Two For The Road: An Exploratory Study Investigating Driver and Co-Passenger Interactions during Automation and the Transition of Control in a Level 3 Automated Vehicle

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ABSTRACT

To explore the impact of a front-seat passenger during SAE level 3 (L3) automation, eighteen established driver-passenger pairings undertook three 30-minute journeys framed as 'days-out' in a L3 driving simulator. Participants were reminded of their responsibilities at L3 (as per SAE lexicon), and were given agency to decide what behaviour was acceptable, but were otherwise free to behave as they wished with the only stipulation that they should resume manual control and exit the motorway at the correct junction to reach a specified destination. Distracting behaviours emerged, in the form of participatory activities, that engaged both vehicle occupants in cooperative tasks, such as watching shared content or playing competitive games on a smartphone, and these delayed or disrupted the resumption of the driving task. Supportive behaviours were also evident amongst more loquacious passengers, who assisted with route-finding and keeping the driver awake/alert. Findings provide empirical evidence regarding permissible activities at L3 and can inform in-vehicle design to promote appropriate behaviour.

Keywords: SAE level 3, conditional automation, non-driving related tasks, conversation, passenger

1 INTRODUCTION

Near-future vehicles capable of operating at SAE level 3 conditional driving (L3) automation [1] will enable drivers to undertake secondary tasks, or non-driving related tasks (NDRTs), if they choose to relinquish control to the vehicle, but will inevitably still involve episodes of manual driving and hence, will require the driver to transition in and out of control, and be prepared to do so. This represents a radical change in driving ideology, completely redefining the role of, and expectations placed upon, the driver [2]. The types of NDRTs and the impact these have on the driver's attention to the road situation and their ability to resume manual control thus remain the focus of ongoing research activities. In a novel, longitudinal simulator study, in which participants were given agency to behave as they wished during multiple simulated 'commute' drives during a 5-day working week, Large et al. [3] observed a diverse range of NDRTs and novel behaviours during manual driving and L3 automation. Drivers' NDRTs (undertaken during periods of L3 automation) often had high visual, manual and cognitive demands, such as using a mobile phone, reading books or magazines, using a laptop or tablet computer, and even included short episodes of sleeping. These behaviours were reflected in participants' subjective ratings, which indicated a high level of trust from day one, and this increased over the week. When asked to resume control after periods of L3 automation, drivers took longer to respond during each subsequent visit, and focused primarily on control level driving tasks, suggesting that they were overly optimistic about the capability of the automation and their own ability to resume manual driving when required to do so [3].

While the behaviour and performance of the driver at L3 automation understandably predominates research activities, it is also noted that a significant proportion of cars currently on the road contain at least one passenger – over one third in the UK according to recent figures [4]. Moreover, there is an expectation that multiple-occupant travel is likely to increase due to predicted behavioural changes from single occupancy to shared mobility solutions. The presence of one or more passengers has been shown to distract drivers during manual driving, with reported reductions in situational awareness and increases in the risk of taking unsafe actions – factors that elevate crash risk, particularly for young drivers and passengers [6]. Moreover, in the presence of other vehicle occupants, the car becomes a social space [7] [8]. This can lead to new collaborative behaviours, which may divert the driver's attention away from the road situation and even lead to 'social discomfort' caused by contentious conversations with passengers, particularly if they are known to the driver [8].

There has been considerable focus on human behaviour in vehicles containing multiple occupants at SAE Level 4 (L4) high driving automation or SAE Level 5 (L5) full driving automation [1]). These studies are often associated with devising novel vehicle cabin designs and seating configurations to enable (or potentially, inhibit) different (non-driving-related) activities and social situations, for example, through 'interior metamorphosis' [10] [11]. Findings from these studies are therefore commonly articulated using measures of user experience (UX) and acceptance (e.g. see: [12]). These studies are fundamentally grounded by the fact that the vehicle occupants will not be required to resume the driving task (in fact, there may be no physical controls to enable this), and this significantly limits their relevance and applicability for lower levels of automation in which the driver will, by definition, need to switch between manual driving and periods of automation.

In contrast, the presence of a passenger in vehicles offering L3 automation has, to date, received no empirical attention, yet such vehicles are generally considered to be close to large-scale deployment, with several examples already in the market, and this will likely be drivers' first experience of 'automation'. Inspired by previous investigations undertaken by the authors (see: [3] [4]), and utilising the same methodological approach, we conducted an exploratory study to investigate the interactions that naturally took place between the driver and a front-seat co-passenger in a vehicle offering L3 automation, representing the next evolution of the driving task. The aim of the investigation was to document the types of NDRTs that drivers and co-passengers naturally undertook, and to consider the impact these had on distraction and performance as they transitioned between manual driving and L3 automation. The study thus builds on knowledge of the impact of a passenger during manual driving and aims to inform the design and acceptance of emerging vehicles with L3 automation.

2 BACKGROUND

Vehicles offering L3 automation present a unique situation: to 'users', these vehicles are unlikely to appear substantially different in design to manually-driven cars, and the driver (and indeed, any co-passengers) are therefore unlikely to appreciate the different challenges they present; moreover, evidence suggest that drivers are likely to misjudge their own ability to successfully interact with L3 automation, and indeed, the capability of the automation itself (see: [2]). As a consequence, the current study primarily builds on work from manual driving, in which our understanding of the impact of passengers is well-established, to consider how this knowledge may apply to vehicles capable of transitioning between manual driving and automation.

In manual driving, the presence of a passenger can significantly influence various aspects of manual driving behaviour, including driving performance, attention allocation and risk-taking behaviour. While much of the literature supports the common wisdom that passengers are a distraction to drivers in manually driven cars, and that their presence can therefore increase crash risk, reported findings are rather nuanced, with some reported instances in which a passenger can provide a supportive or protective effect during manual driving, thereby minimising crash risk, for example, by encouraging good driving behaviours or helping the driver with specific driving-related tasks, such as route-finding.

If a passenger is present in a manually driven vehicle, interaction with the driver is likely to occur. Many studies have subsequently highlighted correlations between interaction with passengers and road crashes during manual driving (e.g., [20] [21]). In their meta-analysis, Theofilatos et al. [15] reported that 'interaction with passenger' is one of the most frequently cited distracting activities undertaken by drivers and resulted in a 'non-negligible' number of crashes. Moreover, they showed that there is a significant increase in injury severity associated with passenger presence, compared to injuries sustained when a driver is alone. Similarly, Orsi et al. [22] undertook an analysis of accident data and highlight passenger presence as a factor influencing crash outcome. They also highlight that the influence of passenger presence on crash outcome severity for drivers was found to depend on driver age: amongst young drivers (under 25 years of age), the consequences of a road crash were more severe if there were passengers in the car. The reported increase in injury severity reported by the aforementioned authors ([15] [22]) (amongst others) is thought to be due to an increase in risky driving behaviours in the presence of a passenger, for example, a reduction in the wearing of seat belts amongst young drivers and young passengers [23]. These findings are also in line with the results of other studies which show an increased risk of injury or death in young drivers carrying passengers [24] [25] [26].

Moreover, Orsi et al. [22] report that crash outcome for young drivers is more likely to be severe when the passenger is male. Indeed, other studies have also highlighted an increased risk of crashes [23] and risky driving behaviour [27] in the presence of male passengers. Such findings are also supported by Ouimet at al. [6], who showed increased risk for young drivers with at least one passenger compared with solo driving. Increased risk was also found for fatal crashes and for combined or nonfatal crashes with male versus female passengers and for younger versus older drivers [6]. Results were mixed for nonfatal crashes, with no clear evidence that teenage passengers or passengers of any age are associated with increased risk, although there is some reported evidence of a small protective effect (that is, reduced risk) associated with male driver-female passenger partnering [25] [28].

In the presence of a passenger, interaction often takes the form of conversation, although this in itself might develop to something more significant, for instance, an argument, or 'dealing with children' [14]. Nevertheless, it has been reported that passengers modulate their conversation based on their perception of the road situation, suggesting that they are aware of the potential distraction they pose [30]. Indeed, Drews at al. [30] report that passengers frequently and intuitively withdraw from a conversation when the driver approaches a complex junction. Interestingly, similar effects are not noted during mobile phone conversations with a driver as the so-called 'remote passenger' is evidently not experiencing the driving situation first-hand and is thus unable to modulate their conversation appropriately [31]. There is also some evidence of reciprocal behaviour from drivers, who may compensate for their reduced attention when talking to a passenger by facilitating the driving task, for example, by driving more slowly while they are engaged in a conversation [32].

It has also been suggested that passengers often discuss items pertinent to driving (particularly if they are also an experienced driver themselves) thereby supporting the driver and enhancing their situational awareness (SA) (in so far as improving their perception of critical factors in the environment at 'level 1' SA) [18] [33]. For example, passengers who are familiar with the driving task have been noted highlighting significant features and events in the driving environment or monitoring the condition and performance of the vehicle or, indeed, the driver (for example, to determine if they are tired or affected by alcohol) [34] [33] [35]. Passengers have also been observed actively assisting with the navigation task when approaching a motorway or highway exit [30], although Vollrath et al. [36] warn that certain driving cues such as traffic signs, apparent hazards or warnings, are often missed by passengers. In contrast, conversation with a passenger who has no, or very limited, driving experience can actually have a negative impact on the driver's situational awareness [18]. Indeed, any conversation can be a distraction in and of itself, as it requires attention and imposes cognitive load, regardless of topic, and this can divert the driver's attention away from the primary driving task [37]. Consequently, 'talking to passengers' is one of the most commonly reported distractions by drivers [14], with 21% of distractions attributed to passengers and their verbal interactions [37]. Moreover, driver-passenger conversation reportedly contributes to up to 20% of distraction-related road accidents [38].

Passengers can also offer other protective effects during manual driving. For example, drivers' involvement in physical activities within the car, such as adjusting the radio or using electronic devices, notably reduces when a passenger is present [29]. In their interview study, Sagberg et al. [29] conjecture that this is either because the passenger undertakes the secondary task on the driver's behalf (recognising that the driver is currently engaged in the driving task, and therefore unable to do so themselves) or because the presence of a passenger has an inhibitory effect on the driver's motivation for undertaking distracting secondary tasks. It has also been noted that the presence of a passenger can reduce the likelihood that a driver will commit a traffic violation [39].

Although passengers have the potential to support drivers and facilitate positive benefits, for example, by contributing to a shared awareness of the road situation, or through the encouragement of positive safe-driving behaviours such as suggesting taking a break on a long drive [30], these effects may be influenced by certain sociodemographic factors, such as the driver's and passenger's age and gender. For example, Rueda-Domingo et al. [28] found that the presence of passengers had a more protective effect for older drivers than younger drivers. Vollrath et al. [36] also report protective effects associated with passenger presence in their analysis of accident data, although they too cite a number of modifying variables, such as the driver's age, time of day etc. (notably, protective effects were lowest for young drivers and during night-time driving). Negative effects are typically attributed to social facilitation theory [40], which describes how people are affected differentially by the presence of others (also referred to as the audience or spectator effect): young drivers are purportedly more susceptible to peer pressure than adult drivers [41] [27], and this may account for the higher incidence of risky behaviours. However, social facilitation theory may also explain positive effects, such as the lower incidence of traffic violations if one or more passengers were present [39], and a higher likelihood of seat-belt usage and lower likelihood of alcohol use in the presence of passengers (notwithstanding younger drivers) [32].

The nature of the relationship between the driver and their co-passenger can also influence the effects of a passenger during manual driving. Notably, drivers who are romantically involved with their passenger often engage in contentious or emotionally charged conversations [42]. If their partner is present in the vehicle, this can adversely affect vehicle control (longitudinal and lateral), compared to situations when the driver talks to their (romantic) partner on a hands-free mobile phone [42]. Laurier et al. [7] go further to suggest that the privacy of the car is an occasion that enables, or even encourages, conversations on 'very serious or difficult' topics amongst close friends and partners. They highlight that car-bound conversational partners cannot easily walk away from the conversation, and thus, being co-located in a car allows for slow and considered responses to complex or difficult issues. Moreover, Laurier et al. [7] highlight that in manual driving, the driver and their passenger are both facing forward (and the driver would be notionally required to remain so at L3 automation) and this avoids them having to make 'awkward' eye-contact which can ease difficult discussions.

Despite the evident impact of a passenger (both positive and negative) during manual driving, there is currently a scarcity of published works regarding the effect of passenger presence in vehicles offering L3 automation which maintains manual driving as a fallback in all situations. The current study therefore aims to explore the behaviour and opinions of the driver and their co-passenger as they transition between states of manual driving and L3 automation.

3 METHOD

The overall goal of the research was to conduct an exploratory study to investigate the behaviour of a driver and a front-seat, co-passenger during L3 automation [1]. In builds on previous work undertaken by the authors (see: [3] [2]), which effectively forms the methodological baseline. In particular, we were looking to uncover the impact of a co-passenger during periods of L3 automation and when resuming the manual driving task, and to provide both qualitative and quantitative data to inform the debate regarding permissible activities during L3 driving automation and the design of in-vehicle information systems and functions to support and promote the safety of drivers and passengers, and, indeed, all other road users. The research aimed to address the following research questions:

RQ1. What will drivers and their co-passengers naturally do in vehicles offering level 3 automation?
RQ2. What impact does the presence of a co-passenger have during periods of L3 automation and when transitioning between states of L3 automation and manual driving?
RQ3. What levels of situational awareness, workload, trust and acceptance are experienced by drivers and co-passengers?

3.1 Participants

Established driver-passenger pairings (n=18 pairs) were recruited to take part. Unfortunately, one pair withdrew partway through the study due to symptoms of simulator sickness. All reported data refers to the remaining 17 pairs (or 34 individuals). All driver-passenger pairings were known to one another, and they were asked to self-articulate their relationship. Relationships were thus described as “Friends” (n=6), “Partners” (n=8) and “Colleagues” (n=4). The study included multiple journeys and participants fulfilled the same role (driver or passenger) during each journey for consistency. All drivers were experienced (14 male, 3 female; mode age: 25-34; mean years driving: 12.0; mode annual mileage: 5,000 to 10,000); eleven of the passengers were also experienced drivers (2 male, 9 female; mode age: 25-34; mean years driving: 12.0; mode annual mileage: up to 5,000). All participants completed a consent form and received a £30 (GBP) shopping voucher as a token of goodwill for taking part. The study design was approved by the University of Nottingham Faculty of Engineering ethics committee, which requires approval from two independent members of the committee.

3.2 Equipment

The study took place in the University of Nottingham Human Factors driving simulator, which was chosen to ensure an equitable driving experience for all participants and to ensure their safety and wellbeing. The simulator comprises a right-hand drive, mark one Audi TT car (Figure 1). Three ceiling-mounted, high-definition projectors provide an approximately 270 degrees forward and side view of the dynamic, unfolding driving scene onto a curved screen, with edge-blending and image warping ensuring a contiguous image is presented to participants. Side mirror displays are integrated within the original mirror housings. The rear view is displayed via a display screen placed behind the vehicle. Vehicle performance data is presented on a 7-inch LCD screen, replacing the original Audi instrument cluster. A Thrustmaster T500RS force feedback steering wheel and pedal set are integrated with the existing Audi primary controls and cabin environment. The driving simulator has been used in numerous behavioural studies and has been specifically validated in the context of driver behaviour and distraction (see: [39])

The simulated driving environment was created using AV Simulation SCANeR software (https://www.avsimulation.com/scaner/) and was designed to replicate a geo-typical UK road network comprising suburban and 3-lane motorway elements (Figure 2). The road layout, junctions, markings and signage conformed with UK standards, as far as practicable, although road names and locations were fictitious, with no association with real places implied or intended. Traffic levels were moderate to heavy throughout the journey to reflect typical, changing traffic conditions. The same road network was used for all drives although the volume and behaviour of surrounding traffic differed between drives.

Figure 1: Driving simulator, showing (clockwise from top left): side view, vehicle cabin/interior, control room and full vehicle with surrounding screen

Figure 2: AVSimulation SCANeR rendering of motorway scenario, showing accident and traffic jam on counter carriageway (top) and inclement weather prompting unexpected, emergency handover on drive 3 (bottom)

3.3 Procedure

Three journeys were curated and framed as ‘days-out’ occurring over a week to reflect genuine driving experiences, with the aim of eliciting authentic behaviours rather than for experimental convenience or control. The three journeys were described to participants as: (1) visiting a shopping outlet on Monday, (2) a walk in the country on Wednesday, and (3) dinner with friends on Friday. In practice, the three journeys occurred during the same day to aid participant recruitment and retention. After completing drive (1), participants left the vehicle and were asked to complete various questionnaires (see Section 3.4). After a short break, they returned the driving simulator to undertake drive (2), and so on.

Each journey began in the same residential setting, described as the driver’s home. Participants drove manually to the motorway (approximately 5 minutes) and always joined at junction 27. L3 automation was made available as they approached the motorway and routinely activated on the slip road. Participants were required to resume manual control (using a specified voice command which began a 10 s countdown) and to leave the motorway at the correct exit based on the specified destination. The current vehicle status (manual driving, automation available, automated driving etc.) was communicated multimodally, as a text-based notification on an HMI located in the centre console of the vehicle and as a voice message which announced any change of state, for example, “automated driving available”. Each journey lasted between 20 and 30 minutes, depending on the distance to the required destination. The destination was described in detail to the driver and passenger before each journey, including the destination’s name, motorway junction and expected duration, for example, *“You’re going shopping in Tyson’s outlet shopping centre. You will need to exit the motorway at junction 33, signposted to A68 Tysons. This journey should take approximately 25-30 minutes.”* During drive 3, an unexpected situation necessitated the ‘emergency’ handover of control approximately 11-minutes into the drive and notably prior to the specified junction. This was due to inclement weather (i.e. heavy rainfall) affecting the vehicle sensors (Figure 2-bottom) and was described as such to participants using the in-vehicle HMI and an accompanying voice message.

Participants were told that during periods of automation they were free to undertake any activities they deemed to be acceptable in the context of L3 automation (having also been made aware of this prior to attending so that they could bring with them any artefacts or paraphernalia they deemed appropriate). No restrictions were placed on the types of activities drivers and passengers could do, other than their own interpretation of their role and responsibility at L3 automation, which was described exactly as per the SAE definition [1], effectively replicating a ‘user manual’, prior to undertaking any drives. Participants were also informed that they would be video recorded and so should not discuss any topics, or reveal any information, that they would not want a stranger to hear.

3.4 Measures and Analysis

Videographic data were used to determine the activities undertaken by the driver and passenger, and their behaviour immediately prior to and during the handover of control, replicating the coding scheme and techniques employed by Large et al. [3] in their study.

Subjective ratings of situational awareness (SA) [44], situational trust (ST) [45] and workload (WL) [43] were captured immediately after each of the three drives. Ratings of trust in automation [46] were captured before and after the full experience (i.e., all three drives), and ratings of technology acceptance (TA) [47] were captured at the end of the study. All ratings were provided independently and in isolation by both the driver and the passenger with the aim of investigating each occupant’s own engagement with the driving scenario and driving task, and their attitudes towards the automation, rather than to determine any interrelationship between partners’ ratings. Thus, for SA, ST and WL, ratings were compared between the three drives using repeated-measures ANOVAs, with the role (driver or passenger) as a between-subjects factor. For trust, ‘before’ and ‘after’ ratings were compared using paired-samples *t*-tests. Drivers’ and passengers’ TA and trust ratings were also compared using independent samples *t*-tests.

A bespoke post study questionnaire examined the perceived role and influence of the passenger (from both the driver’s and passenger’s perspective) using Likert rating scales and written responses. Thirteen statements were rated independently by the driver and passenger using 7-point Likert scales, where 1 was labelled “completely disagree” and 7, “completely agree”. Again, ratings were provided independently by both parties with the aim of investigating their attitudes as an individual rather than to explore any influence of their partner’s attitudes and ratings. Where possible, statements were worded identically for the driver and passenger. For example, the statement: “I attempted to maintain awareness of the driving scene while the vehicle was in control” was used for both the driver and passenger. For analytical purposes, any negative statements were reverse-scaled, such that a higher numerical value always indicated a more positive attitude towards the stated behaviour or more positively perceived impact of the passenger. Statements were grouped into three clusters for analysis: during automation, decision to takeover and during takeover. Cumulative ratings were computed for each of the three clusters by amalgamating and scaling ratings. Drivers’ and passengers’ ratings were subsequently compared using independent-samples *t*-tests to determine any statistically significant differences between their responses.

In addition, we transcribed all dialogue that occurred between the driver and passenger during the routine takeover on drive one and during the unexpected, emergency handover on drive three. For the routine handover, this also included any dialogue associated with the decision to resume control, immediately before the takeover was initiated, until the car left the motorway. For the unexpected, emergency handover, all dialogue associated with the emergency itself was transcribed until manual control has been transferred to the driver. This included any dialogue in response to the emergency notification as well as any dialogue associated with the conditions leading to the unexpected handover, for example, if the driver or passenger noticed and commented on the degradation in weather conditions. Salient dialogue was subsequently analysed using speech act theory [48] by applying the driving skills hierarchy [13] as a framework (in other words, each speech act was associated with its relevant aspect of the driving task: control, tactical or strategic). In addition, episodes of perspicuous dialogue were captured verbatim to support findings.

Finally, vehicle control data immediately following the resumption of control were captured by the SCANeR simulation software (notably, lane position, lateral instability, speed and speed variability, driver's first primary control input), and analysed to evaluate the driver's performance during the take-over.

4 RESULTS

4.1 NDRTs

Smartphone use was popular amongst drivers and passengers, with 65% of drivers and 71% of passengers engaging with their smartphone at some point during their drive (Figure 3). This is largely unremarkable, given the role that smartphones play in many people's daily lives. However, there was also some evidence of drivers and passengers using smartwatches, ostensibly as a surrogate to using a smartphone (for example, to quickly read or respond to a message). Despite the prevalence of smartphone use, there were concerns expressed by some drivers and passengers regarding whether the driver should be allowed to use their phone or not, even during periods of automation (*Driver: "I do have my phone, but I don't really want to go on it." Passenger: "I don't want you to go on it either."*).

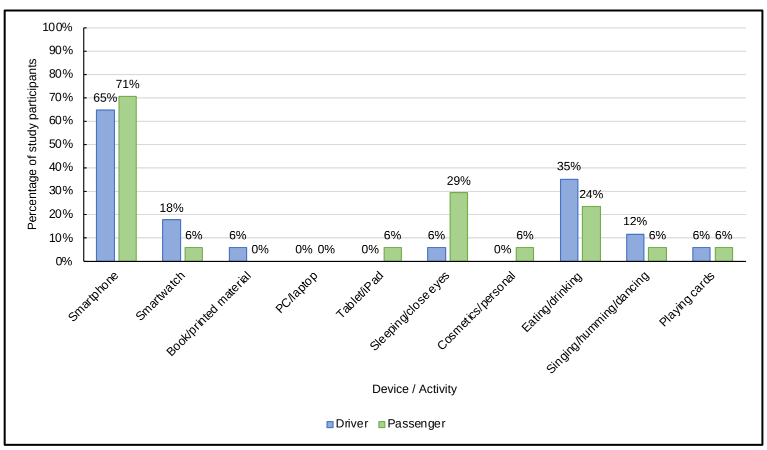

Figure 3: Secondary devices and activities undertaken by drivers and passengers during periods of automation

There were some notable differences in the activities conducted by drivers compared to passengers. For example, passengers tended to relax ('sleep') more and use their smartphones for longer periods than drivers. Participants comments suggested that many thought the passenger was more able to completely disengage from the driving task (for example, sleep, watch engaging content on their phone) than the driver, who ultimately retained responsibility for driving and the vehicle (*Passenger: "Even though I can sleep, you can't!"* Pair 1). Some passengers therefore admonished the driver if they suggested that they may sleep (*Driver: "I suppose I could have a nap really." Passenger: "No, no."* Pair 15). However, some drivers were quite prepared to sleep (often reclining their seat to do so) and were supported in their decision by their respective passenger (*Driver: "Can I sleep?" Passenger: "Yeah. You don't need to drive."* Pair 2), and there were also examples where the driver and passenger appeared to notionally share the driving task, for example, by taking turns to rest or sleep, while the other stayed alert. While some activities were initially undertaken in isolation (for example, the driver and passenger used their smartphone to check their own messages), they often subsequently shared their news or updates with their partner, typically by physically showing their partner the phone.

It was also common for the driver and passenger to use their smartphones to facilitate joint gaming activities, for example, playing a game of chess, solving an online crossword puzzle or playing a word game. However, not all joint activities were digital or device-based; there were also examples of participants who chose to play games in a more traditional manner, such as a game of cards, with physical playing cards. Notably, several participants, who were jointly engaged in gaming, missed their junction in drive one, prioritising their NDRT above preparations to resume control and exit the motorway. In contrast, some joint activities, such as sharing drinks and snacks, enabled the driver and passenger to remain visibly attentive to the road – at least in so far as their gaze was still directed to the forward driving scene.

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

In situations where the driver and passenger were also engaged in a joint NDRT while talking (for example, discussing chess moves), the conversation appeared to move seamlessly between this and driving. For example, while playing chess, the driver and passenger tended to glance back at the road between turns (though notably still missed their exit in this particular example); other participants (drivers and passengers) looked up in response to the noise of a passing vehicle or in response to their vehicle changing lanes, suggesting a natural 'chunking' to their NDRT. In addition, we observed drivers and passengers waving to other motorists in the simulation. This natural inclination to share observations and engage with other road users shows good immersion within the simulated driving experience, from a methodological perspective, but also suggests the potential for continued engagement with the road situation even during periods of automation and while undertaking NDRTs. Nevertheless, participants commonly described their experience in the automated vehicle as somewhat tedious: *"It's actually really boring."* (Driver, Pair 2); *"After 5 minutes, I'll be sleeping. Very boring."* (Driver, Pair 14); *"If you didn't have to do anything, it would be so boring."* (Driver, Pair 16), confirming common knowledge that it is challenging to stay attentive and alert during long periods of automation.

Conversation was particularly perspicuous when deciding when to resume control and during the takeover itself, with drivers often discussing and negotiating this decision with their accompanying passenger. Overall, participants tended to discuss more *control* [13] aspects during routine takeovers, whereas more conversational turns and speech acts were dedicated to *tactical* and *strategic* [13] aspects during the unexpected, emergency takeover. This arguably reflects the nature of the experience: during routine handovers, participants had already decided to resume manual driving, meaning that they were, to some degree, strategically prepared and had made some (albeit, cursory) assessment of the road situation in preparation for this (tactical). Thus, their focus during routine takeovers was arguably directed more to the control aspects of resuming control. During the third drive, however, participants were not expecting to take over control so soon, having prepared for a longer journey, and were therefore required to promptly stop their NDRT, make a quick assessment of the tactical situation and then consider the strategic elements, in response to the emergency notification (for example, assessing where their required junction was in relation to their current position). This was subsequently reflected in the additional dialogue and speech acts associated with tactical and strategic elements. In contrast, the control aspects of taking over were less commonly discussed during the unexpected, emergency handover as this was largely imposed upon drivers by the 'unexpected' nature of the takeover request.

4.2 Situational Awareness, Situational Trust, Workload, Trust in Automation, Technology Acceptance

For SA, no statistically significant differences were evident, indicating that drivers' and passengers' ratings of SA were comparable between drives ($F(2,64) = 2.35$, $p = .10$), and indeed, between roles ($F(2,64) = .26$, $p = .77$). In addition, drivers' and passengers' ratings of ST were statistically comparable between drives ($F(2,64) = .46$, $p = .63$), and indeed, between roles ($F(2,64) = .09$, $p = .92$). Drivers' and passengers' ratings of workload were also statistically comparable between drives ($F(2,64) = .86$, $p = .43$) and between roles ($F(2,64) = .62$, $p = .54$) (Table 1).

For trust in automation, there were no statistically significant differences between drivers' ratings before and after the drives ($t(16) = .24$, p = .81). However, passengers' ratings show a significant increase after the drives ($t(16) = 2.19$, p = .04), suggesting higher trust in automation. The independent samples *t*-tests show no significant differences overall between drivers' and passengers' ratings of trust in automation ($t(66) = .39$, p = .70). Finally, there were no significant differences between drivers' and passengers' ratings of technology acceptance ($t(32) = .05$, p = .96) (Table 2).

	Drive 1		Drive 2		Drive 3	
	Driver	Passenger	Driver	Passenger	Driver	Passenger
Situational Awareness	19.8 (4.5)	17.3 (6.8)	21.8 (5.4)	20.5 (7.1)	20.2 (4.9)	19.8 (6.7)
Situational Trust	4.1 (0.6)	4.1 (0.5)	4.1 (0.7)	4.1 (0.4)	4.2 (0.6)	4.2 (0.5)
Workload (NASA-TLX)	14.3 (3.4)	14.5 (4.6)	13.1 (4.7)	13.9 (4.6)	14.4 (5.6)	13.5 (3.2)

Table 1: Drivers' and passengers' ratings of situational awareness [44], situational trust [45] and workload [43], showing mean (standard deviation) values

	Before		After	
	Driver	Passenger	Driver	Passenger
Trust in Automation	3.26 (0.32)	3.16 (0.42)	3.28 (0.30)	3.31 (0.36)
Technology Acceptance	N/A	N/A	4.93 (0.76)	4.91 (0.93)

Table 2: Drivers' and passengers' ratings of trust in automation [46] and technology acceptance (TA) [47], showing mean (standard deviation) values

4.3 Bespoke Post Study Questionnaire

The bespoke post study questionnaire aimed to evaluate the impact of a passenger during the drives. Overall, there were no significant differences in mean ratings made by drivers and passengers regarding the presence of the passenger during automation, on the decision to resume control or during the takeover itself (Table 3). Nevertheless, mean ratings were generally above the scale median, suggesting that drivers and passengers thought the passenger's presence had a positive impact, on average, in all three situations. The larger range (standard deviation) of responses from passengers regarding their impact on the decision to resume control and during the takeover itself suggests a wider diversity of opinion amongst passengers regarding the impact of their presence in these situations. Notably, some passengers felt that they had a very positive impact (more so than their counterpart drivers' ratings might suggest), particularly during the takeover itself.

	Driver	Passenger
During automation	3.9 (0.79)	4.0 (0.69)
Decision to take over	5.1 (0.98)	5.1 (1.37)
During takeover	4.7 (0.54)	5.0 (0.90)

Table 3: Drivers' and passengers' ratings for bespoke post study questionnaire, showing mean (standard deviation) values

4.4 Route Choice and Driving Performance

During the first drive, five out of the seventeen drivers (29%) failed to resume control within sufficient time to exit the motorway at the correct exit, ostensibly because they were distracted. While two of these (P2 and P9) did request control but were subsequently too late to exit the motorway (in other words, they requested control with less than ten seconds to go), three drivers (P3, P5 and P14) were apparently so engaged in and distracted by their chosen activities, that they failed to even request control. For those who were successful, control was requested, on average, after passing the 'one mile to junction' road sign. Vehicle control data following resumption of manual driving (Figure 4) suggests that initially, lateral control was typically good, with all drivers appearing to maintain a steady central lane position and negligible variability in lane position in the first 3 or so seconds. Thereafter, lane position and variability became more erratic – up to 1.5 m for some drivers, and in both directions. It is worth noting that the lane width was 3.5 m, and the car was 1.8 m wide. Thus, any lateral position exceeding a magnitude of 0.85 m would result in the edge of the ego-vehicle exceeding the lane boundary and increasing the risk of colliding with a vehicle in the adjacent lane. After 10 seconds, lane position was still somewhat variable (Figure 4). Similarly, vehicle speed and speed variability (interpreted as standard deviation of speed) appeared good initially, but there was, again, high variability after approximately three seconds. It is notable that the first control input by all drivers during drive one (i.e. their first experience with L3 automation) was the accelerator, with this actuated, on average, after 2.1 seconds post takeover.

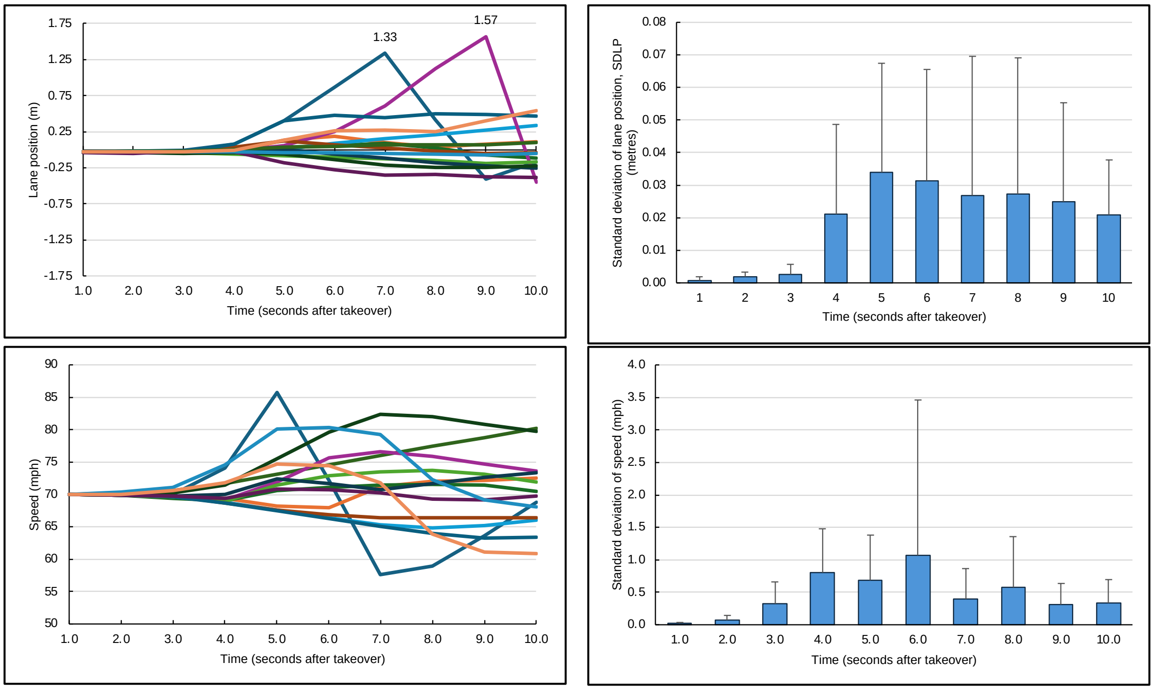

Figure 4: Vehicle control data captured from SCANeR simulation software, showing (clockwise from top left): lateral lane position (note: lateral positions exceeding a magnitude of 0.85 m have been highlighted; these would result in the edge of the vehicle exceeding the lane boundary), standard deviation of lane position (SDLP), mean standard deviation of speed, and vehicle speed (all at one second intervals after taking over control in drive one)

5 DISCUSSION

The current study aimed to uncover what drivers and their co-passengers will naturally do in vehicles offering level 3 automation (RQ1). Findings from our study show that smartphone use is still likely to be very popular during periods of L3 automation in which a driver and a co-passenger are both present, but we also noted the increased use of smartwatches to fulfil a similar role (ostensibly, to view email and message notifications). However, although drivers and passengers often interacted with their own smartphone in isolation to undertake a specific task, for example, to check their own messages, or conduct a search on a particular topic of interest to them at that time, they commonly shared their content and news items with their partner immediately thereafter by physically showing them the phone screen. Smartphones also featured in joint, participatory tasks, for example, using one smartphone to watch shared content together, such a film or a social media video feed, or playing online games together, with the driver and passenger each using their own smartphone as their digital playing board, for example, to each enter their chosen move during a digital game of chess. These joint, participatory tasks were often highly captivating and immersive, particularly if there was a competitive element involved, and this resulted in several drivers requesting manual control too late and subsequently missing their designated junction during drive one, thus raising significant concerns relating to distraction.

However, arguably the most notable observation was the propensity for routine, often unremarkable, conversation that took place between the driver and passenger – as also noted during manual driving [7]. Conversation was generally prolific during the journeys and covered a wide range of topics, suggesting at the very least that participants were largely unphased by the fact that they were taking part in a research study and being observed, and their behaviour being recorded. The prevalence of conversation also highlights that some drivers and passengers were apparently content to continue existing behaviours (in so far as conversation commonly takes place in the presence of one of more passengers during manual driving [7]), despite the change in the capability of their vehicle and the driving task. As such, we might not necessarily expect all users of future L3 automation to develop outlandish new habits, but must also be prepared for the continuation of conventional in-vehicle behaviours, particularly during the early stages of introduction.

In addition, conversation was often intertwined with other NDRTs, such as discussing chess moves or clues to a crossword. As with everyday conversation, interactions were initiated by both the driver and the passenger and the dialogue moved seamlessly between different topics, including aspects of the driving task. Indeed, features in the road environment were routinely observed and commented upon, as was the behaviour of the participants' own automated vehicle in response to other road users, and their attitudes towards automated vehicles more generally. In addition, drivers and passengers routinely discussed more social topics, such as recent sporting events or their plans for the weekend (see also: [33]).

It was also noted that the driver and passenger remained forward-facing due to the side-by-side seating arrangement with their gaze notionally directed to the road ahead; in practice, this facilitated the observation of features in the driving scenario. It would therefore seem prudent to retain this seating configuration, at least in so far as L3 automation is concerned, rather than attempting to create a more flexible and adaptive design. Indeed, some authors have recommended that front seats rotate to face passengers in the rear [12]. However, suggestions for this, so-called 'interior metamorphosis' [10] [11] tend to be aimed at and inspired by higher levels of automation, in which the driver seldom (if at all) drives manually.

In RQ2, we aimed to explore the impact of a co-passenger during periods of L3 automation and when transitioning between states of L3 automation and manual driving (and indeed, their role in the decision to do so). Analysis of conversation revealed that passengers provided help and advice in preparation for and during the takeover of control, akin to the support observed during manual driving [33]. However, during routine handovers (drives one and two), discussions included more control aspects (that is, relating to the operation of the vehicle – speed adherence, steering etc.), whereas tactical and strategic elements featured more dominantly in dialogue during the unexpected, emergency takeover request in drive three; these were more commonly related to road positioning and lane selection (tactical), and the journey goals, for example, determining the remaining distance to their required exit immediately following resumption of manual driving (strategic).

Conversation analysis also highlighted the role of the passenger as mediator, for example, reprimanding the driver if they attempted to undertake an activity that the passenger deemed to be unacceptable or inappropriate, such as sleeping (or if the driver even suggested that they may consider doing so). Other examples show the passenger helping to keep the driver alert or awake in preparation for resuming control. In contrast to manual driving, however, drivers were not required to rely on their passenger to undertake tasks on their behalf during periods of automation, such as unwrapping food, opening a drink bottle, retrieving items that were out of reach (we observed several drivers retrieving items from their bags in the rear of the car); in essence acting as a second pair of *hands* for the driver (as noted by [33]). However, there were still abundant examples of the passenger acting as a second pair of *eyes* for the driver, for example, when asked to confirm the details on a road sign.

Although post-study comments indicated that passengers (and indeed, drivers) were generally aware of the potential distraction created by their presence, they also highlighted examples of positive influences, such as helping the driver to locate the correct junction and to decide when to take control, or helping the driver stay awake and alert (given how *"boring"* many of our participants thought periods of automation were). On average, passengers tended to rate their own role and influence during these situations more highly than did their accompanying driver, with over half of the drivers (9 out of 17) indicating that they felt the presence of a passenger had no, or negligible, impact on their actions and behaviour. During manual driving, [33] noted a similar attitude, reporting that the majority of drivers (in their case, more than 70%) responding to their survey indicated that the presence of a passenger would make no difference to their behaviour. There are, of course, notable benefits associated with helping one another retain or rebuild situational awareness during periods of automation or taking it in turns to monitor the road situation. As such, it is important to note from the subjective ratings made in our post-study questionnaires, that the driver and passenger purportedly experienced equivalent levels of situational awareness, trust, workload and acceptance during the journeys (also in answer to RQ3).

The most noticeable impact on the driving task was evident amongst drivers and passengers who became so engrossed in their secondary activity that they failed to resume control within sufficient time to leave the motorway at the correct exit. However, it was also evident that vehicular control during the ten seconds immediately after resuming manual driving was generally poor (e.g., high levels of lateral instability) for all participants. Notably, and in contrast to Large et al. [3], there was an apparent tendency for vehicular control to become worse (i.e. increased instability) after two to three seconds and to remain erratic even after ten seconds. Considered in conjunction with the other metrics (most notably dialogue between the driver and passenger), we believe that, in some situations, this increase in speed variability (erratic accelerating and braking) and severe lateral instability (or 'wavering' in the lane) actually reflects the driver actively testing the primary control inputs (steering wheel, accelerator, brake), presumably to demonstrate to their passenger that they were now actively in control.

Much of the related literature highlights the impact of young drivers and young passengers [6] and has identified differences based on various driver-passenger relationships and demographics [42]. While we had a cohort of younger drivers in our study, and representatives from different driver-passenger partnerships (friends, partners, colleagues), participants volunteered as pairs known to one other and were therefore likely to have a positive relationship. Thus, our findings may be biased towards more 'cooperative' behaviours and less reflective of those occurring in neutral or difficult relationships; this arguably limits the generalisability of the results. We also recognise that we only explored behaviour with one front seat adult passenger present, and there are other possible occupant configurations at L3 automation (multiple co-passengers, young children in rear seats etc.) that could also be investigated. In addition, the research was conducted in our driving simulator. Whilst risk in a driving simulator may indeed be different to real-world driving, the driving simulator nevertheless offers a rigorous methodological approach to provide controlled observational data. In presenting the study to participants, we aimed to preserve the intrinsic motivational aspects of the driving experience by framing each drive as a genuine journey, with a different goal or aspiration, and immersing participants within this, for example, by encouraging them to take all their belongings into the car with them ("in case they were needed at their destination"). The driving scenarios were also designed to enhance ecological validity, for example, by including commonly occurring situations, such as a collision and subsequent traffic jam on the counter-carriageway, unusual vehicular activity on crossing bridges, and the vexatious behaviour of nearby vehicles (e.g. speeding / undertaking the ego vehicle). Moreover, the behaviour of our participants suggests that they were all actively (and appropriately) engaged with the task presented to them (selecting and exiting the motorway at the specified junction), other than in situations when they were distracted by their NDRTs, and strictly complied with speed limits, road signage etc. The broad topics of conversation also suggested that participants were speaking freely and were uninhibited by the situation and gave us no cause to question the validity of their behaviour. Even so, we recognise the use of a driving simulator as a potential limitation to our study and suggest that results are treated accordingly and in the manner intended – as an exploratory study to highlight the interactions that might naturally take place between a driver and a front-seat co-passenger in a vehicle offering L3 automation, and to set the groundwork for future investigations into how in-vehicle technologies could mitigate risks or enhance the benefits of passenger interactions.

Overall, our findings provide evidence of both distractive and protective behaviours when a front-seat passenger is present during L3 automation, although we recognise that our sample size was limited and demographically diverse, and this may limit the generalisability of our findings. Future investigations should explore strategies to remove or reduce the harmful, distractive elements and to enhance the positive, protective influences, and might also consider how protective effects could be provided in situations in which there is no passenger present. Indeed, technological solutions could support this: for example, recognising the proliferation of conversation that occurred in the presence of a co-passenger, and the influence this evidently has on the driver, a voice interface (or digital assistant) could encourage or invite discussion of relevant driving-related information between the driver and passenger, or even engage a lone driver as a passenger might. Furthermore, technology-mediation of NDRTs could ensure drivers and passengers do not become so engrossed in their activity that they miss their exit or other key driving information, for example, by enforcing natural breaks in activities ('chunking' tasks) and/or encouraging re-engagement with the driving scene at appropriate intervals. In addition, simple behavioural training interventions, similar to those evaluated by Shaw et al. [2], could remind drivers (and indeed, their co-passengers) of the potential risks when a passenger is present and provide best practice guidance to interacting with L3 automation in the presence of a passenger.

6 CONCLUSION

Driver behaviour in vehicles offering L3 automation is affected by the presence of a front-seat passenger. Our findings show that a co-passenger introduces new opportunities for the driver to engage in shared, participatory activities during periods of L3 automation, such as watching shared content or playing games together on a smartphone, jointly solving crosswords puzzles, playing cards etc. Although the emerging, shared activities had the potential to distract drivers and reduce the amount of attention they were able to direct to the road situation, particularly if there was a competitive element to the activity, they were often intrinsically bound with conversation and dialogue. Analysis of dialogue subsequently revealed that drivers and passengers also shared their engagement with, and responsibility towards, some aspects of the driving task. This was evidenced by examples of drivers and co-passengers jointly observing and discussing the behaviour of other road users during periods of automation, discussing and negotiating *appropriate* secondary activities to undertake (for example, discussing whether sleeping is permissible at L3 automation), and discussing tactical and strategic elements during the transfer of control. We therefore conclude that a front-seat co-passenger in vehicles offering L3 automation can offer both distractive and protective effects but would recommend further investigations to evaluate these phenomena further. More specifically, further work should seek to preserve and enhance the protective behaviours whilst eliminating the distractive effects and seek to uncover any nuances in behaviour associated with different sociodemographic groups, most notably young drivers, and between less familiar or even contentious partnerships.

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