performance, this experimental rigor potentially omits important motivational factors that could have a significant bearing on driver behavioural adaptations at this level of automation. For example, the increase in automation capability, changes the perspective on driver engagement with NDRTs from one of driver distraction to task interruption and task switching (Janssen et al., 2019). When humans divide their attention between two competing tasks, intervening factors such as prioritisation and motivation will determine the time-on-task. During periods of automation control, the human driver may prioritise the NDRT over interaction with the driving task, regardless of their fallback responsibility, taking them further out-of-the loop of control and impacting their readiness to take over control of the vehicle.

Current concepts such as 'complacency' help to identify patterns in driver behavioural adaptation due to automation, which can influence the design and development of mitigation solutions. For example, alert systems or attention monitoring devices. However, concerns have been raised about the specificity of models to accurately predict human behaviour. For example, 'complacency' describes an overly optimistic assumption of satisfactory system states due to limited knowledge of safe and efficient modes of operation. This lowered expectation of failure is more commonly, but not exclusively, seen in novice users of automation (Kaber, 2018). This reflects the limited knowledge and experienced uncertainty that affords higher levels of cognitive decisionmaking behaviours (Cummings, 2018). However, an increase in knowledge and experience does not prevent human operational deviations that could be construed as complacency (Kaber, 2018), therefore, mitigating solutions targeting the current construct of complacency may be ineffective. Satisficing, known as the 'good enough' heuristic, is the behavioural tendency of humans to use the most accessible solution rather than the optimal one. This bias assists decision making and reduces strain on mental resources, increasing efficiency in operations. For example, driver reliance of automated blind-spot detection systems without the additional vigilance or monitoring behaviours required from the human driver (Sullivan et al., 2016). Use of this cognitive heuristic is often successful. However, in human-machine systems, where control is shared and dynamic in nature, the use of satisficing requires a level of error acceptance that reduces performance reliability (Kaber, 2018). It is argued that consideration of cognitive strategies and biases can increase understanding and precision of constructs, which outline implications of automation on human behaviour. This will allow better identification and selection of mitigation strategies within systems design or driver training (Dekker and Woods, 2002).



Figure 1: HMI display alerts split by participant group and TOR type

## Aims and Overview of the Study

The current study carried out analysis on an extensive existing data set, from a recent longitudinal study (White et al., 2019; Burnett et al., 2019), where participants had carried out a series of simulated drives in a level 3 vehicle. The aim was to investigate and interpret behavioural adaptations of human drivers during automated to manual transitions, carried out during the simulated drives. Video data from the study, which investigated driver interactions with level 3 vehicles, provided a rich and immediately accessible data source. The study's longitudinal design and driver-led choice of NDRT presented an opportunity to investigate how driver behaviour changed over time, and any mediating effects of motivational factors on driver behavioural adaptations.

## Method

49 experienced drivers took part in the original study (for full details see White et al., 2019; Burnett et al., 2019), completing five 30 minute, simulated drives over consecutive days. All drives included a controlled TOR to resume manual driving and an additional emergency TOR was included on the fourth consecutive drive. The TORs consisted of a series of audio-visual alerts on an in-vehicle human-machine interface (HMI), which provided both text and images for visual feedback and matched spoken text and tones for audio feedback. The transition information displayed on the HMI varied between participant groups. For example, some groups received additional cues such as a visual countdown bar or timer and an instruction to check for hazards and others received more basic information (see Figure 1). A spoken alert stating "Manual Mode Engaged" was triggered as the "Manual Driving" display appears. The end of the spoken text marked the end of the automation mode and control was handed back to the driver. Drivers were given the option to resume manual driving from the automation at any point using a verbal command. Split-view videos were captured of each drive, providing 245 videos in total for analysis.

The focus of this study was driver behaviour during automated to manual transitions of control. For the purposes of video analysis, the period of 'transition of control' was defined as: from the timestamp that marked the audio-visual "Prepare to drive" HMI alert, to the point the driver was perceived to have resumed control of the driving task. This was determined using observation of salient driver behavior, interpreted as demonstrating the driver was relaxed and in full control of all aspects of the driving task. For example, a combination of the vehicle visibly being laterally and longitudinally controlled, alongside a change in the driver's posture, a sigh, or a change in their hand position on the steering wheel.

	>1	≥ 5	Total no. of drivers	
Day 1	22	4	31	
Day 5	25	6	29	

Table 1: Table showing the number of people who glanced at their NDRT after the Prepare to drive alert and those who glanced more than 5 times at their NDRT

Coding categories were selected following initial observations of salient driver behaviour from three videos of different drivers. Categories included: hand or body posture movements, such as hand position on the steering wheel, or relaxed/alert body posture; verbal or physical 'startle' reactions, such as a gasp or jolt of the body; and salient glance fixation locations, such as the HMI, dashboard, rear-view mirror, or external to the front windscreen or left/right windows. Key points within the transition of control were also coded and recorded. This allowed timestamps of behaviour to be analysed in accordance with standard system actions and events during the transition, for example, HMI alerts and manual mode engagement. Ad hoc notes were also made to provide additional detail for coding categories to support and enhance coding information. For example, hand position on the steering wheel (represented as numbers on a clock face) and the type and number of NDRT being used.

Behaviour Observation Research Interactive Software (BORIS)(Version 7.4.7; Friard and Gamba, 2016) was used to create and store an ethogram. Frame by frame coding of behavioural observations was conducted during the defined 'transition period' for all driver videos. Observations were analysed to explore behaviour both within individual journeys and over the course of the five drives, with reference to relevant theory and research on vehicle automation.

## **Results and Discussion**

For the purposes of this paper, results and discussion focus on key observations of driver behaviour during the transition of control. Video analysis was used to categorise glance behavior. 'Readiness to drive' was defined as the driver having both hands on the wheel and having made at least one glance to the front windscreen. Number and duration of behaviours were calculated from time stamp data extracted from BORIS. For example, where a glance at the front windscreen (taken as eyes on the road ahead), preceded a glance at the HMI, 'glance duration on the road' was calculated as: Time stamp glance (HMI) – Time stamp glance (front windscreen) = glance duration (road).

Analysis of driver behaviour suggested that use of a driver-led choice of NDRT during automation, added an additional layer of complexity to human behaviour in transitions of control, not seen in studies that use a prescribed NDRT. Janssen et al. (2019) posited that when humans are required to switch between two different tasks, the time-on-task will be affected by individual priorities. Driver behaviour provided evidence that engagement with an NDRT of personal interest to the driver, increased distraction at the point of transition. Following the 'Prepare to drive' alert where the NDRT and driving tasks conflicted, drivers appeared motivated to continue interacting with the NDRT. For example, a number of drivers throughout the study continued to glance at their NDRT after the audio alert to 'Prepare to drive'. By the fifth consecutive journey the number of drivers who continued to glance at their NDRT, after this alert had been issued, increased, as did the number of glances made to the NDRT (see Table 1).

Additionally, there was an increase in the number of drivers who interacted with their NDRT after the TOR or where the NDRT directly or indirectly continued to provide distraction to the driver once the driving task had been resumed, impacting the time it took drivers to turn their attention fully to the driving task. For example, continuing to write a message on a phone or glancing at the phone after manual mode had resumed (Figure 2a and 2b). Other examples included where the driver had re-organised the driving cab during automation mode and readjusted these physical changes, either during the HMI instruction to check for hazards or after manual mode had resumed. For example, adjusting the seat or turning off the reading light (Figure 3a and 3b). Even during the emergency TOR scenario some drivers took care to 'save' where they were in their NDRT before turning their attention to the driving task. For example, placing their bookmark into the book, or closing programmes on their phone, before placing the item on the passenger seat.

Results from the original study (see White et al., 2019; Burnett et al., 2019) showed an improvement in driver lateral and longitudinal control performance, at the point of manual mode engagement, over the five days. However, observed behavioural patterns suggested that this did not necessarily portray a state of driver readiness. Although drivers demonstrated a pattern of learning and applied strategy to improve performance of the control level tasks involved in the take-over, they did not demonstrate the same pattern or focus on improving tactical level task performance. This pattern become more noticeable by day 5. For example, the average time it took for drivers to place both hands on the wheel, after the 'Prepare to drive' alert, increased from 16 seconds on day 1, to 20 seconds on day 5. There were also a number of drivers, who used the timer on the HMI as a countdown to cease interaction with their NDRT and switch attention to the driving task, rather than a period to carry out actions to increase performance on controlling the steering wheel but not on gaining situation awareness prior to the controlled transition. It also suggests that as the drivers gained familiarity with the HMI, they found ways to use it to reduce mental workload during the transition, suggesting evidence of the use of satisficing (Kaber, 2018).



Figure 2a: Driver continues to interact with laptop after "Prepare to drive" HMI alert, b: Driver distracted by phone on passenger seat after manual driving mode had resumed



Figure 3a: Driver adjusting seat during 'resume control' request in emergency takeover, b: Driver adjusting light after manual driving mode had resumed



Figure 4: Driver using HMI countdown bar as a cue to disengage with the NDRT

Table 2: Number of drivers with eyes on HMI, dashboard or front windscreen at manual mode engagement

	HMI		Dashboard		Front windscreen		
	No.	%	No.	%	No.	%	Total
Day 1	16	33	11	22	22	45	49
Day 5	5	10	5	10	39	80	49



Figure 5: Evidence of driver behavioural adaptation over the 5 days

Driver eye glance behaviour also suggested a learning strategy. For example, the average time it took for drivers to glance at the road, after a controlled TOR had been issued, decreased from 7 seconds on day 1, to 4 seconds on day 5. There was also an increase in the number of drivers who had their eyes on the road at the point of transition, whereas on day 1 there was a pattern of drivers

looking at the HMI at the point of manual mode engagement (Table 2). These factors suggest that drivers learnt the importance of looking at the road for transition performance. However, other behaviours suggested tactical tasks were not prioritised in the same way. For example, although the average time it took drivers to look at the external environment after the "Prepare to drive" alert, decreased by day 5, the time between the first and second glances at the road increased by the same amount of time. This was because drivers turned their attention immediately back to the NDRT after the first glance at the road. There were also a number of drivers who requested take-over prior to the vehicle handing control to them but they requested this without having looked at the road and, in some cases, without their hands on the wheel. There were also instances where drivers showed a prolonged focus on the speedometer between glances at the road. When coupled with the increased prioritisation of NDRTs and the use of the HMI count-down to acknowledge when engagement with the NDRT needed to cease, this behaviour suggests that 'eyes on the road' was a strategy to aid lateral driving performance, rather than the driver recognising that increasing their situation awareness was a necessary task to get them ready for manual driving. This is an important point, especially when taken into account with the increase in delay to placing hands on the wheel. It suggests that as driver's knowledge of the system and how to operate it increased, so did their propensity to use satisficing to aid their decision making associated with preparing to drive, even following the emergency TOR.

The story board in Figure 5 illustrates these points. Day 1 (image 1) the driver's gaze is focused on the HMI at the point of manual mode engagement, whereas on day 2 (image 2) they made a conscious effort to focus their gaze on the road at the same point, suggesting learnt behaviour to improve transition performance. On day 5 (image 4 and 5), the driver made a verbal request to resume manual driving but their eyes were not on the road and both hands were not on the steering wheel, suggesting that the request was made ahead of the driver being 'ready'. When the driver did put their hands on the steering wheel, they were positioned at the base rather than in the 10-to-2 position as they were on day 1 and 2, suggesting that the driver was feeling more relaxed about the transition to manual driving. Additionally, although the driver had their eyes on the external driving environment at the point of manual mode engagement, they immediately moved their focus to make 2 longer gazes at the speedometer (1 and 1.5 seconds long, with a 0.5 second glance at the front windscreen between). This again suggests that the driver was focused on controlling the operational driving tasks and placed little focus on monitoring the external environment to regain situation awareness.

It can be inferred from these outputs, that drivers did not recognise a need to undertake tactical level tasks, during the transition phase of the take-over. The lack of engagement with the driving task, in particular monitoring of the external environment during the "Prepare to drive" phase, suggests evidence of complacency. The speed at which drivers were able to learn dynamic take-over of control level tasks and their limited experience of uncertainty, may have led drivers to develop an unjustified satisfaction with the shared human-machine system and therefore failed to recognise the importance of tactical level task performance for maintaining system reliability. This observation suggests that an increased exposure to system failure scenarios through training interventions could improve transition performance. However, evidence of the use of cognitive heuristics, such as satisficing, demonstrates a desire to reduce demand on cognitive resources, which may remain even after training interventions. Employment of heuristics could reflect an increase in cognitive demand of carrying out control tasks during a transition and therefore a prioritisation of cognitive resources towards control rather than tactical level driving tasks. However, it could also reflect a motivation to prioritise NDRTs until the moment of manual mode engagement which could have long term implications on drivers 'readiness' to drive. These findings highlight the importance of accurately defining and applying concepts such as complacency, heuristics and biases when looking for

patterns in behavioural adaptations in automated driving, particularly for the purposes of the identification and selection of effective mitigation strategies.

## Conclusion

This study presented patterns of human behaviour that raise important points regarding the interaction of human drivers with level 3 automated vehicles. Findings showed that drivers placed an emphasis on learning how to master control level driving tasks, whilst neglecting tactical level tasks, demonstrating evidence of complacency. Driver focus on tactical tasks, during the transition phase showed no evidence of change despite performance improvements on control tasks and drivers' exposure to a failure scenario. Instead, as drivers gained experience and knowledge of the system, they adopted cognitive strategies, such as the use of the satisficing heuristic, to allow prioritisation of NDRTs. This suggests that, at the point of manual mode engagement, drivers may not be 'ready' to effectively carry out tactical level tasks and resume complete control of the driving task. However, perhaps more importantly, it highlights that training or system design strategies aimed at combating the effects of complacency by increasing driver system knowledge and performance, whilst necessary, may not be a sufficient mitigation strategy for behaviours such as satisficing. These findings have important implications for future automation research, the design of automated systems and potential training interventions for human drivers. Additionally, they highlight the importance of clearly defining concepts, such as complacency, to accurately identify and interpret patterns of behaviour so that appropriate mitigation strategies can be found. Recommendations for future research include investigating the impact of behavioural adaptations on driver performance. In particular, in the presence of critical scenarios immediately after takeover, to inform mitigation requirements and strategies for system design and training.

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