
Monograph:
Carsten, O. orcid.org/0000-0003-0285-8046, Perrier, M. and Jamson, S. (2023) Driver Attentiveness to the Driving Task During ADAS Use. Report.

https://doi.org/10.13140/RG.2.2.31985.04961

Driver Attentiveness to the Driving Task During ADAS Use

Commissioned by the Department for Transport (T0305)

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May 2023

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Acknowledgements

We would like to express our gratitude to the suppliers of driver monitoring systems who gave their time to be interviewed and provided us with insight into the capabilities of current technologies.

Executive summary

This research has been carried out on behalf of the Department for Transport to gain insight and evidence to support the further development of regulations governing the specification of Advanced Driver Assistance Systems for vehicle control. These systems can assist and even supplant the human driver in sustained lateral and longitudinal control of the vehicle, while still leaving the driver responsible for the safety of vehicle operation and with the obligation to intervene in control where necessary to maintain safety.

Current international vehicle regulations require that assistant systems for steering also prompt drivers not to remove their hands from the steering wheel, with escalating warnings and eventual system disengagement if they fail to do so. These are therefore “hands-on” systems. By contrast, in North America, some manufacturers have introduced “hands-off” systems which allow the driver to remove both hands from the steering wheel. For these systems, driver monitoring technology is used to identify when driver are inattentive and prompt drivers to shift gaze back to the road scene. Currently there is discussion of whether such systems should be permitted in international vehicle regulation, which could potentially allow them to be fitted in vehicles sold in the UK.

The evidence review reported here has used the published literature, supplemented with interviews with suppliers of driver monitoring systems, to ascertain:

1. Whether driving with ADAS that provides continued longitudinal and lateral control stimulates driver inattentiveness;
2. Whether driving with hands-off ADAS further promotes inattentiveness;
3. Whether means exist to mitigate any tendency for driver inattention when driving with such ADAS and promote rapid reengagement.

The overall conclusions are that the research evidence points to increased driver inattention with hands-on longitudinal and lateral assistance as compared to manual driving, which is exacerbated with hands-off driving. However, given that hands-off systems are only available in North America, it is not certain that these findings can be transposed to UK drivers, who generally are much less likely than their North American counterparts to engage in non-driving related tasks.

The capability of current driver monitoring systems to reliably capture driver inattention is somewhat in doubt, as is the willingness of UK drivers to respond appropriately to prompts to resume attention. Thus overall, there are some gaps in understanding of whether hands-off control assistance should be permitted. This points to a need for further research to help resolve the uncertainties.

1. Introduction

1.1 Problem space

It is increasingly common for new road vehicles to provide drivers with advanced driving assistance systems (ADAS) that can support the driver in the control and manoeuvring aspects of the primary driving task. These systems can analyse the vehicle environment, inform or warn the driver, and increase driving comfort by actively stabilising or manoeuvring the vehicle (Knapp et al., 2009). Some of these systems can be enabled in appropriate circumstances in order to substantially reduce or even supplant the driver's input in both longitudinal and lateral vehicle control, relieving the driver of interaction with the pedals and assisting, to various degrees, in steering control. Such functionalities, however, still leave the driver responsible for the safety of the dynamic driving task[1] and therefore conform to Level 2 (L2) of the Society of Automotive Engineering (SAE) hierarchy of the Levels of Automation (see Figure 1). In the case of L2 driving, the driver is expected to immediately resume their input into the driving controls upon realisation that the ADAS is not capable of handling a situation, or more generally, whenever necessary to maintain their safety and that of other road users. Such technology therefore constitutes 'driver support', in contrast with 'automated driving' at Levels 3 and above, where the responsibility for the safety of the dynamic driving task is assumed by the automated driving system. With L2 driver support, continued driver attention to the roadway and traffic scene is required.

Currently, when using such functions, UK drivers are required by the system itself to keep one or both hands on the steering wheel, as with unassisted driving. This is in accordance with the United Nations Economic Commission for Europe's (UNECE) Regulation 79 on steering, which does not allow for systems designed for hands-off driving. The regulation requires that, if drivers remove both hands from the steering wheel for a period of 15 seconds when driving with assisted steering, an optical warning is issued. If a further 15 seconds passes with no hand on the wheel, then an acoustic warning is issued. The assisted steering is deactivated if a further period of 30 seconds passes without a hands on the wheel.

UK drivers have a general legal obligation to exercise proper control of the vehicle at all times, and there is instruction in Rule 160 of the Highway Code to 'drive with both hands on the wheel where possible.' This rule also states that in the case of ADAS use, the driver should 'use any system according to the manufacturer's instructions.' The rules of the Highway Code may, be used as evidence of misconduct against the driver during court proceedings. By contrast, in North America vehicles with L2 systems which allow hands-free driving, such as Cadillac's Super Cruise, are legally permitted. Such systems are designed to maintain driver focus by providing warnings when it is determined that the driver is devoting insufficient visual attention to the forward roadway.

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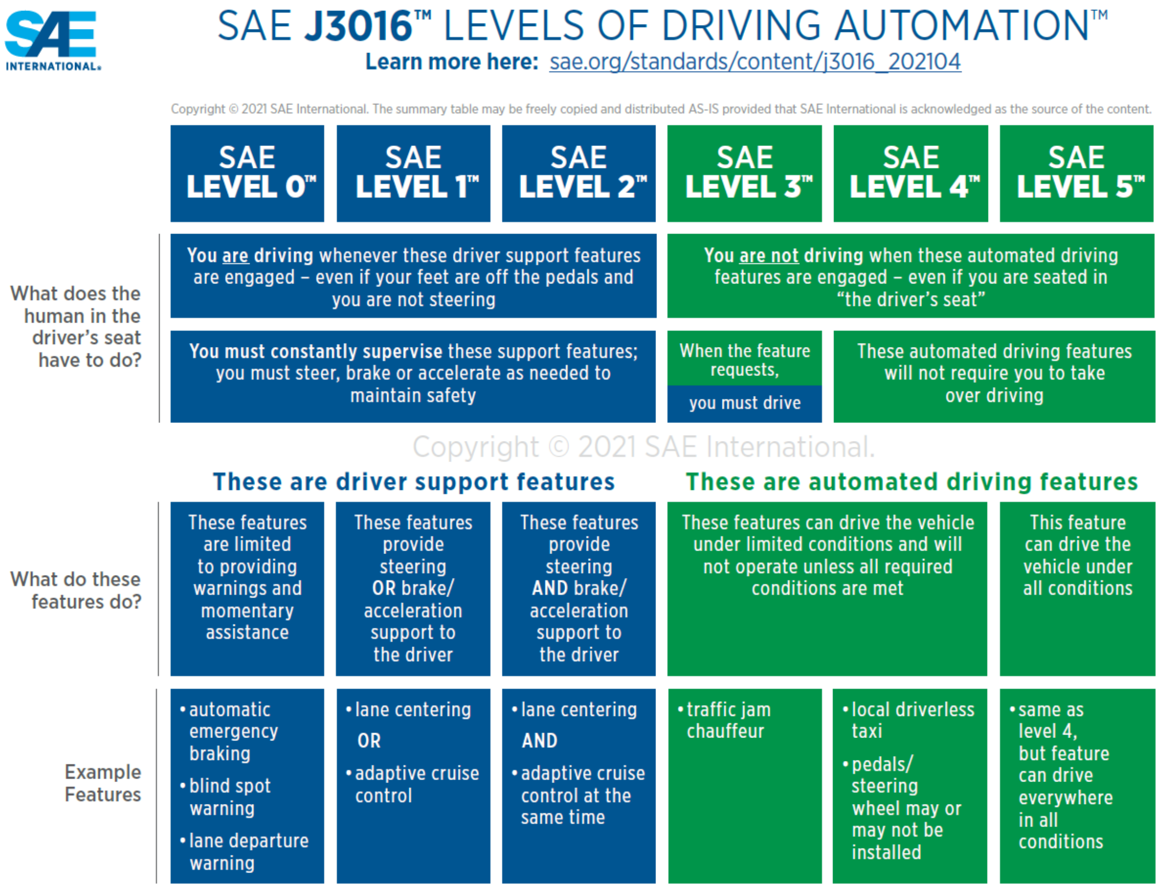
[1] The dynamic driving task is defined by SAE (2021) as "*All of the real-time operational and tactical functions required to operate a vehicle in on-road traffic*."

Task Force ADAS at UNECE is also considering the possibility of a regulation that might permit such hands-free assisted driving under the broad name of Driver Control Assistance Systems (DCAS; UNECE, 2022). Such a DCAS system, in addition to the sustained driving-in-lane capability of existing L2 assistance, could also provide lane-change capability without a need for driver confirmation. Were such a variant of L2 functionality to be approved at an international level, the potential for its use in the UK would arise.

Hands-free driving completely frees the driver from any coupling with vehicle controls, as shown in the outer loop of Figure 2. Divorce from the control loop comes with a risk of promoting driver inattention, because the need for steering input promotes attention and because the monotony of observing a road scene which is generally uneventful (supervisory control) can encourage the driver to seek stimulus elsewhere. While this risk can also be true for hands-on L2 driving, this greater decoupling from vehicle controls could reduce drivers' engagement with the driving task, as we know that the actions that are available to an individual will guide their attention and exploration of the environment (e.g., Ferretti, 2021).



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	SAE LEVEL 0™	**SAE LEVEL 1™**	**SAE LEVEL 2™**	**SAE LEVEL 3™**	**SAE LEVEL 4™**	**SAE LEVEL 5™**
What does the human in the driver's seat have to do?	**You are driving** whenever these driver support features are engaged – even if your feet are off the pedals and you are not steering			**You are not driving** when these automated driving features are engaged – even if you are seated in "the driver's seat"		
	You must constantly supervise these support features; you must steer, brake or accelerate as needed to maintain safety			When the feature requests, you must drive	These automated driving features will not require you to take over driving	
	These are driver support features			**These are automated driving features**		
What do these features do?	These features are limited to providing warnings and momentary assistance	These features provide steering **OR** brake/ acceleration support to the driver	These features provide steering **AND** brake/ acceleration support to the driver	These features can drive the vehicle under limited conditions and will not operate unless all required conditions are met		This feature can drive the vehicle under all conditions
Example Features	• automatic emergency braking • blind spot warning • lane departure warning	• lane centering **OR** • adaptive cruise control	• lane centering **AND** • adaptive cruise control at the same time	• traffic jam chauffeur	• local driverless taxi • pedals/ steering wheel may or may not be installed	• same as level 4, but feature can drive everywhere in all conditions

Figure 1: Definitions of the SAE Levels of Automation (SAE, 2021).

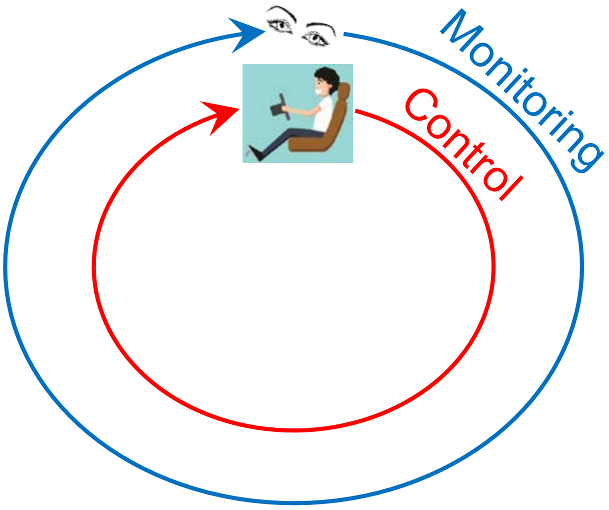

Figure 2: The monitoring and control loops (Carsten and Martens, 2019).

As a consequence, this research has been carried out on behalf of the Department for Transport to gain insight and evidence to support the further development of regulations governing ADAS features. There is a need to ensure that such features achieve one of their principal objectives of reducing collisions and that they do not have the negative side effect of reduced driver attentiveness or misuse, to the detriment of the vehicle occupants and other road users. There is a need to ascertain:

4. Whether driving with ADAS that provides continued longitudinal and lateral control stimulates driver inattentiveness;
5. Whether driving with hands-off ADAS further promotes inattentiveness;
6. Whether means exist to mitigate any tendency for driver inattention when driving with such ADAS and promote rapid reengagement.

1.2 Research topics and methods

This research has focussed on four topics:

1. The degree of assistance with the driving task provided by ADAS systems
2. Methods to monitor user attentiveness, covering both the current state of the art in real-time driver monitoring and the robustness of the various approaches. One major question here will be whether “mind on the road” can be surmised from measures of visual attention.
3. The impact of ADAS and in particular of an ADAS that permits hands-off driving on user attentiveness
4. Techniques to alert the user and reengage their attention

Topic 1 has been addressed by examination of the trade literature and of Euro NCAP test protocols and test outcomes. Topic 2 has been addressed by (i) interviews with suppliers of driver monitoring systems, (ii) interviews with researchers on driver attention, and (iii) our awareness of the current discussions in the European Commission’s Motor Vehicles Working Group on the specification of an Advanced Driver Distraction Warning system. This system is to be implemented in accordance with the EU General Safety Regulation of 2019. A systematic literature review was conducted to ascertain the research findings on Topic 3. Finally, Topic 4 has been informed by existing guidelines, trade literature, and research outputs.

2. Degrees of assistance provided by ADAS

As mentioned previously, advanced driving assistance systems (ADAS) can support drivers to conduct their primary driving task by (i) providing visual, auditory, and/or haptic warnings, and/or by (ii) influencing some aspects of vehicle control. The automation of vehicle controls may either be temporary or sustained over a longer period of time, and will primarily influence either longitudinal control (i.e., acceleration, deceleration, braking) lateral control (i.e., steering) or the two together.

2.1 Categories of systems assisting with driver attentiveness

2.1.1 Driver drowsiness and attention warning (DDAW)

This system, as defined in EU General Safety Regulation [Regulation (EU) 2019/2144], "*assesses the driver's alertness through vehicle systems analysis and warns the driver if needed*." The system detects how many times the vehicle deviates from the centre of its lane of travel over a certain period of time and will chime and show a symbol (e.g., commonly a coffee cup) when it judges the driver should take a break from driving. Additional auditory and haptic warnings are sometimes also provided.

2.1.2 Advanced driver distraction warning (ADDW)

This system, as defined in the EU General Safety Regulation [Regulation (EU) 2019/2144], "*helps the driver to continue to pay attention to the traffic situation and warns the driver when he or she is distracted*." At this stage, technical provisions/requirements are still being developed by the European Commission, in consultation with the EU Working Group on Motor Vehicles. These warnings may be based on driver monitoring that uses an eye-tracking device to estimate the driver's focus of visual attention over a certain period of time or, as a fallback, to analyse the driver's head posture and orientation as an estimation of their gaze direction. This system is targeted at attention in general and not specifically at maintaining attention during L2 driving. However, it has clear relevance to driver monitoring in L2 driving.

2.2 Categories of systems assisting with longitudinal control

2.2.1 Forward collision warning (FCW) — SAE L0: no driving automation

This system provides alerts to the driver when it detects imminent forward collisions in order to promote intervention by the driver. It is defined as a part of the advanced emergency braking (AEB) system in UN Regulations No. 131 and No. 152.

2.2.2 Advanced emergency braking (AEB) — SAE L0: no driving automation

This system, as defined in UN Regulations No. 131 and No. 152, can automatically detect imminent forward collisions, warn the driver, and activate the vehicle braking system to avoid or mitigate the severity of collisions with other vehicles or vulnerable road users.

2.2.3 Cruise control (CC) — SAE L1: assisted driving

This system, as defined in ISO standard 7000 - 2047, "*automatically accelerates or decelerates the vehicle to maintain a pre-set speed*."

2.2.4 Adaptive cruise control (ACC) — SAE L1: assisted driving

This system, as defined in ISO standard - ISO 15622:2018, is an "*enhancement to conventional cruise control systems […] which allows the subject vehicle to follow a forward vehicle at an appropriate distance by controlling the engine and/or power train and potentially the brake*." ACC systems can either be Full Speed Range (FSRA) or Limited Speed Range (LSRA) systems. The former is equipped with a so-called stop-and-go function that allows the vehicle to come to a full stop while the latter will only operate above a fixed minimum speed.

2.3 Categories of systems assisting with lateral control

2.3.1 Emergency steering function (ESF) — SAE L0: no driving automation

This system, as defined in UN Regulation No. 79, detects potential collisions and *"means a control function which can automatically detect a potential collision and automatically activate the vehicle steering system for a limited duration, to steer the vehicle with the purpose of avoiding or mitigating a collision."*

2.3.2 Lane departure warning (LDW) — SAE L0: no driving automation

This system, as defined in UN Regulation No. 130, warns "*the driver of an unintentional drift of the vehicle out of its travel lane*." This system, although it can be used independently, almost always accompanies the lane departure avoidance (LDA) system described in the next subsection.

2.3.3 Lane departure avoidance (LDA) — SAE L0: no driving automation

This system, as described in UN Regulation No. 79 (p. 2), "corrects the steering angle to prevent departure from the chosen lane", although only for a limited duration. This system can be categorised as a:

- Corrective Steering Function (CSF), in the said UN Regulation No. 79;
- Automatically Commanded Steering Function (ACSF) of Category B1, also in the UN Regulation No. 79 ("*assists the driver in keeping the vehicle within the chosen lane, by influencing the lateral movement of the vehicle*");
- Lane Keeping Assistance System (LKA/LKS), as defined in ISO standard 7000 - 3128, which is the term most used in the automotive market;
- Lane Departure Prevention (LDP) system by some authors (e.g., Sullivan & Flannagan, 2019).

In addition, the Emergency Lane Keeping System (ELKS), which consists of the combination of LDW and LDA, is defined by the latest update of the EU General Safety Regulation [Regulation (EU) 2019/2144] and fully specified by the European Commission Implementing Regulation [Regulation (EU) 2021/64]. This ELKS system is to be fitted on all new M1 and N1 vehicle types in the EU from July 2022 and on all new M1 and N1 vehicles from July 2024.

2.3.4 Lane guidance — SAE L1: assisted driving

This system adaptively applies some steering to reduce the effort required by the driver in keeping their vehicle centred in the lane.

The system corresponds to an ACSF of Category B1 as defined in UN Regulation No. 79 and is sometimes termed LKA or Lane Centring Assistance (LCA) in the automotive market.

2.3.5 Lane keeping — SAE L2: partially automated driving

This system automatically applies steering to keep the vehicle in the centre of its current lane of travel, effectively reducing the need for driver input on lateral control.

This system also corresponds to an ACSF of Category B1 as defined in UN Regulation No. 79, and is sometimes termed LKA or LCA in the automotive market, or as Lane Centring Control (LCC) by Sullivan and Flannagan (2019).

2.3.6 Lane change system — SAE L2: partially automated driving

This system, some versions of which may require an initial command or confirmation by the driver, automatically applies steering to move the vehicle to an adjacent lane without additional driver input on lateral control.

This system corresponds to an ACSF of Category C as defined in UN Regulation No.79, and is sometimes termed Auto Lane Change or (Highway/Active) Lane Change Assist in the automotive market.

2.4 Differences between the lane avoidance, lane guidance, and lane keeping systems on the automotive market

Lane Departure Avoidance (LDA) systems are limited in how much control they have over steering and may ping-pong the vehicle within its lane if no driver input is applied to keep the vehicle in the lane. The driver is expected to provide continuous input on lateral control with LDA assisting in preventing lane departures.

Lane Keeping can effectively reduce a driver’s input on lateral control as it will handle most of the straight and curved portions of a road by itself. Nonetheless, as per the regulations, these systems are still limited in how much lateral acceleration can be applied as a function of the vehicle’s travel speed, and therefore, may not be able to provide sufficient input/assistance to keep the vehicle within the lane in tighter curves. Consequently, the driver is expected to remain attentive to the road scene and to the system’s performance, while only intervening if necessary. Most Lane Keeping systems on the market are so-called ‘hands-on’ systems and will require the driver to keep one or both hands on the steering wheel at all times, although, without providing steering input. Some other Lane Keeping systems on the global market, but not currently available in the UK, are marketed as ‘hands-off’ systems. Here a driver is allowed to remove their hands from the steering wheel but is still required to monitor and ascertain the safety of the driving by the system and to intervene in vehicle control when necessary.

Finally, Lane Guidance is positioned somewhere in between these two systems as it continuously provides steering assistance and helps the driver keep the vehicle centred in its current lane while the driver is continuously providing input on lateral control. Systems of this sort should be able to keep a vehicle relatively straight on their own but are not permitted to operate in tighter curves without driver input. Here, lateral control is shared between driver and vehicle, in the form of haptic shared control. This method implies that the driver receives additional feedback forces via the interface used to control the vehicle either to communicate boundaries or guide the driver along an optimal trajectory (Abbink, Mulder, & Boer, 2012). How much force is applied by either party can help frame and shift the level of control shared between the driver and vehicle.

2.5 Differences between the lane keeping systems on the automotive market

2.5.1 Speed range

The extent between the minimum and maximum driving speed of the Lane Keeping systems will usually depend on the ACC system as this latter is a prerequisite for the activation of a Lane Keeping system. Nonetheless, this speed range is occasionally modified after activation of a Lane Keeping system. The minimum speed that drivers can set generally revolves around 40 mph | 64 km/h. However, some Lane Keeping systems may be used down to a full stop depending on whether the ACC is a Full or Limited Range system. The maximum settable speed observed on the market is 130 mph | 209 km/h [BMW's Assisted Driving], although it is typically around 90 mph | 145 km/h.

2.5.2 Hands-off systems

Vehicles equipped with OEM hands-off systems are always equipped with an eye-tracking camera facing the driver, installed behind the steering wheel, near the A-pillar or above the windscreen. To our knowledge, all OEM hands-off systems are currently geo-fenced to certain motorways or portions of roads. Current known hands-off systems offered in the North American market are BMW's *Extended Traffic Jam Assistant*, Ford's *Blue Cruise*, General Motor's *SuperCruise* (and announced *UltraCruise*), and Nissan's *ProPilot Assist 2.0*. Nonetheless, there also exists post-registration kits in the USA operating on cameras only (e.g., Comma Three; https://comma.ai/) that can be installed in various existing car models to enable hands-off L2 driving capability. There are hints that Tesla will switch off the hands-on requirement for users of the beta version of its *Full Self-Driving* L2 system (https://www.teslarati.com/tesla-fsd-beta-steering-wheel-nags-update-elon-musk/).

2.5.3 Hands-on systems

Vehicles equipped with a hands-on system require drivers to keep their hands on the steering wheel while the vehicle carries out the driving task. The driver's hands are usually detected via the resistance they apply to the torque actuator of the steering wheel. Hence, a lack of resistance will be detected as the driver's hands being absent from the wheel. This detection mode explains why first warning signals are conveyed arguably late since the computer needs to evaluate the level of resistance over a certain period of time before making a decision. Additionally, vehicles can be equipped with touch sensors around the rim of the steering wheel, which have the advantage of being more sensitive and responsive.

In practice, these systems are sometimes used inappropriately by drivers as hands-off systems, either knowingly or unknowingly, despite their intended design as hands-on systems. Complacent drivers have been observed misusing and duping their monitoring system by either applying resistance to the bottom of the steering wheel with their lap or installing an object onto the steering wheel (e.g., a ball). Additionally, these systems do not guarantee the maintenance of appropriate levels of driver attentiveness as it is possible to occasionally nudge the steering wheel to dismiss the warnings issued by the system. Manufacturers should take measures to guard against reasonably foreseeable misuse by the driver and tampering with the system. Anecdotally, Tesla, whose systems were affected in the past by the 2nd misuse listed above, appear to have updated their algorithm and reduced this problem.

Finally, few hands-on systems have been observed to penalise drivers for failing to comply with a hands-on requirement as long as drivers consistently respond after the first (visual) warning (issued 5 to 15 seconds after the hands have been removed, depending on the system). Nonetheless, this variability in delay length may depend on the applicable legislation of the specific country where a system is used. Additionally, both Tesla and Hyundai adapt this delay in their USA offerings to road layout (straight versus curvy) and driving context (e.g., following another vehicle or not). With these systems, a delay of up to 70 seconds has been observed. The Hyundai system is also one of the very few systems to be geo-fenced to prevent activation where inappropriate. In summary, some hands-on systems can appear too permissive in that they allow hands-off use for arguably long periods of time and thus rarely penalise their users for misusing them.

3. The impact of ADAS on driver attentiveness

There has been little research conducted to compare hands-on and hands-off L2 automated driving. The available literature, however, indicates that L2 driving, regardless of whether drivers have their hands on or off the steering wheel, tends to reduce driver attention to the driving scene and promotes distraction.

3.1 Effect of L2 partially automated driving on driver engagement

Studies have observed that driver attention to the road and traffic decreases during hands-on L2 driving, even without the presence of a secondary task (Lenné et al., 2019; Noble et al., 2021). More precisely, driver attention to the road centre decreases in line with the reduction of driver physical control of the vehicle: drivers' attention tends to be directed only towards those elements that are relevant to their level of control and responsibility (Gonçalves et al. 2019, 2020; see also Reimer et al., 2016).

In a recent survey conducted by the Insurance Institute for Highway Safety (IIHS) in the United States, users of General Motors Super Cruise, Tesla Autopilot, and Nissan/Infiniti ProPilot Assist showed different propensities to disengage from the driving task and engage in non-driving related activities (NDRA; Mueller et al., 2022). These three systems, although they are all L2 systems, vary in the level of physical control that the driver is expected to maintain: the Super Cruise system is a hands-off lane keeping system, the Autopilot a hands-on lane keeping system, and the ProPilot Assist is a hands-on lane guidance system (i.e. haptic shared control). Due to these differences in "design philosophies", as termed by Mueller et al. (2022), 38% of ProPilot Assist users declared never having received any inattention warning, against only 10% and 16% for Super Cruise and Autopilot, respectively. These numbers show how different L2 system designs may influence drivers' attentional engagement to the driving task. In addition, 44% of Super Cruise and 38% of Tesla users had already experienced being locked out of their partial automation feature due to their prolonged non-response to the system's warnings. Congruently, the hands-off Super Cruise system was the one most regarded as being fully self-driving by its users, most likely due to the reduced physical interaction between the driver and the vehicle controls. Of course, it is possible that users of these systems have different demographics and personality characteristics. However, the results line up with both theory (in the sense that the greater the physical decoupling, the more the likelihood of inattention) and the findings of experimental studies.

Another recent real-world driving study conducted by Reagan et al. (2021) compared driver behaviours while driving manually and driving with Volvo's Pilot Assist hands-on L2 system. Their results showed a significant increase in the number of participants disengaging from the driving task and removing their hands from the steering wheel the longer they were driving using the L2 system. Those drivers were also more likely to manipulate their mobile phones in comparison to manual driving or driving only with an ACC (L1).

3.2 Factors influencing driver disengagement

The tendency for a driver to misuse a hands-on system as a hands-off system could be modulated by their prior experience with similar systems. Indeed, Reagan et al. (2021) observed that an increased experience with L2 driving led to more engagement with NDRA, such as eating, drinking, using a mobile phone, tablet, or laptop, conversing, sleeping, grooming, or reading a book, for instance (Mueller et al., 2022). Other authors have also found that experienced users of driving automation systems engage more in NDRA because of their overreliance on the systems (Dunn et al., 2021; see also Feldhütter et al., 2018). Nonetheless, a driver's experience with driving in general can also influence their propensity to remove their hands while driving with a hands-on L2 system. Dunn and Donmez (2019) observed that novice drivers tended to engage more with NDRA than experienced drivers when using driving automation features. In this study, novice drivers were required to have held their driving licence for less than 3 years and driven less than 10,000km | 6,213 mi in the past year, whereas experienced drivers had held their driving licence for more than 8 years and had driven more than 20,000km | 12,427 mi.

3.3 Risks associated with L2 driving for driver safety

Negative impacts of secondary tasks (e.g., music selection) on a driver's performance during takeover were observed in a test track study by Yang et al. (2021). These authors found that, when misusing Tesla's Autopilot as a hands-off L2 system and receiving a request from the system to resume control, the time necessary for drivers to take over the vehicle's control was increased. This effect was not observed when looking at mean takeover times, but only when looking at rather long ones (85th percentile). Long off-road glances also increased response time to takeover requests with three instances of participants failing to respond at all, thus indicating negative consequences to driver distraction when driving with L2 assistance.

A driver's disengagement from the driving task is further concerning because U.S. drivers tend to speed more during L1 and hands-on L2 driving, thus potentially increasing the risks associated with inattention (Monfort et al., 2022). Such a tendency can perhaps be attributed to a driver's awareness that there is typically an allowed margin above the speed limit for enforcement. Finally, a driver's engagement with their mobile phone is an important concern for safety as mobile phone usage has been associated with gaze funnelling, that is, focused gazing towards the road centre and reduced gazes towards the periphery (e.g., Victor & Johansson, 2005). This can potentially relate to the "looked but failed to see" phenomenon, wherein a driver may look towards other road users but fail to become aware of their presence and react appropriately (Brown, 2005). Mobile phones provide a channel for drivers to engage in various activities whose consequences have not necessarily been thoroughly studied, but which are nonetheless detrimental to road safety because they require manual and visual engagement — activities such as texting, playing games, surfing the web, or watching videos (e.g. Mueller et al., 2022).

3.4 Summary

To summarise the various studies we have reviewed:

- Driving automation at levels L1 and L2 appears, among U.S. drivers at least, to promote speeding with drivers deliberately setting their desired speed above the limit
- Novice drivers and experienced ADAS users engage more in NDRAs

- L2 driving increases the propensity to remove one’s hands from the steering wheel and engage in NDRAs
    - NDRAs have negative cognitive effects such as gaze funnelling
    - Hands-off and hands-on L2 driving lead to decreased attention to the road centre
    - Misuse of a hands-on L2 driving system as a hands-off system exacerbates the tendency of drivers, who are already slow to take over when using a hands-on L2, to delay their takeovers

4. Methods to monitor user attentiveness

4.1 Introduction

The type of driver monitoring applied by manufacturers depends on whether or not the Level 2 ADAS support requires one or more hands on the steering wheel. For systems with a hands-on requirement, monitoring typically consists only of some means of verification that a driver is keeping a hand on the wheel. UNECE Regulation 79 revision 3 on vehicle steering control (UNECE, 2017) permits assistance to the driver in lateral control by means of an Automatically Controlled Steering Function (ACSF). ACSF category B1 as defined by Regulation 79, provides within-lane support at speeds above 10 km/h, and comes with a requirement for detection of the driver holding the steering wheel.

For systems that allow hands-off operation, such as GM’s SuperCruise and Ford’s BlueCruise, passive monitoring of user attention is applied. Here camera-based technology is applied to detect face and gaze direction. Such technology is also used for the detection of driver inattention more generally, i.e. not just linked to driving with Level 2 support. Euro NCAP is planning to award points to inattention warning based on this technology from 2023 under its Safety Assist Protocol in order to encourage fitment by manufacturers (Euro NCAP, 2022). The European Union is committed to mandating the fitment of Advanced Driver Distraction Warning (ADDW) systems under the amendment of the General Safety Regulation adopted in 2019. ADDW has to be fitted on new vehicle types sold in the EU from July 2024 and on all new vehicles from July 2026. The precise performance requirements of such ADDW are currently being discussed in the European Commission’s Working Group on Motor Vehicles. The ADDW would operate during driving with L2 assistance and thus could potentially help to support hands-off L2 driving were such usage to be permitted. However, whether the UK would adopt a similar requirement is as yet unknown.

4.2 Hands-on requirement

The hands-on requirement primarily attempts to mitigate visual-manual distraction resulting from the engagement in activities not related to safe driving, such as using a handheld device, reading a book, putting on makeup, or any activity requiring both sustained manual and visual interaction (e.g., Mueller et al., 2022). At least two methods exist to monitor the presence of a driver’s hands on the steering wheel: torque resistance and haptic sensors.

As has been pointed out previously, the requirement for drivers to keep their hands on the wheel during ADAS use, in practice, can be very permissive and easily abused, especially with a monitoring system relying on torque resistance. Firstly, most systems only require a nudge to the steering wheel every now and then to dismiss all warnings. Secondly, a visual warning almost always comes before an auditory warning (with hands-on L2 systems), increasing the delay before a warning becomes a nuisance for the driver. Thirdly, the delay between a driver's hands being off the wheel and the emission of the first auditory warning can be relatively long (UNECE Regulation 79 permits a delay of up to 30 seconds), increasing the risk of the driver not noticing the warnings if they are engaged in a visual-manual secondary task and not being monitored for visual attention. Regulation 79 permits a further delay of up to 30 seconds before the ACSF is deactivated, thus in effect allowing a period of 1 minute of driving with no hand on the wheel. This monitoring method, therefore, has clear limitations in ensuring attentiveness, although, judging the effectiveness of these monitoring systems needs to be done on a case-by-case basis.

Nonetheless, a monitoring system relying on haptic sensors rather than torque resistance to detect the presence of a driver's hands on the steering wheel may diminish the problems. Indeed, the time necessary for the haptic sensors to detect whether a driver's hands are present or not is much shorter than by assessing a resistance applied to the torque actuators of the steering wheel over a certain period of time to avoid false rejections. Certain systems such as IEE's capacitive sensing mat[2] can differentiate between full hand grasps, palm-touches, and finger-touches, and notify the driver in less than 500 ms (according to this manufacturer). This type of driver-monitoring system would therefore be the recommended method for detecting hands on the wheel.

4.3 Eye-tracking and head posture

This method is primarily focused on detecting and preventing driver visual distraction. A camera coupled with an eye-tracking device is normally placed in a position facing the driver (most often behind the steering wheel) to monitor the driver's gaze orientation. If the driver's eyes are not detected, the system may estimate their gaze orientation via their head posture. Depending on the software and on the number of cameras used, the system can assess how much drivers use their mirrors, look at the instrument panel, central stack, out of the window, and other areas of interest (AOI) as defined by the manufacturer. This assessment of visual distraction can be based upon the measurement of long glances and short repetitive glances away from the road centre. According to a contact at SmartEye, whose monitoring system is installed in more than 1 million vehicles, a threshold of 2 seconds before conveying a warning was judged annoying by truck drivers.[3] A threshold of 3 seconds, thus, would be preferable, although manufacturers are pushing for longer times, e.g. in the European Commission forum discussing the specification of the ADDW, which would increase the potential risks of driver distraction. Prospective improvements for these systems might be the integration of road-type dependency in the algorithms used. Indeed, looking at the road centre is generally insufficient for situation awareness, but especially in certain case scenarios such as lane changes or intersections.

Some of the limitations of these systems are the reliability of camera calibration, camera occlusion by the steering wheel, drivers wearing sunglasses, and bright sunlight flooding the camera. It is possible

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[2] Visit https://iee-sensing.com/automotive/assisted-automated-driving/handsoffdetection/

[3] This information was conveyed verbally and no specific study was cited.

for users to deliberately defeat eye tracking by wearing so-called “privacy” glasses, which can be easily purchased on the internet. Increasing the number of cameras helps to address occlusion and increases the horizontal range of eye movement that is covered, but is more costly, both in computing power and material, and is therefore yet to be seen fitted in vehicles on the market. Another limitation of these systems is the failure to detect the gaze funnelling associated with cognitive distraction, wherein a driver may have looked at something but failed to become aware of it.

These systems also have the potential to detect manual distraction by use of the camera(s) within the vehicle and the detection of activities such as phone use, eating, smoking, and more. To our knowledge, this feature is not in current use in commercially available vehicles. However, it is also the case that the systems currently being used for real-time driver monitoring do not address the visual phenomena induced by cognitive load or by mental inattention. Both cognitive load (as might be induced by a hands-free phone call or other mentally demanding task) and inattention from mind wandering result in a pattern of visual funnelling where gaze shift is reduced and eye glances are focussed staring ahead, typically at the expansion point. When this occurs, it is likely that the driver’s mental processing of the exterior scene is lacking, rather like the “looked but failed to see” crash causation factor (Brown, 2005). The effect of cognitive load on visual performance is shown in Figure 3, which provides a spectral density plot of driver gaze distribution in motorway driving. It compares the baseline situation of no additional task with the gaze distribution when drivers were performing a cognitively demanding auditory task (testing memory of multiple sounds). It can be observed that, with cognitive load, gaze scatter was substantially reduced, indicating a diminished ability to detect activity and threats away from the centre-point. In the current discussion under the European Commission’s Working Group on Motor Vehicles to define the minimum performance of the Advanced Driver Distraction Warning system, the vehicle manufacturers have asserted that current driver monitoring technology cannot detect such visual symptoms of inattention and cognitive distraction.

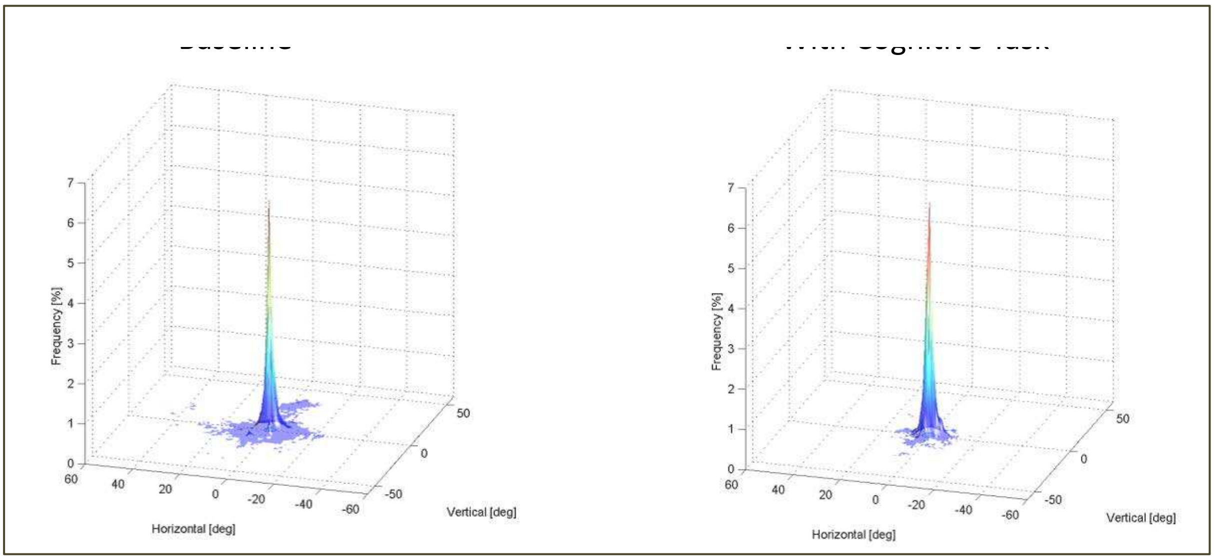

Figure 3: Drivers’ gaze distribution in motorway driving without and with cognitive task (source: Carsten et al., 2005 based on Victor et al., 2005).

To summarise, eye-tracking systems are very capable of detecting various forms of visual-manual distraction, but they do not seem to be used to the extent of their potential in consumer vehicles, perhaps due to costs. Systems currently on the market cannot identify cognitive distraction in real-time. Finally, whether drivers will appreciate being called out for failing to abide by their duty of attention as system supervisors, when they may feel that they have capacity to be engaged in other activities since the vehicle is handling control, is currently not known.

4.4 Lessons from the rail domain

Rail operations present perhaps the closest analogue of road vehicle driving in terms of the need for operator attentiveness and the impact of assistance and automation systems on the train driver tasks. Consequently, a review has been performed of how train driver attention is supported by in-cab systems.

According to the Rail Industry Standard for Driving Cabs (RSSB, 2022), requirements for the driver's activity control function are set out in the LOC&PAS National Technical Specification Notice (NTSN; Department for Transport, 2021a). This National Technical Specification Notice is a replacement of the previous EU regulation. The LOC&PAS specification applies to locomotive and passenger rolling stock.

The driver's activity control function (DACF) performs the functions previously covered by the Driver Safety Device (DSD, commonly known as the dead man's pedal or handle). This device monitors the driver's physical activity — activation and deactivation of the relevant device or interaction with other interfaces. It provides an initial alarm and then subsequently applies the train's brakes if, for a specified time, no activity is detected or if a single continuous activity is detected (see page 115 of the LOC&PAS NTSN).

Effectively, this system is an extension of the dead man's handle or pedal concept for detecting vigilance. The driver is monitored by means of checking driver response to physical devices, and not by means of a dedicated camera for driver or cab monitoring. It is not really translatable to the road vehicle driving domain, except perhaps at L0 or L1 where driver activation of pedal or steering wheel could be used to indicate engagement. For Level 2 driving, it could only be applied in combination with a shared haptic control implementation of steering, i.e. where the driver is required to maintain active control of vehicle steering albeit with assistance from the L2 system.

It can be concluded that current rail systems are focused not on detecting inattention but rather on repeated confirmation of driver responsiveness, including for detecting drowsiness or even sleep. It is most likely that, if a similar approach were applied to road vehicle driving at Levels 0 through 2, then users would become annoyed by the frequent requests to confirm that they are still attentive. Furthermore, responding to such requests could directly cause a diversion of attention from monitoring the road scene and visual-manual distraction. Such interaction could be relevant to the indication of readiness to resume control from L3 automation but is unlikely to be useful for confirmation of attentiveness in L2 driving. It can also be noted that the rail approach is directed more at detecting driver incapacity from illness and drowsiness than at confronting inattention to the out-of-cab scene. Engagement in prohibited activities is far less of a problem in rail than in road operation, although it is not unknown (see e.g. the fatal crash of a commuter train in Los Angeles on 12 September 2008).

4.5 Summary

We have described two monitoring methods currently applied to passenger vehicles, each with two variants:

- Tracking via one or more cameras of the driver’s:
    - Eye-gazes;
    - Head posture.
- Monitoring of the driver’s hands via:
    - Torque resistance;
    - Haptic sensors.

While the most reliable method to assess a driver’s attention to the driving task would be eye-tracking, head posture estimation is a satisfactory and required backup in case eye gaze direction is not detected. However, the physical decoupling between the driver and vehicle controls, inherent in hands-off L2 systems, introduces risks of attentional disengagement from the driving task and engagement in non-driving related tasks. Requesting drivers to keep their hands on the steering wheel and monitoring their adherence to this requirement via the detection of torque resistance seems an inappropriate method as it is currently implemented because of the potential for abuse of this technology. The evidence collected suggests that manufacturers should either improve this approach or opt instead for haptic sensors that are able to detect the absence of a driver’s hands in a matter of milliseconds.

5. Techniques to alert the driver and reengage their attention

In the event that a driver-monitoring system qualifies a driver as being distracted, warnings will be issued to the driver in the expectation that they resume their supervision of the ADAS or resume their input into the driving controls. Strategies are defined for each system wherein the urgency of the warnings will escalate over time to reflect an increasing urgency for the driver to regain control of the vehicle. These strategies need to account for the type of L2 system being used, balancing warning saliency, urgency, annoyance, and sensory modality (e.g., visual, auditory, haptic).

5.1 Visual warnings

5.1.1 Static warnings

Hands-off warnings are commonly first conveyed via a yellow and relatively small alert on the instrument panel and, if equipped, the head-up display (HUD). For example, a yellow steering wheel and white hands can accompany a text message asking the driver to keep their hands on the steering wheel (e.g., see Figure 5). A second visual warning normally follows, showing a red steering wheel which is sometimes enlarged for emphasis, thus becoming more salient and urgent. This is generally the moment when an auditory warning will be heard (see Section 5.2 below). The delay between each of these warnings varies depending on the vehicle manufacturer or legislation involved.

Interestingly, Tesla distinguishes between take-over requests due to *technical limitation*[4] (e.g., unable to handle a tight curve) or *improper human use* to comply with the hands-on requirement (Figure 4). In the first case, technical limitation, the steering wheel is red with white hands whereas in the second, improper human use, the hands are red and the steering wheel is white.

Figure 4: Left: Tesla’s take-over request due to a technical limitation/failure. Right: Tesla’s hands-on request after the driver kept their hands off for too long.

5.1.2 Dynamic warnings

5.1.2.1 Animated graphics

BMW’s vehicles show a looping animation of white hands grabbing a yellow steering wheel to prompt drivers to do the same. These animations may have two advantages: attention is attracted by the

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[4] ‘Technical limitation’ and ‘improper human use’ are not official terms used by Tesla. These are only used here to distinguish between two types of warnings.

motion and the requested action is represented (i.e., grabbing the steering wheel), which may prime and facilitate the triggering of the same action. Indeed, psychology research has shown an advantage of congruent dynamic primes over static ones in the identification of hand-graspable objects (e.g., Vainio et al., 2008) as well as for the execution of corresponding movements (e.g., Castiello et al., 2002).

Figure 5: Three stages of BMW's hands-off animated warning.

5.1.2.2 Flashing graphics

Static warnings may also start flashing after some time to communicate the urgency and better attract drivers' visual attention. Some car models may flash a LED strip on or behind the steering wheel (Figure 6, left). Other manufacturers may start flashing parts of the instrument panel or centre screen, like Tesla for instance where a blue or white light (depending on car models and software update) flashes at the top of the screen (Figure 6, right). Increasing flash pulse frequency has been associated with increased ratings of both perceived urgency and annoyance by drivers (e.g., Baldwin et al., 2012, 2014).

Figure 6: Left: Cadillac's LED strip used to indicate system status and warn drivers with flashing red lights. Right: Tesla's centre console flashing blue to warn drivers.

5.2 Auditory warnings

The warning sequence for hands-on L2 systems is not usually initiated by an auditory warning and such a warning is typically emitted to accompany a second (repeat) visual alert — the justification being that auditory warnings are more often perceived as an annoyance than other modalities (e.g., Baldwin & Lewis, 2014; Geitner et al., 2019). This escalation only applies to hands-on systems, though, as hands-off systems will always start by simultaneously issuing both an auditory and visual warning. The reason here is that drivers might be looking away from the instrument panel or road centre and fail to detect unimodal visual signals.

Design guidelines usually advise the use of auditory signals as these lead to faster reactions as well as lead to fewer misses and false responses (Geitner et al., 2019). However, several parameters need to be taken into consideration when designing auditory signals to ensure that they reflect the appropriate level of urgency while keeping the annoyance induced to a minimum to avoid drivers disabling their safety features (Marshall, Lee, & Austria, 2007). For instance, longer sounds will be perceived as more urgent and slightly more annoying than shorter sounds, while longer intervals between sounds will be seen as less urgent and less annoying than shorter intervals. Annoyance, although not directly linked to safety, is still a parameter to consider as an annoying system can undermine the acceptance and usage of a system (e.g., Block Jr., Nuutinen, & Ballast, 1999) and potentially distract its user due to the strong emotional response (e.g., stress) that can result from receiving oppressive auditory warnings (Fagerlönn, 2011).

5.3 Haptic warnings

5.3.1 Seat vibration

While vibrations in the steering wheel may be used with LDA systems, this is not true for requesting drivers to keep their hands on the wheel. Instead, vibrations can be emitted from different locations in the driver seat (e.g., Gaspar et al., 2015). This method has received contradicting results as a forward collision warning (Gaffary & Lécuyer, 2018; Gaspar et al., 2015) but is seemingly effective to reduce driver reaction time to lane departure warnings and is perceived as less annoying than an auditory warning (Gaffary & Lécuyer, 2018).

5.3.2 Seat belt tensioner

Another solution is to apply some tightening on the driver seatbelt, which appears to be more effective than seat vibration, auditory, or visual forward collision warnings (e.g., Chun et al., 2012; Gaspar et al., 2015). There is no evidence that such feedback affects willingness to be belted.

5.3.3 Brake pulse

Brake pulsing, or decelerating the car momentarily, has been investigated as a modality of warning and appears to also be an effective way of warning drivers of a potential forward collision (e.g., Gaspar et al., 2015; Lloyd et al.,1999).

5.3.4 Steering wheel torque/jerk

Finally, another way of warning the driver is by briefly applying some steering jerk (Campbell et al., 2016). No research to our knowledge has been conducted comparing the effectiveness of this modality to warn drivers against other modalities. This method is primarily investigated as a means of warning drivers of lane departures (e.g., Beruscha, Augsburg, & Manstetten, 2011; Hollopeter, Brown, & Thomas, 2012; Huang, Wu, & Liu, 2015).

5.4 Multimodal warnings

Multisensorial warnings are advocated as they are more efficient to attract one’s attention than single-modality warnings (e.g., Campbell et al., 2016). Visual-auditory alerts, for instance, are more effective than visual signals alone (e.g., Geitner et al., 2019), although also adding vibrotactile signals can have usability advantages for drivers with particular sensory deficits (e.g., age-related vision or hearing loss; Laurienti et al., 2006). It is therefore suggested to use a combination of visual and auditory warnings while also ensuring that the levels of urgency and annoyance remain adapted to the context and incidence of this type of warning. Haptic warning could be considered as an alternative or a supplement to auditory warning.

5.5 Haptic shared control

Designs of L2 lane guidance systems that promote continued driver steering input, as opposed to only registering hands on the wheel by means of haptic shared control, such as Nissan's ProPilot, keep the driver directly engaged in the driving task as opposed to supervisory control (Mulder et al., 2012). Such control tends to stimulate driver attentiveness to the road and traffic scene and reduce the inclination of drivers using L2 assistance to engage in non-driving related activities.

5.6 Summary

There is a lack of systematic studies of the capabilities and deficiencies of current driver monitoring systems, both as regards detection of hands on the wheel and of detection of visual attention. Equally, the various warning modalities and strategies have not been systematically compared. Finally, haptic shared control is a promising approach to positively maintaining driver engagement and should be compared to the alternative approach of warning the driver about misbehaviour.

6. Applicability of findings to the UK

Much of the evidence reviewed here has been drawn from outside the UK. Of course, there are similarities between driver motivations and behaviours across the world and especially across the various high income countries. Yet it is also important to consider how rule compliance differs between countries.

As regards driver attention and willingness to engage in both illegal and legal non-driving related activities, previous research using the UDRIVE naturalistic drive database indicates that UK drivers compare favourably with U.S. drivers and Polish drivers, but are not as compliant as German drivers (Carsten et al., 2017). Further analysis of the non-driving related activity by the UK drivers in the UDRIVE database indicated substantial amounts of handheld interactions as well as a practice by some drivers of keeping their phones low, possibly as a strategy to avoid detection, but with the consequence of increasing the tendency to move glances to positions where sharing attention between device and road scene was more difficult (Hibberd et al., 2019).

There are also substantial differences between countries in driver compliance with speed limits. In Great Britain, observations in free-flow traffic in 2021 found 48% of car drivers to be exceeding the speed limit on motorways (Department for Transport, 2021b). By comparison, in the United States in 2015 70% of U.S. drivers were observed to exceed the speed limit in free-flow conditions on limited access highways (De Leonardis et al. 2018). Thus there is a need to ascertain whether UK drivers are as willing as their U.S. counterparts to set their intended speed above the speed limit when using L2 assistance and thereby to increase the risk of serious or fatal consequences in the event of a collision.

The effect of L2 driving, both hands-on and hands-off, on UK drivers' attentiveness has not been investigated, nor has their willingness to comply with system prompts to put their hands on the wheel or refocus attention to the road scene. This is a significant knowledge gap, as is how UK drivers use the maximum speed setting in L2 driving.

7. Conclusions and knowledge gaps

The literature review strongly suggests that usage of hands-on L2 systems encourages drivers to at times disengage from the driving task, become inattentive, and also engage in non-driving-related activities (NDRA) such as mobile phone use. The literature further suggests that driving with hands-off versions of L2, not currently approved in the UK, further aggravates the tendency to engage in NDRA (Mueller et al., 2022).

The latest driver monitoring systems provided by manufacturers are not part of current type approval and therefore are of unknown robustness. There are problems with some of the means for detecting that a driver has at least one hand on the steering wheel when required to do so by an L2 assistance system, and vehicle manufacturers use different time thresholds for hands-off wheel warnings. The driver monitoring systems currently available to generate attention warnings have a number of deficiencies in that they do not always capture even serious inattention, they are not robust enough to work in certain real-world conditions and they may be vulnerable to intentional abuse by drivers. Thus the extent to which the monitoring systems currently available or available in the near future for production vehicles can capture safety-relevant inattention is in doubt.

It is not sufficient for the vehicle to detect inattention. Drivers must also respond to the consequent warnings issued by the vehicle. It is clear from research carried out elsewhere, e.g. in the U.S. and Australia, that many drivers fail to react to inattention or hands-off-the-wheel warnings promptly and that in some cases they fail to do so at all. Although the assistance may automatically deactivate as a consequence, that is likely to involve an additional time gap and a risk of neither the system nor the driver having control. The willingness of UK drivers to respond appropriately when issued initial alerts and escalating warnings is unknown.

These findings suggest that further work is needed to understand:

1. Whether use of L2 assistance encourages UK drivers to become inattentive to the road and traffic scene, with consequent loss of situation awareness, and also to engage in legal and illegal NDRA. A study would also allow investigation of how driver demographics and attitudes influence the propensity for inattention, thus shedding further light on any consequential risks, i.e. on whether a propensity for inattention in L2 driving is associated with other risky behaviours.
2. Whether driving with hands-off L2 would further encourage such tendencies for UK drivers
3. Whether, in real-world conditions, current driver monitoring and warning systems reliably identify and signal inadequate attention and improper behaviour
4. How UK drivers would respond to a variety of attention and hands-off-wheel warnings
5. How can warning systems effectively reorient drivers towards the driving task while avoiding annoyance

A combination of laboratory studies and more naturalistic real-world studies is recommended to advance understanding. The laboratory studies should use state-of-the-art driver monitoring technology, so as to provide verification of the ability to robustly detect inattention. In those same studies, warning thresholds could be systematically varied to provide insight into the balance between the maintenance of safe driving and the potential for driver annoyance. Real-world driving would complement the laboratory investigations by providing insight into driver behaviour in varying conditions when motivated by the real apprehension of crash occurrence when required attention is reduced.

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Appendix: Summary of interviews

State of the art of driver monitoring systems

The question of how much time should drivers be inattentive before receiving warning signals is debated, and whether this should be measured in distance or time. The research community would typically identify glances longer than 2 seconds off the road as already creating elevated risk. The Euro NCAP Safety Assist protocol to be implemented in 2023 (Euro NCAP 2022) defines a glance away from the forward roadway that is equal to or greater than 3 seconds as being a long distraction. On the other hand, vehicle manufacturers have been arguing for a threshold greater than 4 seconds, and in some situations up to 6 seconds, in the recent discussions of the specification of the Advanced Driver Distraction Warning System in the EU Working Group on Motor Vehicles. Ideally, the time frame should depend on the road type and traffic: driving on a straight road at low speed in low-density traffic is not comparable to approaching an intersection at high speed. At the expense of requiring greater capability, a driver monitoring system could exploit a digital map to ensure that drivers check appropriately before entering an intersection. In certain situations, drivers' may use their peripheral vision, and this can be a challenge as eye-trackers cannot track drivers' covert visual attention, that is, visual attention without eye-movements.

There is a possibility of capturing long glances away from the road (or any defined target) as well as repeated glances away. While long glances can be detected in a single occurrence, repeated distractions need a longer time buffer to be detected. Different areas of interest can be defined, such as the windscreen, mirrors, centre stack, instrument panel, etc. Additionally, various driving-related and non-driving related activities can be detected via camera observation of the cabin.

Reliability of the systems

The SmartEye and PupilEye systems are reportedly "robust", although all systems can suffer from certain limitations such as occlusion (e.g., when the camera is placed behind the steering wheel), drivers' wearing dark glasses, reflective materials, eye make-up, sunken eyes, eyes with smaller palpebral fissures, strabismus. Having several cameras (at least two) can increase the reliability of these systems, notably by decreasing the risk of having no camera operating appropriately. Issues such as looked-but-failed-to-see, although, are still a problem.

Miscellaneous

With cabin monitoring (i.e., cameras observing the passengers and driver), one can detect safety belt compliance and passengers being out of position. Detection of eating, drinking, smoking, or phone use is also possible. All this is limited by camera position and the field of view captured by the camera.