A longitudinal simulator study to explore drivers' behaviour during highly-automated driving

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Design Implications of Drivers' Engagement with Secondary Activities During Highly-Automated Driving – A Longitudinal Simulator Study

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Abstract

Highly-automated vehicles will provide the freedom for drivers to engage in secondary activities while the vehicle is in control. However, little is known regarding the nature of activities that drivers will undertake, and how these may impact drivers' ability to resume manual control. In a novel, long-term, qualitative simulator study, six experienced drivers completed the same 30-minute motorway journey (portrayed as their commute to work) at the same time on five consecutive weekdays in a highly-automated car; a system 'health-bar' indicated the overall status of the automated system during each drive. Participants were invited to bring with them any objects or devices that they would expect to use in their own (automated) vehicle during such a journey, and use these freely during the drives. Inclement weather (heavy fog) on the penultimate day of testing presented an unexpected, emergency 5.0-second take-over request (indicated by an urgent auditory alarm and a flashing visual icon replacing a system 'health-bar'). Thematic video analysis shows that participants were quickly absorbed by a variety of secondary activities/devices, which typically demanded high levels of visual, manual and cognitive attention, and postural adaptation (e.g. moving/reclining the driver's seat). The steering wheel was routinely used as a support for objects/devices. Drivers were required to rapidly discharge secondary devices/activities and re-establish driving position/posture following the unexpected, emergency hand-over request on day four. This resulted in notable changes in participants' subjective ratings of trust on the final day of testing, with some participants apparently more sceptical of the system following the emergency hand-over event, whereas others were more trusting than before. Qualitative results are presented and discussed in the context of the re-design of vehicles to enable the safe and comfortable execution of secondary activities during high-automation, while enabling effective transfer of control.

Keywords

Automation; Secondary Activities; Transfer of Control; Simulation; Design

1 Introduction

The prospect of highly-automated vehicles on public roads has invited fervid speculation regarding the type and variety of activities that drivers may undertake within their vehicles during periods of automation. In particular, vehicle manufacturers and designers are keen to discover the likely impact that engagement in activities, previously considered secondary to driving, will have on drivers' behaviour and the subsequent design of future vehicles. A key consideration (during highly-automated driving) is that drivers should be able to comfortably and effectively undertake secondary activities of their choosing, while the vehicle is in control, but must be able to resume manual driving in situations not covered by the automation. This will naturally impact and inform the design of next-generation vehicles – potentially inspiring radically new vehicle interior designs – and appears key to the acceptance of highly-autonomous cars [1].

1.1 Vehicle Automation

The driving task is made up of numerous individual subtasks [2]. Automation can be applied to many of these subtasks to augment or replace aspects of manual control. The allocation and demarcation of control functions between the driver and automated subsystems has been defined by a number of different taxonomies (e.g. [3] [4]). Whilst these differ in the specific nomenclature, narrative and the number of levels of autonomy they profess, there is general consistency between taxonomies in the adoption and utilisation of three key descriptors: *partial*, *high* and *full*.

During ‘partial’ automation, the human driver retains full responsibility for safe vehicle control and driving practice, and must therefore permanently monitor the automated system and maintain a readiness to resume control at any time. ‘High’ automation removes the need to permanently monitor the system, but the driver must still be prepared to resume manual control within a predefined time-period in certain circumstances (e.g. in situations not covered by the automation, or following minor technical malfunctions, such as sensor failure). During ‘full’ automation (so-called ‘driverless’ cars), safe operation rests solely on the automated vehicle system and the driver is not expected to be available for control at any time during the journey [5].

Rapid developments in technology over the last decade mean that the widespread deployment of automated vehicles is rapidly becoming a reality, with experts suggesting that *highly*-automated derivatives could pervade our roads as early as 2020 [6]. Moreover, public expectations are high, with respondents to a recent survey indicating that they expect *full*-automation in more than 50% of vehicles by 2030 [7].

Exploring and understanding human factors issues associated with vehicle automation is therefore important. Indeed, as vehicles operate at increasing levels of autonomy (i.e. drivers relinquish an increasing degree of control to automation), complex driver-vehicle interaction patterns exist, and therefore understanding issues such as trust and over-reliance, workload, skills degradation and situation awareness [8] [9] [10] – particularly during manual control recovery (MCR) [11] – remain firmly rooted on the research agenda.

Additionally, in situations of high or full-automation, drivers – relieved of their duties and responsibilities for manual control – may be inclined to undertake secondary tasks while the vehicle is in control [12]. This is likely to have a direct impact on vehicle design and drivers’ subsequent engagement with the primary task of driving. For example, drivers may require additional space to conduct complex secondary activities and automotive manufacturers may therefore recline or relax the driver’s seating position, withdraw or collapse the steering wheel, or provide additional interior lighting to enhance comfort, space and visibility for drivers during autonomous control.

1.2 Methodological Approach

Taking a user-centred approach to design means that users’ requirements, goals and tasks are incorporated as early as possible into the design of a system. Understanding what drivers are inclined to do during periods of high or full automation – and how this will impact on their ability to resume manual control if required – is therefore important for future vehicle design. Nevertheless, exploring this before autonomous vehicles have reached wide-scale deployment is inherently difficult. Previous investigations concerning drivers’ behaviour and their engagement in secondary activities during periods of automated control, e.g. [11] [12], have focussed on exploring changes with increasing level of automation and/or have provided limited exposure or artefacts for drivers to use: some of these approaches therefore rely heavily on speculation, and may consequently lack face and ecological validity.

We therefore adopted a more novel approach by modifying the driving simulator to mimic a highly-automated vehicle – thereby relieving drivers of lateral and longitudinal control actions (and all associated cognitive elements) – and inviting participants to attend at the same time on each of five consecutive days (Monday to Friday). During each visit, participants completed the same 30-minute motorway journey – portrayed to them as a regular, daily journey that they might undertake, such as their commute to work. Prior to attending, participants were asked to consider what activities they might undertake in a highly-automated vehicle and to bring with them any related objects or devices, which they were then able to use freely while the vehicle was in control.

As a qualitative investigation, the study primarily aimed to highlight the type and range of activities undertaken by drivers (and the artefacts they used) during periods of high-automation, and identify any behavioural adaptations that these demanded or encouraged. However, it also provided the opportunity to explore the impact that these activities had on primary task engagement (explored through the constructs of situational awareness and trust) and any secondary task carry-over effects, particularly in situations where participants were required to unexpectedly resume manual control.

The intention in presenting this work is not to create an exhaustive list of the entire range of activities that drivers may undertake during highly-automated driving; nor is it to provide a comprehensive set of design guidelines. Rather, we aim to expose novel, qualitative insights, based on the empirical observation of drivers’ behaviour over an extended period of driving, that included episodes of highly-automated driving and manual control recovery (in both routine and emergency situations), and provide a rich palette for designers of next generation vehicles with ‘self-driving’ capabilities.

2 Method

2.1 Participants

Six participants took part in the study, with ages ranging from 29 to 55 years. All participants held a valid UK driving licence and were experienced and active drivers, with more than 5 years driving experience. Participants were self-selecting volunteers who responded to advertisements placed around the University of Nottingham campus and were reimbursed with shopping vouchers as compensation for their time. Due to the risk of simulator-induced motion sickness, participants were screened for the history of motion sickness, migraines, epilepsy, dizziness or blurred vision before taking part in the study, and provided written informed consent.

2.2 Apparatus, Design and Procedure

The study took place in a medium-fidelity, fixed-based driving simulator at the University of Nottingham (Figure 1). The simulator comprises an Audi TT car located within a curved screen, providing 270° forward and side image of the driving scene via three overhead HD projectors. Side and rear view mirror images are captured digitally and relayed to two 7-inch LCD screens, located to replicate the side mirrors, and a 55-inch curved HD LED television positioned behind the vehicle and visible using the existing interior rear-view mirror. A Thrustmaster 500RS force feedback wheel and pedal set are faithfully integrated with the existing Audi steering wheel and pedals, such that drivers interact with the original controls. In addition, the indicators and electrical controls remain fully operational within the vehicle. The driving scenario was created using STISIM Drive (version 3) software to replicate a standard UK motorway, with speed information etc. exported dynamically to a bespoke Java application, and subsequently re-presented on a 7-inch LCD screen within the vehicle to mimic the instrument cluster.

Fig. 1. Driving simulator showing motorway scenario.

Participants were invited to attend at the same time on each of five consecutive weekdays, with each visit representing the same daily commute journey to work. Participants had previously been advised that the car and route supported highly-automated driving, and as such they were not required to permanently monitor the system status or driving situation, but may be requested to resume manual control within a specified time-period. During each visit, participants began driving manually. Automated control (at 70mph) was activated shortly into the drive at the request of the participant using a voice-command: “start automated driving”; this initiated a 5.0-second hand-over transition. During the transition, a voice message: “starting automated driving” followed by a punctuated tone (5 beeps), was used to indicate progress and completion of the hand-over.

During periods of automation, participants were provided with a system ‘health-bar’ presented visually on a 12-inch touchscreen Microsoft Surface Pro tablet computer located in the centre console of the vehicle. Participants were advised that the health-bar indicated the ‘overall status’ of the automated system (encompassing vehicle sensors, road situation etc.). The ‘health’ status ranged from *green*, indicating ‘system ok’ to *amber* (‘minor problem, no driver intervention required’) to *red*, indicating ‘major problem, driver intervention may be required’, with the number of markers also reducing with diminishing health (Figure 2). The health-bar was designed to correspond with similar ‘status’ representations in existing technology (e.g. battery discharge indicator, Wi-Fi signal strength etc.) and cultural expectations (i.e. red, amber and green classifications), and intended to provide an ‘intuitive’ visual representation of vehicle status; as such, participants were not specifically made aware of each individual representation before taking part.

Drivers were provided with a verbal take-over request towards the end of each drive, comprising a warning message delivered at 60 seconds prior to hand-over (“approaching take-over”) followed by an action alert: “resume manual control”, delivered 5.0-seconds before the provision of manual control. Drivers therefore completed each drive manually. They followed the same route every day with each drive lasting approximately 30 minutes. At the end of each drive, participants completed the ‘Trust in Automation’ [13] and ‘Situation Awareness Rating Technique’ (SART) questionnaires [14].

On four occasions (days one, two, three and five), the drive was completed exactly as described and without incident: during these ‘routine’ drives, the health-bar indicator randomly fluctuated between *green* (‘system ok’) and *amber* (‘minor problem’) states. On the penultimate day of testing, inclement weather (the onset of heavy fog) presented drivers with an unexpected, emergency 5.0-second take-over request approximately 20 minutes into the journey. This was accompanied by a rapidly waning health-bar, which entered the *red* zone. The manual take-over request was presented shortly afterwards and comprised an urgent auditory alarm accompanied by a flashing visual icon (instructing drivers to ‘take control’) replacing the health-bar.

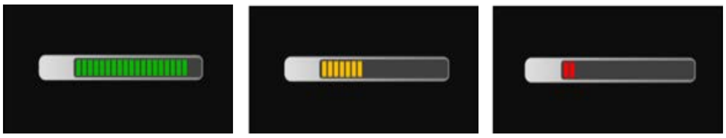

Fig. 2. Automated system ‘health-bar’ showing (left to right) green, amber and red status, with associated declines in the quantity of ‘health’ markers.

2.3 Measures and Analysis

Participants were video-recorded during each drive. These recordings were subsequently analysed using thematic coding to classify drivers’ behaviours, with a coding scheme that emerged during the analysis. Visual behaviour was also determined from the videos. In addition, general comments, captured from participants throughout the study were used to elucidate observations. Results from the ‘Trust in Automation’ [13] and ‘SART’ [14] questionnaires were also compiled.

3 Results and Discussion

Qualitative results are presented and discussed in the following sections: *Activities and Artefacts*, *Manual Control Recovery* and *Design Implications*. Trust and situation awareness questionnaire ratings are included within the discussions to elucidate results, where appropriate.

3.1 Activities and Artefacts

In line with our request, all participants brought with them items and devices of their own choosing, and utilised these freely during periods of automation. The most common items/devices were routine objects, including paper documents (articles, magazines, books etc.) and computing devices, such as laptops and mobile technology (mobile phones, iPads etc.). These enabled drivers to undertake various activities, the most common of which were: reading an article or magazine (using either published or paper copies, or from a tablet, such as an iPad), social networking activities using a mobile device, web-browsing and watching programmes/films on a laptop or iPad. Activities varied between participants. For example, two participants spent most of their time reading, whereas another participant spent almost half of their time accessing websites and the remainder of their time watching films/programmes using a video-on-demand (VOD) provider. A different participant spent approximately one third of their time engaged in social networking activities using their mobile phone (i.e. using Facebook, Twitter, etc.). Drivers also engaged in mobile phone texting/conversations, eating/drinking and personal grooming activities, such as applying hand cream/nail polish etc. A common theme is that all tasks and devices were visually and cognitively demanding.

Drivers were generally quick to begin their secondary activities following the transition to automated driving and tended to remain engaged with the same devices and activities throughout the journey (i.e. until they were asked to resume manual control). The decision to engage in visually and cognitively demanding activities suggests that drivers placed a high level of trust in the automation; this was confirmed by participants' subjective ratings, which were high from the outset and remained consistently high throughout the week. Trust is an important determinant of system performance and predictor of automation use [15]. Therefore, the high trust ratings seen during the study suggest that drivers are likely to adapt very quickly to automated driving, enabling the adoption of a wide range of secondary activities – previous investigations and theory had tended to predict that some drivers may initially be sceptical of relinquishing control to a 'driverless' car, and therefore unlikely to engage in other activities so readily.

Nevertheless, high levels of trust may encourage drivers to delegate full responsibility for vehicle control to the 'system'. In situations of full automation, such behaviour may be appropriate. However, during intermediate solutions (e.g. partial-automation and high-automation), such trust may be misplaced and could result in drivers engaging in secondary activities at the expense of maintaining awareness of the road situation, or relying on the systems for aspects of the driving task for which it is not primarily intended. Indeed, there was a tendency for participants who indicated the highest levels of trust to direct their full attention towards their chosen activities and pay limited attention to the 'system', i.e. fewer glances were made to the health-bar.

This was particularly evident on day four, when inclement weather resulted in the system returning control to the driver part-way through the drive. This 5.0-second emergency hand-over was preceded by a waning health-bar, yet two participants, who were particularly engaged in their secondary activities at the time (in this case, reading an article and watching a film) failed to notice the changes in the health-bar, and were only made aware of the need to resume control when they were presented with an urgent auditory alarm. Participants' ratings of trust consequently varied on the following excursion – interestingly, two participants rated their trust in the system much lower after the emergency hand-over event, suggesting that these drivers interpreted the fact that the system had to hand-back control as a lack of technical competence (this was also confirmed during discussions with the participants at the end of the study), whereas trust ratings from the other three participants increased (unfortunately one participant could not attend on the Friday). For the latter drivers, the 'decision' to hand-back control was heralded as an indicator of system 'intelligence' – i.e. these drivers' believed that the system was capable of identifying the limits of its capability and relinquishing control when these were breached – which was therefore seen as a positive attribute. Such attitudes are likely to increase drivers' engagement in secondary activities, thereby confounding the problem of maintaining (or regaining) awareness.

Nevertheless, participants' comments suggested that they understood the need to regain situational awareness prior to resuming manual control, and were aware of the potentially deleterious effects that engaging in secondary activities prior to this could have on the transfer of attention: "*In automated driving, I feel more relaxed and engaged myself in secondary activities. During the critical event, I felt like I need to quickly transfer from my relaxed state (low demand) to an extremely alert state (high demand) which affects my transfer abilities".* Also, "*I noticed the amber coloured bars started to reach the minimum level and quickly turned into red bars which prompted me to stay more active and expect something might going to happen. Then I placed my hands on the steering wheel to ensure that I could effectively respond to the situation that is going to occur."*

Many of the activities undertaken by drivers involved watching or reading from a secondary device (e.g. iPad) or paper copy. For these activities, the steering wheel provided a natural resting surface (particularly for small items such as books, papers, iPad etc.). For example, in Figure 3, participants can be seen supporting an iPad against the steering wheel, leaning a magazine article against it and resting a mobile phone on top of it. Utilising the steering wheel in this manner was a common strategy – in addition to relieving drivers of the need to physically hold the item, it also allowed them to place it in their forward-facing line of sight, thereby improving comfort and enabling occasional cursory glances at the road situation with minimal effort.

In other situations, e.g. when using larger items such as a laptop, the steering wheel hindered activities and drivers were required to recline or adjust their seating position or place the larger items elsewhere (e.g. the passenger seat) due to the limited space.

Fig. 3. Different configurations for holding secondary artefacts employed by drivers.

3.2 Manual Control Recovery

Although trust ratings generally remained high throughout the study, subjective ratings for situation awareness varied widely (inconsistencies are likely to be due to drivers' interpretation about which 'situation' drivers were assessing, i.e. the road conditions, the automated system, the secondary task etc.). Good situational awareness is important during manual driving and this requires an understanding of both the current situation as well as the projection of future actions [16]. Low ratings of situational awareness, combined with high levels of trust in the automation (as seen during the study), suggests over-reliance, reduced vigilance and lack of understanding of the system capabilities [16]; in such situations, drivers may be ill-prepared to resume manual control, particularly in emergency situations [8].

During the routine hand-overs (i.e. days one, two, three and five), drivers were given a 'prepare' warning ("approaching take-over"), delivered at 60 seconds prior to hand-over. This apparently provided sufficient time to comfortably stop activities, safely discharge and store artefacts, and begin to re-engage with the primary task (i.e. assuming physical driving posture and regain situational awareness, etc.) prior to resuming manual control. However, presented with the emergency hand-over situation on day four, no such early warning was provided, and, given their engagement in secondary activities, most drivers were unaware of the declining driving situation until they received the emergency transfer-of-control request. Consequently, activities were terminated in haste and associated artefacts discharged in a haphazard manner. Moreover, drivers were unable to enact the same routines to regain posture and situational awareness. A further problem was revealed by one of our older participants, for whom aged-related presbyopia dictated that they wore reading glasses while attending to their in-vehicle activities. The issue became particularly apparent when they were required to quickly resume manual control of the vehicle – the 5.0-second emergency hand-over period provided sufficient time for them to safely locate their laptop, but was apparently insufficient time for them to remove and safely store their glasses. It is also possible that this driver was so engaged by the activities associated with resuming manual control that they failed to realise they were still wearing reading glasses – this explanation tends to be supported by comments received later from the participant, who attested that, in addition to safely locating their laptop, had actually also removed their reading glasses (clearly, they had not). In either case, the participant continued for the remainder of the drive wearing their reading-glasses – in the driving simulator, this did not necessarily present a problem with their long-distance vision and they were still able to attend to the road situation, but in a real-world environment, this is likely to be different.

Automated driving has been routinely described as 'hands-free' driving. However, the nature of the problems associated with manual control recover, apparent during the emergency handover (and which were exacerbated by drivers' engaging in visually and cognitively-demanding secondary tasks during periods of automation), tends to suggest that automated driving should also be considered 'eyes-free' and 'mind-free'. It is therefore important that drivers are encouraged to remain engaged with the driving task – particularly during episodes of highly-automated driving, where they may be required to resume manual control at some point during a journey.

It has therefore been suggested that automated systems could disengage automated control if the driver removes their visual attention away from the road centre for longer than a defined period of time [11]. This would encourage drivers to return their gaze to the road to regain situational awareness periodically throughout an automated drive. However, this strategy requires that drivers are aware of the need to do so and also restricts the range of secondary activities available to drivers, e.g. to activities where visual attention can be successfully 'chunked' in this manner. Moreover, it assumes that re-directing visual attention (alone) is sufficient to achieve re-engagement. In reality, secondary tasks are likely to also be cognitively-captivating and therefore significant effort would be required to re-engage drivers with the primary driving task – something that is difficult to assess using driver monitoring systems – before re-enabling automated control. Interestingly, several participants recognised this dilemma during the study. For example, during post-study discussions, one of the participant commented: *"I often used to check the status of health bar when I was involved in activities such as checking email, Facebook etc., but when I watched video episodes on YouTube or Netflix, I hardly noticed the health bar"*.

The nature of secondary activities is clearly of fundamental importance if we are to expect drivers to maintain the ability to resume control, given appropriate notice (i.e. in situations of high-automation). While restricting drivers to a limited set of activities might seem feasible 'on paper', the realities of driving mean that this is unlikely to be a viable option in the 'real-world' (consider the current difficulties restricting texting-while-driving in the UK – which is against the law and carries a significant fiscal and 'points' penalty). A better solution therefore may be to develop other HMI (human-machine-interface) solutions that can keep drivers appraised of the current driving situation (road, traffic, weather etc.) – as well as the state of the automation – through other means/modalities (e.g. auditory, haptic experiences etc.), without the pre-requisite of (or indeed, sole reliance on) visual attention. Nevertheless, it is recognised that drivers may also be highly-engaged in secondary activities from a cognitive perspective, and therefore other solutions employing sound etc. may be equally ineffective. Needless to say, this is a 'hot' topic for further investigation.

It is worth noting at this point that the HMI used during the study to provide system health status was designed for experimental convenience and was necessarily sparse – we did not want to create a major source of visual distraction and were not attempting to use this to keep drivers engaged with the driving situation (although it did provide a highly-abstracted view of this).

3.3 Design Implications

There was a notable change in drivers' behaviour and demeanour, immediately after relinquishing manual control. This was most evident in changes to their physical posture. Indeed, most participants (though notably not all) interpreted the transfer to automated control as an invitation to avail themselves of the 'freedom' from the driving task by relaxing their posture and reclining and/or adjusting the position of their seat etc., although interestingly (although perhaps unsurprisingly), nobody unbuckled their seat-belt. One driver remained in a strict driving posture throughout the study (with their hands placed loosely on the steering wheel), making only very occasional departures to use their mobile phone: this behaviour was more akin to using technology while driving, suggesting that this driver was very suspicious of either the automation, or the 'experimental' conditions.

Provided with advanced warning of the impending need to resume manual control (towards the end of each drive), all drivers were seen overtly re-assuming strict driving posture by sitting upright, grasping the car's steering wheel at classic "10 and 2 o'clock" hand positions, and 'bracing' themselves as if preparing for impact.

Drivers also changed their posture regularly throughout periods of automated control. This primarily occurred due to the adoption of new tasks that required different postural configurations (e.g. to provide additional space when using a laptop), but also appeared to happen routinely throughout each journey. It is likely that this was used as a strategy to alleviate discomfort, boredom, fatigue etc. – the ability to do so during highly-automated driving is in marked contrast to periods of manual control, where such re-posturing is not possible. Several examples of the postures adopted by drivers during periods of automated control are shown in Figure 4.

For attentive drivers, postural changes were also observed in response to changes in the driving situation. For example, one of the participants was watching a film on their computer, which was placed on their lap. On noticing the changes in the weather conditions and associated waning heath bar on day four, they repositioned their laptop on the passenger seat, thereby allowing them to both continue watching the film, while also enabling an effective resumption of the physical aspects of manual control should the need arise, i.e. eliminating the need to move the laptop during the transfer-of-control request, prior to taking control.

For many of the activities under observation, the steering wheel provided a natural resting point for artefacts. Using different devices in highly-automated vehicles is likely to require some form of support, particularly on long journeys. This could be achieved by directly modifying the steering wheel to act as a support. Alternatively, the steering wheel could be withdrawn or collapsed to enable the provision of a bespoke table or platform. Withdrawing the steering wheel would also provide more space, thereby allowing drivers to adopt a more comfortable posture and undertake more expansive secondary activities. However, the steering wheel is a primary control input that epitomises the manual driving task. Removing the steering wheel from a vehicle (even temporarily) would therefore represent a significant change to the driving experience, even if it was only rarely expected to be used (i.e. during episodes of manual driving), and would also preclude the provision of steering feedback to drivers during periods of automation.

Recognising the different activities and postures that drivers adopt during periods of automated control – and incorporating these within the design process as early as possible – is important to ensure the acceptance of future vehicles with autonomous capabilities. Acceptance is based on individual attitudes, expectations and experience as well as the subjective evaluation of expected benefits [17]. Therefore, although the degree of technological innovation has an impact on the acceptance of technology, personal importance is a far more significant predictor [18]. For example, if drivers are not able to undertake the activities that they choose (e.g. due to space limitations or poorly configured/illuminated cockpits), or the vehicle design does not conform with their expectations (e.g. the steering wheel withdraws unexpectedly during automation), acceptance will be poor and market success can hardly be reached [19].

Given the evidence presented here, automotive designers may consider accompanying the transition to automated control with the relaxation of the driver's seating position and the provision of an additional support/surface – thereby providing both the space and infrastructure for drivers to comfortably undertake secondary tasks. For some activities, additionally lighting may also be required – the projection of the simulated environment naturally provided good illumination during the study, however, in a real-world environment, some of the activities identified during the study (e.g. reading a book or printed article) would be difficult during dusk or night-time driving

Fig. 4. Some of the different postures adopted during periods of automated driving.

It is also worth noting, that if a vehicle interior adapts during periods of automation, it should be capable of rapidly reconfiguring for manual driving – if and when the need arises. In particular, physical changes to re-enable manual control should be quick (to account for emergency situations) but also graceful (to avoid injury) – for example to ensure that an iPad (hitherto supported by a reclined steering wheel) is not forcibly thrust back into a driver's face. Successfully resuming manual control is also contingent on drivers being able to rapidly and safely discharge and secure their own devices. A notable observation during the emergency hand-over event on day four of the study was that some drivers found it difficult to quickly store their secondary devices before resuming control. The provision of adaptable storage solutions that are accessible to drivers, would therefore also be beneficial.

Finally, it was apparent that many of the secondary activities required some level of 'connectivity' (e.g. streaming VOD content, web-browsing, accessing social networks etc.). This was taken for granted during the study – the University wireless network was accessible to participants (largely by default rather than design). In a real-world situation, although some technology is likely to have data roaming capabilities (e.g. mobile phones), the provision of wireless network access appears to be or paramount importance to drivers.

3.4 Limitations of Study

Inviting drivers to undertake the same route over an extended five-day period in a driving simulator – to mimic their daily commute driving – is a highly novel approach to study their long-term behaviour during automated driving. Both the methodological approach – as well as the findings themselves – are therefore likely to be of interest to the automated driving community. However, there are inevitable limitations associated with simulation that may have influenced participants' behaviour, such as poor risk perception. Moreover, some in-car features (that drivers may have reasonably expected to use in their own vehicle) were notably absent during the study, for example, the radio/CD player was not enabled. In a real-world situation, listening to music may have been an obvious activity. However, we were keen to discover the artefacts that drivers would select (given complete freedom to choose) and did not preclude drivers from using their own music players during the drives.

There were also no motion cues in the simulator. In a real-world situation, road vibrations and vehicle motion may limit drivers' ability to engage in tasks demanding high levels of visual attention, such as reading – due to the inevitable mismatch between the visual perception and the vestibular sensation of motion – and will therefore likely result in increased incidence of motion sickness.

Finally, it is worth noting that, due to the study design, ratings for trust and situation awareness are based on responses from a very limited number of responses. Consequently, the inclusion of these data is primarily to illustrate the attitudes and opinions of the six drivers who took part in the study, and it should not be assumed that trust and situation awareness ratings are generalizable to a wider population.

4 Conclusion

Qualitative observations of drivers' behaviour in an automated vehicle suggests that they are likely to select and engage with a variety of secondary activities using a range of artefacts during periods of high-automation. Many of the activities had strong visual and cognitive elements and required postural adaptation (e.g. moving or reclining the driver's seat to watch a film on a laptop): for some drivers, activities also necessitated the wearing of reading glasses, which had previously not been required during manual driving. During an unexpected, emergency hand-over request, drivers were required to rapidly disengage from their activities, discharge secondary devices and re-establish driving position and posture. Thus, dynamic design elements to assist drivers in the successful and comfortable execution of their chosen activities (e.g. a platform to support their iPad or laptop), must be quickly (and safely) returned to their original configuration, if and when drivers are required to resume manual control.

The study differs to previous investigations in that drivers were exposed to automated driving over an extended period, involving multiple return visits to the simulator to complete the same 'commute' journey. Moreover, they were encouraged to bring with them their own items or devices to use. Observations were made using a vehicle designed to operate at high-automation, but results are equally applicable to situations of full-automation. The findings have clear implications for the design of next generation vehicles with self-driving capabilities, although further investigations are required. In particular, future studies should consider the effect of road vibrations and vehicle motion on the selection of and engagement with secondary activities during periods of automation.

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