Department
for Transport

Understanding Human Factors in Advanced Driver Assistance Systems: An Evidence Review

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Executive summary

In 2024, the Department for Transport (DfT) commissioned the National Centre for Social Research (NatCen) to conduct a Rapid Evidence Assessment (REA) to provide an evidence base to support the policy development and regulation of emerging Driver Controlled Assistance Systems (DCAS). This review aims to provide a robust overview of the existing evidence on the topic and identify any potential gaps.

Vehicle autonomy exists on a spectrum. It includes Advanced Driver Assistance Systems (ADAS) technologies which offer features like automated emergency braking and lane keeping, aiding drivers without replacing them (Maloy Smith, 2023). At the other end of the spectrum are self-driving technologies, which can assume full or partial control of the vehicle, handling tasks like steering, braking, and navigation autonomously. In such cases, the driver is no longer liable for the safe operation of the vehicle, as the system is responsible for its actions.

DCAS, a more advanced form of ADAS, sits between these two technologies, capable of managing both speed and steering for extended periods while still requiring full driver oversight. Although the driver remains fully responsible for the vehicle, DCAS uniquely blends aspects of driver assistance and fully autonomous systems. System-Initiated Manoeuvres (SIM) are a subset of DCAS; where DCAS relies on a driver to confirm/initiate a manoeuvre, SIM allows for an increased level of automation where the system can initiate and carry out the driving task without driver input. These systems represent a distinct position in the automation spectrum, as the level of automation continues to increase, yet driver liability and responsibility remain unchanged.

These technologies raise concerns about "human factors": *"the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data, and methods to design in order to optimize human well-being and overall system performance"* (IEA, n.d.). In the context of ADAS, this involves understanding how technologies can accommodate human capabilities and limitations to inform a design that enhances safety, performance, and user experience. While these technologies could improve safety by reducing driver fatigue and improving responsiveness, they may also introduce new challenges related to automation, such as overreliance and reduced vigilance. Addressing these challenges is crucial to ensuring that the benefits of ADAS are fully realised while mitigating potential risks.

The findings reveal that there was limited understanding among drivers of their responsibilities and capabilities of ADAS, resulting in uncertainty and overestimation of the system's abilities. Trust in ADAS varied depending on the technology type, system reliability, and driving conditions. Inappropriate levels of trust led to reduced attention and responsiveness, negatively impacting driver safety. Drivers faced cognitive and behavioural challenges with ADAS, such as lower levels of attention and situational awareness, when using Level 2 systems compared to manual driving. To address these human factors challenges, recommendations included intuitive Human-Machine Interfaces (HMIs), multimodal feedback, driver monitoring systems based on physiological data, and enhanced driver education and training.

The study focuses on Society of Automotive Engineers (SAE) Level 2 ADAS vehicle automation, which requires the driver to remain fully engaged while the system controls both steering and acceleration. It presents findings from 59 academic literature studies published from 2017 onwards, using complex search strings to search global academic databases. The review used rigorous methods for searching, screening, assessing, and synthesising evidence.

However, policymakers should be cautious about relying too heavily on existing Level 2 ADAS research when considering DCAS/SIM. The unique human factors challenges necessitate dedicated research specifically focused on DCAS/SIM impacts.

Key Findings

Driver understanding of responsibilities and ADAS capabilities

There was limited understanding among drivers of their responsibilities and capabilities and the operational boundaries of ADAS. Several studies have highlighted that drivers experience uncertainty regarding their level of control over vehicles equipped with Level 2 ADAS, which in turn affects their perception of responsibility and awareness when to intervene. Drivers frequently overestimated the system's ability to handle adverse conditions and complex driving scenarios, which could lead to overreliance and unsafe driving behaviours.

Trust in ADAS and misuse

Drivers generally trusted Level 2 ADAS systems, although there were variations in trust levels influenced by the type of ADAS technology, system reliability or driving conditions. Increased familiarity with the system generally led to higher trust.

Inappropriate levels of trust, when drivers overestimated the system’s capabilities, were associated with reduced attention, monitoring, and responsiveness, impacting driver safety. Over-trust and misunderstanding of system capabilities was associated with ADAS misuse, including engagement in secondary tasks such as using a mobile phone.

Cognitive and behavioural challenges

Drivers experienced a range of cognitive and behavioural challenges when using ADAS, such as exhibiting lower levels of attention, situational awareness, monitoring, and vigilance when using Level 2 systems compared to manual driving.

Evidence on driver engagement and driver workload were mixed, with some studies showing similar engagement levels to manual driving and others showing reduced levels or no difference.

Potential mitigations

Recommendations for potential measures to help mitigate the human factor challenges of ADAS included clearer and more intuitive Human-Machine Interfaces (HMIs), multimodal feedback (such as auditory, visual and haptic feedback), and driver monitoring systems based on physiological data including eye, head, and body-tracking systems, as well as steering wheel sensors to check if hands are on the wheel.

Driver education and training are also suggested as potential solutions for the effective and safe use of ADAS. Various approaches have been proposed, including theory-based instruction to build understanding, strategies to enhance drivers' awareness of their own knowledge gaps, updates to safety guidelines to reflect ADAS capabilities and opportunities for hands-on experience, and customised training programs tailored to different driver demographics.

Recommendations for future research

The findings underscore the need of gaining a clear insight into driver understanding of system capabilities, trust and cognitive and behavioural challenges in the use of SAE Level 2 vehicle automation systems.

Clearer communication of system capabilities and limitations, improved driver monitoring, and tailored education and training are essential to ensure these technologies are used safely and effectively. Future research should evaluate these key areas as well as examine user acceptance of data collection, considering perceived benefits and risks, particularly regarding the sharing of physiological data.

Methodologically, future on-road studies which include a broader range of driving contexts, such as motorways, B-roads, varied lighting and traffic conditions are needed. These studies would require robust methodologies, including adequate sample sizes, case-control comparisons, and extended practice sessions to simulate real-world driving more accurately. Longitudinal studies are essential to track behavioural adaptation over time. It would be useful to do this across diverse user groups, considering variables such as age, gender, and driving experience.

Given limited UK-specific research, regionally relevant studies are essential to examine how Level 2 ADAS perform under local road conditions, infrastructure, and regulatory environments. Naturalistic studies, in which participants voluntarily use ADAS in everyday settings, would yield more authentic insights into real-world usage patterns.

Policy discussion points

The policy implications derived from this review call for a multifaceted approach:

- Explore the best way to deliver educational programmes to inform drivers about their responsibilities and the assistive nature of ADAS technologies, ensuring wide accessibility through driving schools, online platforms, and in-car tutorials.
- Engage automotive manufacturers to promote clearer and more accurate communication regarding ADAS capabilities and driver responsibilities in marketing and advertising materials.
- Advocate for the development of HMIs that balance safety-oriented standardisation with personalisation for user comfort and preference.
- Ensure regulations protect drivers' personal data and address concerns about its use, particularly in contexts that could negatively affect insurance premiums.
- Support further research on Level 2 ADAS in the UK, including long-term naturalistic driving studies in diverse driving environments.

Implications for emerging ADAS: Driver Controlled Assistance Systems (DCAS) and System-Initiated Manoeuvres (SIM)

The evidence on human factors in Level 2 ADAS provides crucial insights into the challenges posed by emerging capabilities, driven by the increasing use of automation in the driving task. Both DCAS and SIM mark a significant progression towards higher levels of automation but raise complex issues regarding driver roles, system transparency, and shared control.

Studies reviewed reveal that drivers using existing Level 2 ADAS systems experience uncertainty about their level of control or struggle with mode awareness, making it difficult to understand system actions and their own responsibilities. As emerging ADAS systems become more proactive in managing driving tasks, they may help reduce driver errors, but they could also create new safety risks if drivers become increasingly passive or disengaged. Successful deployment of these systems will require reliable technology to develop accurate and resilient mental models (cognitive frameworks or representations that drivers form to understand and interact with advanced vehicle technologies) from the outset.

As DCAS/SIM presents distinct human factors challenges particularly in attention management and driver-system interaction, it necessitates dedicated research to evaluate its impacts. As hands-off operation becomes more common, it is crucial to investigate its implications for driver readiness, trust calibration, and control transitions. Further research should investigate drivers' use of DCAS/SIM through real-world studies to provide insights into driving performance and safety.

However, policymakers should be cautious about relying too heavily on existing Level 2 ADAS research when considering DCAS/SIM. The unique human factors challenges, especially in areas like attention management and driver-system interaction, necessitate dedicated research specifically focused on DCAS/SIM impacts to inform sound policy decisions.

1. Introduction

Vehicle autonomy exists on a spectrum. It includes Advanced Driver Assistance Systems (ADAS) technologies, which provide support to the driver but do not replace them, such as automated emergency braking, cruise control, lane keeping, and speed limiters (Maloy Smith, 2023). At the other end of the spectrum are self-driving technologies, which can assume full or partial control of the vehicle, handling tasks like steering, braking, and navigation autonomously. In such cases, the driver is no longer liable for the safe operation of the vehicle, as the system is responsible for its actions. It is important to note that the relevant provisions of the Automated Vehicles Act (2024) concerning self-driving technologies are not yet in effect but will be implemented in the future.

Situated between these two technologies are Driver Controlled Assistance Systems (DCAS), a more advanced form of ADAS capable of managing both speed and steering for extended periods. While the driver remains fully responsible for the vehicle, DCAS occupies a distinct position in the automation spectrum, blending aspects of both driver assistance and fully autonomous systems. System-Initiated Manoeuvres (SIM) are a subset of DCAS; where DCAS relies on a driver to confirm/initiate a manoeuvre, SIM allows for an increased level of automation where the system can initiate and carry out the driving task without driver input. These systems occupy a distinct position because the level of automation continues to increase, yet driver liability and responsibility remain unchanged. Similar technologies are already in use by companies like Tesla, primarily in markets such as the US, Canada, Japan, and China.

These technologies raise concerns about "human factors": *"the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data, and methods to design in order to optimize human well-being and overall system performance"* (IEA, n.d.). In the context of ADAS, this involves understanding how technologies can accommodate human capabilities and limitations to inform a design that enhances safety, performance, and user experience.

DCAS/SIM face several "human factors" challenges, including the risk of driver overreliance, where drivers may become too complacent and slow to take control when necessary (European Transport Safety Council, 2024). Understanding human interaction with DCAS is crucial, as it raises important questions about driver engagement, trust, and safety. As DCAS is a new and emerging technology, much of it is not yet widely available on the UK market. This research reviews existing evidence on ADAS broadly, enabling us to draw relevant conclusions to inform the regulation of more advanced technologies. This research aims to assist the Department for Transport (DfT) by providing an evidence base to inform policies and regulations regarding emerging ADAS, particularly in relation to the human factors involved in their use. By understanding how drivers interact with systems like ADAS, this research will help shape regulations that ensure these technologies are used safely and responsibly, while also considering the evolving role of the human driver in an increasingly automated driving environment.

Research objectives

In 2024, DfT commissioned the National Centre for Social Research (NatCen) to conduct a Rapid Evidence Assessment (REA) to provide an evidence base to support the policy on and regulatory of emerging ADAS. This review aims to provide a robust overview of the existing evidence on the topic and identify gaps in the existing evidence base.

The review used the Society of Automotive Engineers (SAE) Level 2 definition to define the technology in scope. SAE Level 2, also known as partial driving automation, refers to systems that can simultaneously control both steering and acceleration/deceleration under certain conditions. However, the driver must remain fully engaged at all times, continuously monitor the driving environment, and be ready to take over immediate control when required. Unlike higher levels of automation, the responsibility for safe driving remains entirely with the human driver. Examples of SAE Level 2 systems currently on the market include Tesla's Autopilot, Ford's BlueCruise, and General Motors' Super Cruise—each of which can support tasks like lane centring and adaptive cruise control at the same time on specific road types, such as motorways.

The study attempts to answer the following research question:

1. What are the human factors implications of SAE Level 2 vehicle automation systems?
    a) How well do drivers understand the capabilities of Level 2 systems and their responsibilities when using them?
    b) What cognitive and behavioural challenges do drivers face when using Level 2 systems?
    c) How do answers to 1a and 1b vary between the following:
        i. Hands-off vs. hands-on technologies
        ii. Driver-initiated vs. system-initiated manoeuvres
        iii. Different types of monitoring systems vs. systems with no driver monitoring
    d) How do answers to 1a and 1b vary across the following contexts:
        i. Highways vs. urban roads
        ii. Country-specific differences

Report structure

The report is structured as follows:

- **Executive summary**: A high-level summary of key findings.
- **Introduction**: Provides background to this REA and describes the research question and sub-questions.
- **Methodology**: A summary of the methodology used for identifying and synthesising relevant evidence.
- **Driver understanding of their responsibilities when using ADAS and ADAS capabilities:** Explores how drivers understand their role and responsibilities while using ADAS and how they understand ADAS capabilities
- **Trust in and misuse of ADAS:** Explores evidence on driver's trust in Level 2 ADAS systems, as well as factors that influence trust levels and the consequences of uncalibrated trust levels.
- **Cognitive and behavioural challenges when using ADAS:** Discusses issues related to attention and awareness, engagement and workload.
- **Potential mitigations to address the cognitive/behavioural challenges of using ADAS:** Explores mitigations identified in the papers which include system design solutions— Human-Machine Interfaces (HMI), multimodal feedback, and driver monitoring systems—as well as training and broader support solutions.
- **Methodological limitations of evidence and directions for future research:** A summary of the key limitations in the evidence, along with recommendations for future research to address gaps and strengthen findings.
- **Conclusions:** Presents key recommendations for future research and policy and explores the implications of these findings for DCAS/ System-Initiated Manoeuvres (SIM).

Note on terminology

The report refers to Society of Automotive Engineers' (SAE) six levels of driving automation, as set out in the SAE J3016 (Society of Automotive Engineers, 2021), ranging from Level 0 (no automation) to Level 5 (full automation):

- At Level 0, all driving tasks are performed by the human driver.
- Level 1 introduces driver assistance, where the vehicle can control either steering or acceleration/deceleration.
- **Level 2 allows the vehicle to control both steering and acceleration/deceleration simultaneously, but the driver must remain engaged.**

- Level 3 offers conditional automation, where the vehicle can handle all driving tasks within certain conditions, but the driver must be ready to intervene.

- Level 4 provides high automation, with the vehicle capable of performing all driving tasks within a specific environment, even if the driver does not intervene.

- Level 5 represents full automation, where the vehicle can perform all driving tasks under all conditions without human intervention.

The different levels of driving automation, from Level 0 to Level 4, are frequently mislabelled or misunderstood, such as DCAS being described as both Level 2+ and Level 2++. This mislabelling can create confusion regarding the technology's capabilities and the driver's responsibilities.

2. Research methods

The study used a Rapid Evidence Assessment (REA) methodology. An REA sits between a literature review and systematic review: it follows rigorous and transparent methods for searching, screening, assessing and synthesising evidence, whilst making informed compromises on aspects of the systematic review process to deliver findings quickly. This chapter provides a summary of the methodological approach, the criteria and processes for the search strategy, screening, data extraction and reporting, and limitations of the research design. A detailed description of the search strategy can be found in 'Annex 1: Search strategy'.

Scoping phase

Prior to conducting the review NatCen was commissioned by the Department for Transport (DfT) to carry out a short scoping exercise. The Scoping Phase took place in January 2025 and involved an initial literature search and a workshop with academic experts with a background in human factors convened by DfT. The conclusions of the scoping phase indicated that there was enough accessible and high-quality evidence to proceed with an evidence review. The research team and academic experts recommended conducting a single, comprehensive review that takes a broad view of the relevant human factors. This review would focus on SAE Level 2 technologies and their specific features, and consider how the literature around these technologies could support our understanding of emerging challenges in the ADAS space, such as the use of hands-off driving, increasing levels of automation, and the road types these technologies might be used in.

Search strategy

The scoping phase identified that there was a large volume of academic evidence published on this topic, but little or no non-academic (grey) literature. For this reason, we proposed that the review focused only on academic literature.

The search strategy used complex search strings to search academic databases informed by our Information Specialist. The geographical scope was global.

To be included, the sources had to meet the following criteria:

- Published academic literature.

- Written in English.
- Based on data collected from 2017 onwards.
- Focusing on ADAS technologies that can control steering and speed for prolonged periods of time whilst the driver is expected to be attentive, along with the human factors involved in using the technology
- Simulation-based (a type of research method that uses simulated environments to model real-world scenarios) and real-world studies (studies conducted outside controlled lab or simulation environments, including on-road and naturalistic), high-quality evidence reviews and surveys.

This process yielded 6,210 papers returned by the search string. The search strings and detailed inclusion criteria can be found in 'Annex 1: Search strategy'.

Screening

A large language model (LLM) was used to assist in identifying and excluding papers that were not relevant to our research. A LLM is an advanced AI system designed to understand and generate human-like text. This process involved asking a series of questions to determine whether a paper was relevant to the REA. To ensure the output was reliable, a researcher manually checked a selection of papers to confirm the LLM's accuracy. As a result, 1,003 papers were excluded, which sped up the screening process.

The remaining academic papers were screened at two stages: at title and abstract and at full text. A total of 5,207 papers were screened at title and abstract and 250 of these were selected for full text screening.

On completion of full text screening, 102 papers met the inclusion criteria. These studies were quality appraised using a modified version of the Weight of Evidence (WoE) framework.

A prioritisation process was undertaken, based on assessing the relevance and quality of each paper, to determine which 59 studies would be included for final data extraction. Prioritisation criteria included:

1. Real-world studies over simulation evidence;
2. Studies that helped to answer research questions of particular interest (1.c.i to 1.c.iii, and 1.d.i to 1.d.ii);
3. Studies that obtained a higher quality score for the research methods used.

Data extraction and reporting

Based on an initial review of a subset of the prioritised papers, a thematic analysis framework was developed. The framework was structured by the key themes included in the research questions and additional themes emerging from the selected prioritised papers. **Members of the research team read the 59 prioritised papers in full and**

extracted relevant evidence for each theme. Evidence on each thematic area was summarised and used to populate the framework. The report is structured in line with the thematic framework.

Limitations of the research design

This study is a focused REA. It draws on a limited number of sources to answer the research questions, using a systematic screening and prioritisation process to ensure relevance and quality. However, to draw more exhaustive and comprehensive conclusions, a full systematic evidence review would be required.

Additionally, as discussed in the 'Note on terminology', the terminology used in ADAS varies significantly across studies, with inconsistent definitions and categorisations of technology. Different studies examine a wide range of ADAS technologies, often focusing on various car brands and manufacturers, as well as in different contexts, which complicates the ability to make broad or generalisable conclusions. For example, even with the widespread use and understanding of SAE's J3016 six levels of automation within the sector, these were not always used consistently, and some research referred to systems as being, for example Level 2+.

Furthermore, the quality of the studies included in the review varies, with differences in research methods, sample sizes, and data collection techniques, all of which can affect the reliability and validity of the findings. Additionally, only one study was conducted in the UK, which limits the generalisability of the results to the UK context. A more detailed discussion of the limitations of the studies is provided in the 'Methodological limitations' chapter.

3. Overview of the evidence base

Fifty-nine studies were included in the evidence review. The majority of studies were conducted in the United States (27), followed by Germany (6), The Netherlands (6), Japan (5), and Canada (5), with a smaller number from countries including Australia (2), Sweden (2), France (1), China (2), and Austria (1), while several studies did not specify a location (9). Only one of the included studies was conducted in the United Kingdom.

Thirty studies were conducted using real-world driving methods, 21 using simulators, 8 were surveys. Two studies used secondary analysis and one literature review. The section below provides an overview of the key methods used across real-world driving studies, simulators and surveys.

Real-world studies

A total of 30 studies employed real-world driving methods to examine the human factors associated with Level 2 ADAS technology, with nearly half (15 studies) conducted in the United States.

The majority of these studies were on-road studies, meaning driving took place on highways, urban roads, and test tracks, simulating both routine and complex environments, and often included familiarisation sessions. The studies used a variety of experimental designs, including within- and between-subjects comparisons of manual and automated driving. A further five studies used naturalistic methods, tracking drivers in their own or specially prepared vehicles over extended periods to analyse real-world usage and safety-critical events.

These studies used vehicles which provided control of speed and steering. Key capabilities included Adaptive Cruise Control (ACC), Lane Keeping Assist (LKA) and Lane Centring (LC), combined control systems which integrate ACC and LKA or Driver-Initiated Lane Change and some additional safety features. The most frequently used brands included Tesla (Model S, Model 3, and Model X), Volvo (XC90), Audi (A5 and A4 Avant), Cadillac CT6 and Honda models, including different versions of the Accord.

Data collection methods were diverse, combining physiological measures (e.g., heart rate, electroencephalography (EEG)), eye-tracking to assess driver attention, and Detection Response Tasks (DRT) to gauge workload and vigilance. Video and audio recordings captured observable behaviour and interactions with the human-machine interface (HMI), while questionnaires, interviews, and think-aloud protocols provided subjective insights into trust, usability, and perceived safety. Participants were typically given training materials and time to acclimate to the system before testing.

The reviewed studies included a wide range of participant sample sizes, from as few as 10 to as many as 132 participants. Most studies involved between 20 and 100 participants. Participant types included the general public, students, company employees, with varied recruitment methods (e.g., flyers, internal portals). Automation experience was mixed - some studies included only novices, others included experienced users (e.g., Tesla owners, ACC/LKA users).

Simulator studies

Twenty-one studies investigating Level 2 ADAS technology used driving simulators to create diverse virtual environments, including highways, urban roads, and intersections.

The key capabilities tested in the simulator environment for Level 2 ADAS technology included various aspects of control of speed and steering, as well as driver intervention and system transparency.

Experimental designs varied, with some studies exposing different groups of participants to different conditions or using repeated measures to track changes in driver behaviour. Simulated scenarios involved critical events such as automation failures and required driver intervention. Data were collected using eye-tracking, physiological measures (e.g., heart rate, GSR), behavioural metrics (e.g., reaction times, takeover success), and subjective questionnaires on trust and workload. Many studies incorporated training sessions and practice drives to familiarise participants with ADAS systems. A few studies employed mixed methods approaches, combining simulator data with interviews or observational techniques.

Most studies involved small to medium samples, typically ranging from about 20 to 80 participants, often recruited from university students, the general public, or employees of automotive companies. Participants were mostly licensed drivers with varied driving experience, commonly ranging from a few years to over a decade, and driving frequency varied from occasional to daily drivers. Male participants were generally more numerous, though some studies had balanced or female-majority samples. Experience with Level 2 automation was often absent or minimal among participants, though some had prior exposure to related systems like ACC or LKA.

Surveys

Eight studies included surveys as their primary method of data collection. The surveys were conducted across various countries, including the USA, Canada, Germany, Japan, Australia, Sweden, the Netherlands, the UK, and China.

Data collection methods included online surveys, questionnaires, and follow-up surveys. Surveys often included pre-selection criteria to ensure participants had certain levels of driving experience and familiarity with ADAS technology. The surveys used non-probability and convenience sampling methods, with participants recruited from specific communities, such as Volvo or Tesla drivers, or the general public with certain eligibility criteria.

The studies included samples ranging from 100 to 1,137 participants. Gender distribution varied, with some samples predominantly male and others more balanced. Age groups ranged from below 18 to 77 years old, with specific age distributions provided in some studies. Samples included non-professional drivers, car owners, and the general public. Participants had varying levels of experience with ADAS technology, ranging from unfamiliar to frequent users.

4. Drivers' understanding of their responsibilities and ADAS capabilities

Introduction

This chapter reviews evidence on drivers’ understanding of their responsibilities and the capabilities and limitations of Level 2 ADAS technology.

In total, 27 studies examined understanding of system capabilities, comprising ten real-world studies, eight surveys, eight simulator studies, and one secondary data analysis. Additionally, 12 studies addressed understanding of driver responsibilities, including six real-world studies, five simulator studies, and one survey.

Four studies investigated drivers’ mental models, which refer to the cognitive frameworks or representations that drivers form to understand and interact with advanced vehicle technologies, such as ADAS (Jenness, et al., 2019; Zhang, et al., 2024; Biondi & Balakumar, 2021; Zhang, et al., 2024; Biondi & Balakumar, 2021; Huang, et al., 2023).

Key findings

- Several studies have highlighted that drivers experience uncertainty regarding their level of control over vehicles equipped with Level 2 ADAS, which in turn affects their perception of responsibility and awareness when to intervene.

- The requirement to keep hands on the steering wheel influenced drivers' sense of responsibility. Hands-on driving was associated with active engagement, while hands-off driving led to a more passive, passenger-like role. Despite visual prompts, many drivers did not consistently adhere to the hands-on-wheel requirement.

- Drivers' self-reported understanding of ADAS capabilities often did not match their actual knowledge, with drivers overestimating their level of understanding of the technology.

- There was limited understanding among drivers regarding the capabilities and operational boundaries of ADAS. Drivers frequently overestimated the system's ability to handle adverse conditions and complex driving scenarios, which could lead to overreliance and unsafe driving behaviours.

- Factors such as gender, age, urban versus rural driving environments, vehicle ownership, and familiarity with the system affected drivers' level of understanding of ADAS capabilities.

Understanding drivers' responsibilities when using ADAS

Several studies investigated drivers' understanding of their responsibilities when using Level 2 ADAS (Novakazi, et al., 2020; Cahour, et al., 2021; Zhang, et al., 2024; Stapel, et al., 2022: Novakazi, et al., 2021; Morando, et al., 2021; Shutko, et al., 2018). When using Level 2 ADAS, drivers are expected to maintain full responsibility for operation of the vehicle by continuously monitoring the driving environment, staying attentive, and being ready to take control at any time. They are also required to keep their hands on the wheel and eyes on the road.

Monitoring the road and level of control over the vehicle

Several studies highlighted that drivers were uncertain about their level of control over the vehicle, which affected their perception of responsibility (Novakazi, et al., 2020; Cahour, et al., 2021; Novakazi, et al., 2021; Morando, et al., 2021). An on-road study in the United States found that because participants saw the system as handling large portions of the driving task, they struggled to understand the extent of control they were expected to maintain (Novakazi, et al., 2020). Some felt that the system's steering assistance was so effective that they believed it was not necessary for them to intervene (Novakazi, et al., 2020). Similarly, in a simulator study involving Renault employees in France many drivers assumed the level of automation meant the vehicle was fully in control, which they felt reduced their role to that of a passenger (Cahour, et al., 2021).

Other studies, however, indicated that drivers had some level of understanding of their responsibilities, particularly monitoring the road (Shutko, et al., 2018; Zhang, et al., 2024). Two studies examining drivers' use of Autopilot, Tesla's Level 2 ADAS system, demonstrated that drivers were aware of the need to continuously monitor the vehicle and the road environment (Shutko, et al., 2018; Zhang, et al., 2024). For example, respondents in Zhang, et al., 2024's survey demonstrated a relatively high level of awareness regarding their responsibility to monitor the performance of Autopilot, with an average score of 3.87 on a 5-point Likert scale. A Likert scale is a questionnaire tool that measures people's attitudes or opinions by asking them to rate their agreement with statements on a graded scale, typically ranging from "strongly disagree" to "strongly agree" (Bhandari & Nikolopoulou, 2023). This score indicated that respondents generally agreed with the necessity of maintaining vigilance and readiness to intervene while using the system. Participants in these studies recognised that they remained primarily responsible for the safe operation of the vehicle, the need to be physically prepared to take over when requested and to maintain eyes on the road (Shutko, et al., 2018; Zhang, et al., 2024).

Hands-on wheel requirement

Three studies explored the link between driver responsibilities and the position of hands on the steering wheel (Cahour, et al., 2021; Morando, et al., 2021; Zhang, et al., 2024). A simulator study tested user experiences of hands-on versus hands-off driving and found that drivers felt that a hands-off position implied the system would manage driving independently, while hands-on made them feel responsible for managing the vehicle. The authors concluded that a hands-on position gave drivers a sense of active responsibility whereas hands-off led to a passive, passenger-like role (Cahour, et al., 2021).

Two studies investigating Tesla's Autopilot system found a notable lack of clarity about the drivers' responsibility to keep their hands-on-wheel. Despite Autopilot requiring the drivers to keep their hands on the steering wheel, drivers drove hands-free immediately after engaging Autopilot and throughout its use (Morando, et al., 2021). A survey of Tesla's owners and non-owners showed that around 20% incorrectly answered that drivers can put their hands away when the Autopilot is active despite visual prompts to "keep your hands on the wheel" when activating Autopilot (Zhang, et al., 2024).

Understanding of system capabilities

Evidence pointed to limited understanding of system capabilities and its operational boundaries (Cahour, et al., 2021; Morando, et al., 2021; DeGuzman & Donmez, 2024; DeGuzman & Donmez, 2024; Zhang, et al., 2024; Neuhuber, et al., 2022; Novakazi, et al., 2021). The capabilities of Level 2 ADAS vary by system and manufacturer but commonly include maintaining lane position, controlling speed and following distance, and responding to certain traffic conditions. The systems also have notable operational boundaries, such as challenges with operating in adverse weather or dealing with unexpected obstacles, which reinforces the need for constant driver engagement.

Limited understanding how the system operates

A key issue was a lack of understanding of how the system operates (Kim, et al., 2021; Cahour, et al., 2021; Novakazi, et al., 2021; DeGuzman & Donmez, 2024; Wilson, et al., 2020). Studies provided evidence of drivers' being unaware of specific system functions or lacking knowledge of the contexts in which these capabilities should be activated. This was evidenced by a simulator study which investigated the impact of hands-on versus hands-off ADAS on driver behaviour. In this study, 38% of drivers in the 'hands-on' intervention group were unaware of the deactivation feature (when the system is unable to respond to a situation, and so it disengages) ignoring the visual or auditory indicator or misinterpreting it as something else (Cahour, et al., 2021). In another study using a simulator, participants misunderstood conditions for activation of the speed and lane-keeping assistance, such as wrongly believing the system required vehicles ahead or beside it to function (Novakazi, et al., 2021).

Knowledge of system limitations – its operational boundaries – was a particular issue (Neuhuber, et al., 2022; DeGuzman & Donmez, 2024; Zhang, et al., 2024; Novakazi, et al., 2021). Drivers often mistakenly believed that ADAS vehicles could navigate in severe weather or handle complex situations like heavy traffic or poor road conditions. For example, only 9% out of over 700 participants knew that Autopilot, a camera-based system, could not accurately detect pedestrians at night, suggesting a significant misunderstanding of its sensing limitations (Zhang, et al., 2024).

A lack of clarity about the system's capabilities and limitations could lead to a mismatch between driver expectations and system performance. A naturalistic study using data from 50 drivers using Level 2 ADAS vehicles found that although the system operated within its design limits, drivers reported instances where they felt that the vehicle did not perform well. For example, some drivers expected the vehicle to react to other cars suddenly cutting in front of them or if a car ahead of them stopped, as well as to handle blurred lane markings and sharp curves, situations the system wasn't designed to manage (Kim, et al., 2022).

Self-reported understanding vs. objective assessments

Several studies compared drivers' self-reported understanding of ADAS with an objective knowledge measure (DeGuzman & Donmez, 2024; Buchner, et al., 2024; Huang, et al., 2023). Two studies found that drivers rated their own understanding highly but performed poorly on objective measures, particularly being able to identify system limitations (DeGuzman & Donmez, 2024; Buchner, et al., 2024). Contrastingly, a study of ADAS users in China found a general consistency between self-reported understanding of ADAS familiarity and their objective assessments (Huang, et al., 2023). However, they were cautious about making direct comparisons due to differences in scoring methods. They also suggested that potential cultural differences, including vehicle culture (the collective attitudes and behaviours surrounding vehicle ownership, usage, and driving within a particular region or country), traffic rules, advertising strategies and market shares (the proportion of total sales within the automotive market that is occupied by vehicles equipped with ADAS technologies) could explain the varying results (Huang et al., 2023).

Overestimation of capabilities

Evidence found a tendency among drivers to overestimate ADAS capabilities, such as thinking that the system can perform advanced steering or lane changes (Kim, et al., 2021; Novakazi, et al., 2021; DeGuzman & Donmez, 2024; Wilson, et al., 2020). DeGuzman & Donmez (2021 and 2024) highlighted how drivers would overestimate the capabilities of specific ADAS features, for example mistakenly believing that ACC feature could respond to traffic lights. Another study found that drivers who believed the vehicle could handle all driving tasks often exhibited behaviours like "switching off" or becoming inattentive during automated driving (Wilson, et al., 2020). The authors noted that overestimating the system capabilities was particularly concerning, as it could lead to overreliance and potentially unsafe driving behaviours (DeGuzman & Donmez (2021 and 2024).

Mode awareness

Findings across several studies indicate that mode awareness, the driver's understanding of what automation mode the car is in (e.g. lane-keeping or cruise control) and what they, as the driver, is responsible for in that mode, was a significant challenge in the use of ADAS. Research by Novakazi et al., (2020) compared driver understanding of Level 2 and Level 4 modes (partial and full automation) and highlighted a fundamental mismatch between drivers' understanding of the mode and system functionality. Only 10% of participants demonstrated a correct understanding of both the system modes and the division of responsibility associated with each (Novakazi, et al., 2020). The lack of mode awareness could result in unsafe and improper use, for example by not paying attention to the road or assuming it is safe to release the steering wheel during partially automated driving modes (Novakazi, et al., 2020).

Other studies highlighted examples of mode confusion in situations when the automation was turned off without the driver realising (Wilson, et al., 2020). An Australian study examining driver trust and mode confusion compared driver understanding of manual versus partially automated Level 2 modes, documented multiple instances where drivers mistakenly believed the vehicle remained in automated mode when it had actually reverted to manual control (Wilson, et al., 2020). These incidents often occurred without the driver’s awareness, largely due to insufficient or unclear feedback from the human-machine interface (HMI), such as ambiguous cues regarding mode transitions. Landry et al. (2022) also found that mode confusion sometimes resulted from unintended actions such as slightly turning the steering wheel or bumping the cruise control stalk that disengaged the system without the driver's awareness, posing a significant safety risk.

Another factor which could contribute to mode confusion was HMI displays. Landry et al. (2022) looked at the icons used in the HMI across different driving modes and found that mode confusion was a common problem, especially for new or inexperienced users. In a survey of 838 Volvo drivers, many respondents struggled to differentiate between system states such as "available but not active" and "active but not currently intervening". Novice users were more prone to misinterpret visual indicators, such as colour coding or status icons on the HMI, compared to more experienced users.

Differences in level of understanding across various factors

Studies offered evidence on a range of factors which affected drivers’ understanding of capabilities and limitations of ADAS.

Gender

Two studies found gender differences in understanding of ADAS capabilities. Men reported higher self-reported understanding of ADAS compared to women but both genders performed similarly in tests of objective knowledge (DeGuzman & Donmez, 2024). Zhang et al. (2024) found that men and women showed differences in their mental model of ADAS, with women showing a better grasp of the system's limitations and men indicating greater awareness of the need to continuously monitor the system's status and performance.

Age

Older drivers (those aged 50 and over) had a lower level of understanding of ADAS capabilities compared to younger and middle-aged drivers (Wada, et al., 2020; Neuhuber, et al., 2020). A study looking at age-related differences conducted in Austria found that older drivers (aged 50-77) had more difficulties understanding system displays, engaging or disengaging the system, and understanding system functionalities, such as mistakenly thinking that Lane Assist could overtake other vehicles (Neuhuber, et al., 2020).

Urban/rural areas

A study exploring drivers' mental models (the cognitive frameworks or representations that drivers form to understand and interact with advanced vehicle technologies) in urban and rural contexts found that drivers had a greater understanding and more accurate mental models for driving in rural contexts compared to urban environments (Buchner, et al., 2024). Rural scenarios, being less complex, allowed participants to quickly grasp the system's functionality. In contrast, driving in urban areas required additional time to understand ADAS functionality due to more interactions with traffic lights or other vehicles.

Vehicle ownership

Two studies observed that owners of Level 2 ADAS vehicles did not demonstrate better knowledge of ADAS than those who have never owned or used such a vehicle (DeGuzman & Donmez, 2024; Zhang, et al., 2024). DeGuzman and Donmez (2021) showed that both Level 2 ADAS vehicle owners and those who have never used a vehicle with ACC or LKA generally had a poor understanding of the systems' capabilities and limitations (DeGuzman & Donmez, 2021). Zhang et al. (2024) also did not see a difference whether someone owned an ADAS vehicle or not, even though all evaluated items were taken from owner manuals (Zhang, et al., 2024). The authors hypothesised that the extensive nature of owner manuals may act as a barrier, leading to inadequate understanding of the information provided. Additionally, they suggested that owners might receive insufficient training and guidance from dealerships (Zhang, et al., 2024).

Familiarisation with the system

Evidence demonstrated that accurate understanding of the automation system increases over time with further interactions with the system (Forster, et al., 2019); Buchner, et al., 2024) and stabilises at a high level for simpler interactions (Forster, et al., 2019); Buchner, et al., 2024). However, some papers showed that even after multiple interactions with the system, participants still did not have an accurate mental model, implying that building an accurate mental model is a slow process requiring continuous exposure and practice (Forster, et al., 2019).

5. Trust in and misuse of ADAS

This chapter discusses evidence on drivers' trust in Level 2 ADAS systems. It also examines factors that influence trust levels and the consequences of uncalibrated trust levels, including ADAS misuse.

In total, 24 studies examined driver trust in Level 2 ADAS, comprised of 14 real-world studies, six surveys and four simulator studies. An additional six studies examined both trust and misuse, while four discussed misuse without any relation to trust. Across the evidence, trust was measured through self-report ratings, either through surveys, interviews or verbal ratings during the experimental drive. Some studies obtained ratings of trust before and after the experimental drive to measure the effect of experience and familiarisation on trust levels.

Key findings

- Drivers tended to trust Level 2 ADAS systems to be safe and reliable.
- Various factors influenced drivers' trust in Level 2 ADAS systems including the ADAS system itself, human factors and driving conditions.
- There was mixed evidence on how understanding of Level 2 ADAS, automation experience and age influenced trust, with different evidence pointing towards positive, negative or no relationship with trust.
- Drivers' trust in Level 2 ADAS systems increased as they became more familiar with them.
- Inappropriate levels of trust that overestimated the system's capabilities were associated with reduced attention, monitoring and ability to respond to unexpected events, impacting driver safety.
- Over-trust and misunderstanding of system capabilities was associated with ADAS misuse, including engagement in secondary tasks such as using a mobile phone.

Trust and trust calibration

The widely accepted definition of trust in automation is provided by Lee & See's (2004) who describe it as *"the attitude that an agent will help achieve an individual's goals in a situation characterised by uncertainty and vulnerability".* Authors frequently described trust as drivers' confidence and willingness to rely on automation.

Trust was measured through surveys, asking participants to rate the extent to which they trusted the Level 2 ADAS system. Evidence showed that drivers tended to trust the Level 2 system (DeGuzman & Donmez, 2024; Nordhoff, et al., 2021; DeGuzman & Donmez, 2021; Wada, et al., 2020). For example, DeGuzman & Donmez's (2024) survey of 369 drivers in Canada who use Level 2 ADAS found that the average trust rating of drivers was four on a five-point scale. This rating was based on items from Jian et al.'s (2000) trust in automation scale, which included statements such as "I am confident in the systems", "The systems are dependable", "The systems are reliable", and "I can trust the systems". However, it is important to note that although Jian et al.'s (2000) scale is commonly used, it is not considered the most reliable tool for assessing reported trust in automation. This is because it does not directly reflect widely recognised human-automation trust theories, such as those proposed by Lee and See (2004) (Cui et al., 2025). Similarly, Nordhoff, et al's (2021) survey of 1137 users of Level 2 ADAS in the Netherlands indicated that 89% of respondents trusted that their Level 2 ADAS vehicle would maintain speed and distance to the car ahead, and 70% trusted that it would keep the car centred in the lane.

Other evidence investigated trust calibration, which is the adjustment of trust levels to match the technology's actual capabilities (Walker et al., 2018; Nordhoff, et al., 2021). Therefore, the crucial factor is not whether trust merely increases or decreases, but whether the change results in improved trust calibration. Achieving trust calibration requires drivers to clearly understand the system's capabilities and limitations (Walker et al., 2018). If drivers overestimate the capabilities of Level 2 ADAS, better understanding can decrease trust and therefore improve calibration. Conversely, if they underestimate the system, better understanding can increase trust and improve calibration.

Factors influencing trust levels

Evidence demonstrated that various factors influenced driver's trust in Level 2 ADAS systems. These were related to the ADAS system itself, human factors and driving conditions.

ADAS system

Trust levels were influenced by the specific ADAS technology and the system's reliability. Drivers trusted Adaptive Cruise Control (ACC) more than Lane Keeping Assist (LKA) (Ebinger, et al., 2023; Ebinger, et al., 2024) and trusted Lane Change Assist (LCA) the least (Ebinger, et al., 2024), indicating that trust varied by function.

Additionally, the reliability of the ADAS system affected trust. Driving simulator studies in Japan (Lee, et al., 2021; Lee, et al., 2020) observed that the presence of a system-limits failure (a designed failure in automation that can be predicted and occurs because the system encounters conditions it was never designed to handle) and a system malfunction (a hardware or mechanical error that is unpredictable) both reduced trust levels, with a system malfunction leading to a greater decrease in trust. However, trust tended to recover after periods of error-free operation. It was also observed that the decrease in trust experienced after a system-limits failure could be mitigated through the prior provision of detailed information on system failures. This however was not the case for system malfunctions.

Human factors

Studies examined whether trust was associated with various human factors. The human factors investigated were understanding of Level 2 ADAS systems, automation experience, age, perceived risk and safety, trust propensity and experience.

Understanding of Level 2 ADAS capabilities

There was mixed evidence on how understanding of Level 2 ADAS capabilities influenced trust. A study which surveyed 369 drivers who had experience of using ADAS systems showed that those who believed they understood Level 2 ADAS systems (had higher subjective understanding) also demonstrated higher levels of trust (DeGuzman & Donmez, 2024). In contrast, drivers' actual knowledge, measured through objective understanding tests, was not linked to higher trust (DeGuzman & Donmez, 2024). Other evidence further demonstrated that objective understanding alone may not be sufficient to influence trust. Lee et al's (2021) study using a driver simulator in Japan found no difference in trust ratings between the levels of knowledge of the driver, after being given instructions on their responsibilities and completing a five-to-ten-minute practice drive in the simulator.

Conversely, a survey conducted in China which explored driver's mental models, trust and reliance on Level 2 ADAS demonstrated that drivers with better understanding had less trust and reliance on the system (Zhang, et al., 2024). In this study, greater awareness that the technology required drivers to be physically prepared for take-over requests led to lower trust levels. This reflects improved trust calibration, as drivers' trust more accurately matched the actual capabilities and limitations of the system.

Age

In a similarly mixed picture, Huang et al's (2023) survey with owners of Level 2 ADAS systems in China found that increasing age was associated with lower trust, while DeGuzman and Donmez's (2021) survey with both owners and non-owners of Level 2 ADAS systems in the US and Canada showed that increasing age was associated with higher levels of trust among automation experienced drivers. Other evidence (two surveys with automation experienced drivers in Canada and Austria) revealed no relationship between age and trust (DeGuzman & Donmez, 2024; Neuhuber, et al., 2020).

One suggested explanation for this conflicting evidence was that some studies did not capture all indirect effects and interrelationships that were in effect. For example, DeGuzman and Donmez (2021) measured trust for ACC and LKA separately while the other studies measured trust for Level 2 ADAS in general. Additionally, only nine percent of respondents in Huang et al.'s (2023) survey were female. In contrast, participants in Neuhuber et al. (2020) and DeGuzman and Donmez (2024) were balanced by gender, while DeGuzman and Donmez (2021) did not provide a sex or gender breakdown. Gender interactions may be significant, given He et al.'s (2022) findings on gender differences in perceived risk, which will be discussed next.

Perceived risk and safety

The extent to which drivers trusted Level 2 ADAS systems was related to how safe they thought they were; drivers trusted the system more when they felt safe and did not feel at risk of accident (Stapel, et al., 2022; Nordhoff, et al., 2021). Interactions with gender were also examined, demonstrating that women perceived the risk of accident as higher than men, when using Level 2 ADAS systems, and therefore had lower trust in the system (He, et al., 2022). Additionally, those who had previously encountered ADAS-related accidents had lower trust in the system (Huang, et al., 2023).

Experience

Trust levels increased as drivers became more experienced with the Level 2 ADAS system (Neuhuber, et al., 2020; Kundinger, et al., 2020; He, et al., 2022; Ebinger, et al., 2024; Neuhuber, et al., 2022; Dunn, et al., 2021; Zhang, et al., 2024; Stapel, et al., 2022; Lee, et al., 2021) both after short initial exposure (Kundinger, et al., 2020; Ebinger, et al., 2023) and with repeated interaction (Buchner et al., 2024). In Wilson et al.'s (2020) on-road study in Australia, trust grew as drivers saw the vehicle handle corners and regulate speed in traffic. Walker et al.'s (2018) study found that on-road experience improved trust calibration, helping drivers better understand the system's capabilities and limitations, even in scenarios they did not directly encounter, such as an animal crossing the road or driving at night.

However, Zhang et al's (2024) survey examining mental models, trust and reliance of Level 2 ADAS systems among Tesla Autopilot owners and non-owners in China, found that the higher trust among drivers who had used the system for longer may not have been aligned with the system's actual capabilities, indicating that trust calibration had not occurred. Instead, drivers displayed over-trust and over-reliance on the system. Zhang et al. (2024) measured reliance by asking participants to report their likelihood of engaging in non-driving tasks while using Autopilot, or imagining they were using it if they did not own a Tesla. They found that trust and reliance on the system increased with longer use, although the increase in reliance was not statistically significant. They argued that these findings aligned with wider automation literature demonstrating the development of complacency and over-reliance on automation over time.

A study found that after driving a Level 2 ADAS in the real world, drivers' trust in the system to handle various scenarios, such as driving in rain, encountering a deer crossing the road, merging from the left lane, navigating a curved highway, and driving at night, decreased (Walker, et al., 2018). This decline in trust occurred even though drivers did not experience all these scenarios during their drive. The study suggests that hands-on experience with the system led drivers to better understand its overall capabilities and limitations, thereby adjusting trust accordingly, reflecting improved trust calibration. In contrast, one on-road study found that levels of trust did not change with greater familiarisation (Stapel, et al., 2022). The authors suggested that in this study, drivers who had experience using Level 2 ADAS system before had likely already stabilised their views. For the automation-inexperienced drivers it was suggested that either the one-hour exposure was too short to change their levels of trust, or the experimental condition did not result in a change in trust.

Driving conditions

Trust in Level 2 ADAS was also shown to be situational and dependent on the complexity of the driving environment.

Research indicated that drivers exhibit greater trust in Level 2 ADAS when operating in less complex environments (Stapel, et al., 2022; Buchner, et al., 2024). An on-road study in Germany which compared trust in rural and urban settings showed that trust increased on rural roads but then decreased during the drive in an urban context (Buchner, et al., 2024). A different on-road study, which compared trust levels between highways of different complexities, revealed that trust in the situation was affected by the complexity of the road, with greater trust found for less challenging driving conditions (low/moderate traffic intensity, two lanes, and few on/off ramps) compared to engaging driving conditions (high traffic intensity, 3-5 lanes and several on/off ramps and interchanges) (Stapel, et al., 2022).

Different driving scenarios were also found to affect drivers' trust in Level 2 ADAS. For example, drivers had lower trust in the system's ability to handle situations such as driving in poor weather conditions like rain (Wilson, et al., 2020), merging into another lane (Kraft, et al., 2020; Neuhuber, et al., 2022) and a lead vehicle braking with strong intensity (He, et al., 2022). Low trust in such scenarios was shown to result in disengagement of the Level 2 ADAS system and drivers taking over manual control of the vehicle instead (Wilson, et al., 2020).

Consequences of over- and under-trust

Inappropriate levels of trust that do not match the system's objective capabilities have various consequences on driving behaviour (i.e. poorly calibrated trust). For example, high levels of trust and tendencies to over-trust the system were associated with lower feelings of driver responsibility (Novakazi, et al., 2020), reduced attention to the road (DeGuzman & Donmez, 2024; Nordhoff, et al., 2021), and reduced monitoring (Neuhuber, et al., 2022), which can lead to missed system errors or disengagements (Neuhuber, et al., 2022) and reduced ability to respond to unexpected events (Solís-Marcos, et al., 2017). Over-trust can result in ADAS misuse (Neuhuber, et al., 2022), while under-trust can result in ADAS disuse.

ADAS disuse

Disuse describes the rejection of the Level 2 ADAS system and is associated with lower levels of trust (Neuhuber, et al., 2022). There was some evidence of ADAS disuse among the studies examined (Neuhuber, et al., 2022; Ebinger, et al., 2023). For example, Neuhuber et al. (2022) observed that the group of drivers who were sceptical about the Level 2 ADAS system and had low trust in it used the system less. Additionally, Ebinger et al's (2023) on-road study in Central Europe found that drivers adapted how much they used the system according to their level of trust in it, meaning the less they trusted the system, the less they used it. Ebinger et al. (2023) suggested that having limited trust in Level 2 ADAS systems could lead to a negative feedback loop. In this loop, drivers who are sceptical of the technology avoid using it, which prevents them from gaining familiarity and positive driving experiences with the system. As a result, they do not build trust in the system, which further discourages its use.

ADAS misuse

Misuse describes the inappropriate use of Level 2 ADAS that comes from an over-reliance on the system (Neuhuber, et al., 2022). Drivers may misuse ADAS because of their misunderstanding of and over-trust in the system's capabilities and limitations. For example, Zhang et al. (2024) found that drivers were more likely to engage in non-driving related tasks (such as talking to passengers, adjusting a stereo, using a mobile phone, reading or watching a video) if they had lower understanding of the system and higher trust in it. Evidence demonstrated that drivers often did not use Level 2 ADAS as intended and various forms of ADAS misuse were observed (Nordhoff, et al., 2021; Biondi & Balakumar, 2021; Kim, et al., 2021; Wilson, et al., 2020; DeGuzman & Donmez, 2024; Novakazi, et al., 2020; Cahour, et al., 2021). The most commonly examined form of misuse was engagement in secondary tasks, such as eating and using a mobile phone for texting, calling, navigation and music selection.

Engagement in secondary tasks

Research consistently indicates that drivers are more likely to engage in secondary tasks during Level 2 ADAS operation compared to manual driving (Nordhoff, et al., 2021; Biondi & Balakumar, 2021; Kim, et al., 2021; Dunn, et al., 2021; DeGuzman & Donmez, 2024. This trend is particularly pronounced among drivers with prior experience using such systems. A naturalistic study by Dunn et al. (2021) found that drivers with experience using Level 2 ADAS were nearly twice as likely to engage in secondary tasks while the system was active, compared to when driving manually. Conversely, drivers with less experience or unfamiliarity with the system tended to engage less in secondary tasks during automated driving, possibly due to lower trust or comfort with the technology. Further research by Stapel et al. (2022) observed that drivers with varying levels of experience engaged in mentally distracting secondary tasks, such as phone calls, to the same extent as during manual driving. However, they were slightly less inclined to engage in visually distracting tasks, like texting, when the ADAS system was active.

Other forms of ADAS misuse

Other observed misuses of ADAS included using Level 2 ADAS in inappropriate weather conditions, such as rain and fog, and on unsuitable roadways, like residential streets (Kim et al., 2021). Additionally, a few US studies observed drivers operating hands-off when the system required hands-on (Kim, et al., 2021; Novakazi, et al., 2020; Cahour, et al., 2021) and not paying attention to the road (Novakazi et al., 2020). A literature review (Biondi & Balakumar, 2021 cited a study where speeding was more prevalent in Level 2 ADAS vehicles. In another study, one percent of drivers reported always, frequently, or occasionally sleeping while using Level 2 ADAS, a rare but potentially fatal misuse (Nordhoff et al., 2021). Unintended use of Level 2 ADAS was also the most common factor in safety-critical events, such as engaging in non-driving-related tasks (NDRTs) like mobile phone use, using driving automation during adverse weather conditions (e.g., rain and fog), and operating it on roadways for which the automation was not designed (e.g., residential streets). Misuse accounted for nearly 60% of these incidents (Kim et al., 2021).

Five out of six studies on ADAS misuse involved participants with some automation experience. While most did not specify whether misuse was intentional or unintentional, those that did suggested it resulted from drivers misunderstanding the system's capabilities and their responsibilities. For example, Novakazi et al. (2020) found that drivers mistakenly believed they could take their hands off the wheel, highlighting how ambiguously designed systems can lead to complacency and over-trust.

This evidence indicates that overreliance and over-trust in Level 2 ADAS, which develop as drivers become more familiar with the system, may result in unintended consequences that undermine the potential safety benefits of ADAS (Dunn et al., 2021). Improved trust calibration, where drivers' trust is better aligned with the system's actual capabilities, could mitigate these issues and enhance the safe use of ADAS.

6. Cognitive and behavioural challenges

This chapter discusses evidence on cognitive and behavioural challenges that drivers face when using Level 2 ADAS systems, including attention and awareness, engagement and workload. In total, 28 studies examined cognitive and behavioural challenges, comprised of 19 real-world studies, seven simulator studies, one survey, and one literature review.

Key findings

- Drivers displayed lower levels of attention, situational awareness, monitoring and vigilance, and higher levels of fatigue when using Level 2 ADAS systems than when driving a vehicle manually.
- There was mixed evidence on how engaged drivers were when driving Level 2 ADAS systems, with some evidence finding that drivers were similarly as engaged as when driving a vehicle manually and other evidence finding that drivers were less engaged in the driving task.
- Drivers generally had lower levels of readiness, responsiveness and arousal when using Level 2 ADAS systems.
- There was mixed evidence on the level of workload that drivers experienced when using Level 2 ADAS systems, with evidence finding higher, lower and no differences in levels of workload.

Attention and awareness

When using Level 2 ADAS systems, drivers are expected to be fully attentive to the driving task and aware of the driving situation. They are expected to monitor both the ADAS system and the driving environment, remaining vigilant so they can take over control when required. In the UK, drivers remain liable and responsible for the vehicle at all times.

This section highlights evidence on the level of attention and awareness that drivers had when using Level 2 ADAS systems in comparison to manual vehicles. It covers attention, situational awareness, monitoring, vigilance and fatigue, all as concepts related to attention and awareness. 19 studies examined attention and awareness and their related concepts. This included ten real-world studies, seven simulator studies, one survey, and one literature review.

Attention

Evidence pointed towards drivers having lower levels of attention when driving Level 2 ADAS systems compared to manual mode (Biondi & Balakumar, 2021; Solís-Marcos, et al., 2017; Morando, et al., 2021). For example, Eddine et al's (2024) simulator study examining attention allocation revealed that drivers spent more time looking away from the road and fixating on billboards when Level 2 ADAS was engaged. They were also more likely to recognise the billboards when later tested. Their findings implied that attention was increasingly allocated away from the driving task and drivers were more easily distracted by their surroundings.

Morando et al's (2021) on-road study examining driver inattention found that among automation experienced drivers, visual attention to the road was redirected downwards and towards the centre-stack (the controls in the centre panel of the vehicle) immediately after the ADAS system was engaged. They expressed that this indicated that Level 2 ADAS users, who had become familiar with the technology after increased exposure, had developed an over-reliance on the system.

Differences in how attentive drivers were when driving hands-on compared to hands-off systems (using self-report measures) were also examined, revealing that drivers felt they were less attentive and in control of the vehicle when driving a hands-off system. Those driving hands-off also displayed more dangerous driving behaviours, such as delayed response times and larger deviations into other lanes, indicating the potential implications of inattention (Cahour, et al., 2021).

Situational awareness

Situational awareness refers to the understanding of what is happening around an individual in a given situation (Endsley, 1995; Salmon, et al., 2009). It has three levels: perception (noticing and monitoring important elements in the environment), comprehension (understanding what those elements mean in relation to one's goals or tasks), and projection (predicting how the situation might change in the future).

Evidence showed that drivers had reduced situational awareness when driving Level 2 ADAS systems (Biondi & Balakumar, 2021; Wada, et al., 2020). For example, Madigan et al's (2018) study exploring drivers' vehicle control while changing lanes using a simulator in the UK found that drivers took longer to engage the indicator when driving Level 2 ADAS than when in manual mode. The authors stated it was likely that this extra time was needed for drivers to establish situational awareness, checking the system status and surrounding traffic. A different simulator study conducted in the US which investigated hazard perception and anticipation among drivers with ADHD (Attention-Deficit/Hyperactivity Disorder) demonstrated that drivers (regardless of level of ADHD symptomology) generally anticipated fewer hazards when Level 2 ADAS was engaged than when driving manually (Ebadi, et al., 2021).

Monitoring

Across the literature evidence generally found that drivers displayed a decrease in monitoring when using Level 2 ADAS systems, including an increase in glances off the road (Gaspar & Carney, 2020; Dunn, et al., 2021; Biondi & Jajo, 2024) and reduced gaze frequency and duration towards vehicle mirrors (Wada, et al., 2020; Dunn, et al., 2021). However, Shutko et al's (2018) naturalistic study conducted in the US, which explored Tesla owners' driving behaviours while Autopilot was activated, observed that drivers kept their eyes on the road 89% of the time when the system was engaged, demonstrating that drivers generally kept their eyes on the road and stayed alert and engaged in the driving task. Additionally, Forster et al's (2019) simulator study in Germany showed an improvement in visual scanning efficiency with increased use of and familiarisation with Level 2 ADAS systems.

Vigilance

Vigilance is the ability for a driver to sustain attention over longer periods of time (Warm et al., 2008; Langner and Eickhoff, 2013 cited in Solís-Marcos, et al., 2017). Evidence found reduced levels of vigilance in both manual and Level 2 ADAS driving conditions, however the nature of the reduction was different and more pronounced when the ADAS system was operational (Greenlee, et al., 2022; Biondi, et al., 2024). For example, when driving with a Level 2 ADAS system in a simulation, drivers were less able to discriminate between safely and hazardously stopped vehicles as the drive progressed. Towards the end of the drive, they also increasingly identified a hazard where there was none, while in manual driving, the number of such false alarms decreased over the course of the drive. This indicated that hazard detection performance deteriorated to a greater extent when driving with Level 2 ADAS systems engaged compared to manual mode (Greenlee, et al., 2022). As described, Greenlee et al. (2022) measured vigilance through performance of a hazard detection task while Biondi et al. (2024) used response time to a detection task to measure vigilance. In contrast, Solís-Marcos et al.'s (2017) study, which used a simulator and measured vigilance through subjective ratings of how alert drivers felt while driving, found that the ADAS system had no effect on drivers' self-reported vigilance.

Fatigue

Sleepiness and drowsiness were examined through a mixture of self-report measures and physiological measures, such as percentage of eye closure, blink duration, pupil diameter and heart rate. Higher levels of sleepiness (Ahlström, et al., 2021) and drowsiness (Kundinger, et al., 2020; Dunn, et al., 2021) were found among drivers when driving Level 2 ADAS systems compared to manual. However, an on-road study conducted on a motorway in Sweden (Ahlström, et al., 2021) demonstrated that this increase in sleepiness mainly came from driving at night: using Level 2 ADAS had little or no detrimental effects on driver fatigue during the daytime. The authors argued this indicated that when sleep pressure was high, an already fatigued driver became even more fatigued when using Level 2 ADAS systems. The other studies did not include nighttime driving, so their results cannot be directly compared.

An on-road study in the Netherlands, however, uncovered no difference in driver-rated levels of sleepiness between manual and Level 2 ADAS modes (Stapel, et al., 2019). This study included sixteen participants and involved relatively short periods of driving (ten minutes at a time for a total of 40 minutes). In comparison, the evidence that showed higher levels of fatigue had larger samples (between 30 and 89 participants) and involved longer drives. For example, Dunn, et al. (2021) conducted a naturalistic study over the course of 20 months and Kundinger et al's (2020) study involved a 90-minute drive that was split into two 45-minute drives. This experiment also used a small, closed loop test track to evoke monotonous driving. These findings suggest that the duration and conditions of the driving experience influence the impact of Level 2 ADAS on driver fatigue.

Reasons for reduced attention and awareness

Several reasons were suggested to explain why drivers were less attentive and aware when driving Level 2 ADAS systems. Effects of underload, which means the driver is paying less attention or putting less effort into monitoring (Warm et al., 2008; Langner and Eickhoff, 2013 cited in Solís-Marcos, et al., 2017), may have resulted in lower attention levels, as the basic driving tasks had been taken over by the system leaving the driver with little to do. This could have consequently reduced their level of engagement and attention to the driving task and increased the potential of distraction. Inattention may have also been a result of over-reliance on the system, with drivers lacking understanding of system capabilities and over-trusting the technology. The evidence further suggested that attention may have been affected by mental fatigue over prolonged driving periods that occurs regardless of automation level.

Consequences of reduced attention and awareness

The reduced levels of attention, situational awareness, monitoring and vigilance, and increase in fatigue that were generally found across the evidence were argued to have various potential consequences on road safety. The studies suggested that lower attention and awareness could affect a driver's ability to supervise the vehicle (Eddine, et al., 2024), take over control when required (Eddine, et al., 2024) and respond to unexpected events (Solís-Marcos, et al., 2017; Gaspar & Carney, 2020). Reduced attention was also suggested to be associated with increased engagement in non-driving related tasks (Morando, et al., 2021; Biondi & Jajo, 2024). For example, an increase in glances downwards while driving was associated with secondary task engagement, which could lead to drivers failing to note visual cues and detect system malfunctions, increasing the likelihood of collisions (Morando, et al., 2021).

Engagement

When using Level 2 ADAS systems, drivers are expected to be fully engaged in the driving task and in monitoring the system. This section outlines evidence examining driver engagement when using Level 2 ADAS systems. It further covers readiness, responsiveness and arousal as concepts related to driver engagement. This section is based on 11 studies: nine real-world driving studies, one simulator study and one literature review.

Evidence examined levels of cognitive and visual engagement in the driving task and in monitoring the system. Levels of engagement were measured in a variety of ways, namely self-report measures through questionnaires (Lohani, et al., 2021; Greenlee, et al., 2022; Neuhuber, et al., 2022) and electroencephalography (EEG) measures to assess how engaged a person is with visual stimuli (Lohani, et al., 2020; McDonnell, et al., 2021). One study used self-reported levels of mind wandering as a measure of engagement (Biondi, et al., 2018).

There was mixed evidence on how engaged drivers were when driving Level 2 ADAS systems. Some studies showed that drivers were similarly as engaged in the driving task and in the monitoring task when driving Level 2 ADAS vehicles as they were when driving manually (Lohani, et al., 2020; Biondi, et al., 2018; McDonnell, et al., 2021; Lohani, et al., 2021). All these studies were on-road, used participants with no prior experience of the automation system, and three out of five used physiological and behavioural measures of engagement. McDonnell et al. (2021) suggested the concern that drivers would be less engaged when driving Level 2 ADAS systems may not have been grounded in physiological evidence and drivers may have remained engaged as they were still required to monitor traffic conditions and maintain readiness to take over control of the vehicle. However, other evidence, which used self-report measures of engagement, a mixture of on-road and simulation methodologies and participants with varying levels of prior automation experience, found that drivers were less engaged in the driving task when driving Level 2 ADAS systems (Greenlee, et al., 2022; Neuhuber, et al., 2022).

There were various potential explanations for this conflicting evidence on a driver's ability to remain engaged when driving with Level 2 ADAS. Firstly, the research methodologies used could have elicited different results, specifically the use of on-road versus simulation methods. The potential consequences of driving on-road may have forced drivers to remain engaged in a way that simulation studies did not (McDonnell, et al., 2024). Secondly, indirect effects of automation experience could have been a contributing factor (McDonnell, et al., 2024). Drivers with no prior automation experience may have remained engaged when driving Level 2 ADAS systems due to the novelty of the technology, whereas, with increased familiarisation, automation experienced drivers may have felt more able to disengage from the driving task, possibly due to over-trust and over-reliance in the system as previously discussed in 'Trust in and misuse of ADAS' chapter. Finally, while Biondi et al. (2024) proposed that the type of vehicle used could have also explained variations in driver engagement, with different vehicle characteristics, such as the user interface, affecting how engaged drivers were.

Readiness, responsiveness and arousal

Evidence also examined concepts related to engagement, including readiness, responsiveness, arousal and boredom.

Evidence showed that drivers displayed reduced responsiveness while using Level 2 ADAS systems (Biondi & Balakumar, 2021; Biondi, et al., 2018) which was implied to be due to a reduction in mental workload, for example, mental, physical or temporal demand, and effort when using the system (Eddine, et al., 2024; Biondi, et al., 2018) (explored further in 'Workload' section).

Driver readiness is defined as the driver being ready to regain control of the vehicle from the system and continue driving manually (Morales-Alvarez et al., 2020). It was observed that drivers displayed readiness while using Level 2 ADAS systems, but this readiness reduced over the course of the drive. For example, Stapel et al. (2022) conducted an on-road study involving 30 participants experienced with ACC and found that drivers kept their feet on or above the accelerator approximately two-thirds of the time (65.8%) while ACC was active. However, time with feet away from the pedal increased over the course of the drive, indicating that drivers were either increasingly reliant on the system or wanted to adopt a more comfortable position later in the drive. This overall demonstrated that drivers had reduced readiness the longer they drove for.

Regarding arousal, one study showed that driving with Level 2 ADAS systems was associated with a decrease in physiological arousal and behavioural signs of arousal, such as yawning and difficulty keeping eyes open. This reduction in arousal resulted in reduced vigilance and awareness of traffic hazards (Biondi, et al., 2018).

In contrast, Lohani et al's (2020) on-road study with drivers new to Level 2 ADAS systems revealed no difference in cognitive arousal in driving with Level 2 ADAS compared to manual driving and another found that drivers did not feel more bored when driving Level 2 ADAS systems compared to manual (Lohani, et al., 2021).

Workload

Workload refers to the effort a driver exerts in response to tasks and demands. This includes cognitive workload, or mental effort (Fairclough et al., 2005 cited in McDonnell, et al., 2021). Automated driving aims to reduce the workload placed on drivers by removing basic driving tasks from the driver, reducing human error and improving road safety. However, Level 2 ADAS systems still require the driver to supervise both the ADAS system and the vehicle within its driving environment, which has raised concerns around the level of workload that drivers experience when using Level 2 ADAS systems. This section outlines the evidence on workload and cognitive demands that drivers experience when using Level 2 ADAS systems, and how this compares to manual driving. It also outlines factors that influence workload.

Across the evidence base, workload was measured in a variety of ways, with measures being either subjective or objective. Subjective measures of workload were based on drivers' self-reported, perceived level of workload and were measured through questionnaires. Objective measures were based on physiological measures, such as heart rate, heart rate variability, brain activity and reaction time to detection response tasks. 14 studies examined workload; 11 were on-road studies and three used a simulator.

Evidence showed a mixed picture on the level of workload and cognitive demands that drivers were under when using Level 2 ADAS systems. Some evidence demonstrated that drivers might experience significant cognitive demands and higher workload when driving Level 2 ADAS systems compared to driving manually (McDonnell, et al., 2024; Greenlee, et al., 2022; Stapel, et al., 2019), while others indicated that drivers experienced lower cognitive demands (Solís-Marcos, et al., 2017; Stapel, et al., 2022; Biondi, et al., 2018; Eddine, et al., 2024). Most research, however, revealed little or no difference in workload and cognitive demands on drivers when driving Level 2 ADAS systems compared to manual (Lohani, et al., 2021; Lohani, et al., 2020; McDonnell, et al., 2021; Stapel, et al., 2019; Biondi & Jajo, 2024; Jajo & Biondi, 2023; Neuhuber, et al., 2022).

These conflicting results could be explained by a range of factors, including general research limitations such as small sample sizes, different measures of workload and different levels of experience with ADAS (research limitations are explored further in 'Methodological limitations'). Two out of three studies which found higher workload when using Level 2 ADAS systems used objective measures of workload, three out of four studies which showed lower workload used subjective measures, and five out of six studies which revealed no difference used objectives measures, with one of these studies employing both subjective and objective measures. (Stapel, et al., 2019) observed that drivers perceived their level of workload while using Level 2 ADAS systems to either be lower or equivalent to that experienced during manual driving (this varied by level of automation experience (explored further in 'Factors influencing workload'). However, for both groups (automation experienced and in-experienced), objective measures indicated that cognitive load increased when using Level 2 ADAS, implying that driver's perception of cognitive load may not match physiological indicators.

Research design could have also contributed to the mixed picture. All seven studies that highlighted no difference in workload were on-road experiments, while two out of the four studies which found lower cognitive demands were simulator studies. Two out of the three studies that found higher workload were on-road studies. One on-road study (Stapel, et al., 2019) is included in both groups as they observed different results for objective and subjective measures of workload, as previously discussed.

Factors influencing workload

Evidence examined the effect of various factors on the level of workload that drivers experienced when driving Level 2 ADAS, including the driving environment, automation experience, familiarisation, vehicle type and age.

Driving environment

Evidence found that driver workload was greater when driving on more complex and engaging highways than more monotonic highway conditions, regardless of automation (Stapel, et al., 2019; McDonnell, et al., 2024). However, this difference was revealed to be larger when driving Level 2 ADAS compared to manually (McDonnell, et al., 2021).

Automation experience

Automation-experienced drivers perceived a lower workload while automation-inexperienced drivers perceived workload to be similar as when driving a manual vehicle (Stapel, et al., 2019).

Familiarisation

Workload was shown to decrease the more familiar that drivers were with the Level 2 ADAS system (McDonnell, et al., 2024; Buchner, et al., 2024). For example, McDonnell et al. (2024) demonstrated that six weeks of on-road practice in vehicles equipped with a Level 2 ADAS system decreased driver workload, but only when driving in more simple driving environments. Drivers remained at elevated levels of workload in more complex driving environments, such as a curved, mountainous highway in comparison to a straight highway. A different on-road study by (Buchner, et al., 2024) found that workload decreased from the first to the second interaction with the system. The level of workload then stabilised for following drives. This was argued to imply that initial interactions with the system may involve higher workload as drivers become familiar with the system and are in the process of building a mental model for it. But once the initial mental model is built, workload on the driver decreases.

Vehicle type

McDonnell et al.'s (2021) on-road study in the US observed a small effect of vehicle type on workload, with lower levels of cognitive workload found for those driving a Nissan Rouge compared to Tesla Model 3 and Volvo XC90. They stated that this demonstrated that different characteristics of the technology and interfaces can have different effects on workload for drivers (further exploration of this in 'Mode awareness').

Age

The effect of age on driver workload was also examined in McDonnell et al. (2021) and was shown to have no effect, indicating that the cognitive demands of driving a Level 2 ADAS system was equivalent for younger and middle-aged drivers.

7. Potential mitigations to address the challenges associated with using ADAS

Introduction

This section outlines the recommended measures to help address the human challenges associated with ADAS. Twenty-four papers included in the review recommended various mitigations. Some of these papers used multiple methods, whilst others relied on one approach: 12 papers used surveys, ten driving simulators, and nine real-world studies. One paper was based on secondary data analysis.

Several papers offered solutions to address the human challenges of ADAS related to system design. These proposed improvements included changes to the Human-Machine Interface (HMI), driver monitoring systems, feedback mechanisms (Neuhuber, et al., 2022; Roberts, et al., 2022; Itoh, et al., 2018; Novakazi, et al., 2020; Neuhuber, et al., 2022; Kim, et al., 2021; Landry, et al., 2022; Kim, et al., 2024; Cramer & Klohr, 2019; Uchida, et al., 2019; Ahlström, et al., 2021; Hwang, et al., 2025; Solís-Marcos, et al., 2017; Lee, et al., 2020; DeGuzman & Donmez, 2021; DeGuzman & Donmez, 2024; Gaspar & Carney, 2020) and driver education (Itoh, et al., 2018; Lee, et al., 2020; DeGuzman & Donmez, 2021; DeGuzman & Donmez, 2024; Walker, et al., 2018; Gaspar & Carney, 2020; Neuhuber, et al., 2022).

Key findings

This evidence review identified several key measures to mitigate the human factors challenges associated with using ADAS:

- HMIs should provide more information that is clear and intuitive to the driver. This may enhance drivers' awareness of hazards or vehicle failures, improve driving performance, and/or mitigate over- or under-reliance on the system.

- Providing multimodal (such as auditory, visual and haptic) feedback and notifications from the vehicle can improve trust, acceptance and situational awareness.

- Driver monitoring systems should be designed based on the driver's physiological state rather than solely on driving performance. ADAS vehicles should use driver monitoring systems that incorporate camera or physiological data to monitor drivers' state.

- Driver education/training should be detailed and increase drivers' self-awareness of gaps in their knowledge of ADAS systems.

- Tailoring driver education and training to certain groups of drivers can improve their understanding and reliance on ADAS technologies.

HMI design

Evidence suggested that HMIs provide clear and detailed information to the driver to help mitigate the challenges of using ADAS, improve awareness of hazards and automation failures (Neuhuber, et al., 2022), and help prevent accidents (Neuhuber, et al., 2022; Gaspar & Carney, 2020; Itoh, et al., 2018; Novakazi, et al., 2020; Kim, et al., 2021; Landry, et al., 2022). The study suggests that when drivers are given additional information about the road conditions, such as the shape and layout of the road, before they are asked to take control of the vehicle, they respond more safely. This implies that having more context about the driving environment helps drivers make better decisions when they need to take over (Roberts, et al., 2022).

Research showed that drivers often misunderstand the system's capabilities during critical events, such as crashes or near-crashes (Kim, et al., 2021). Providing clearer information about the system's capabilities and limitations may reduce over-reliance. A real-world study revealed that vehicle mode changes were poorly communicated, reducing drivers' awareness of the current mode (Wilson, et al., 2020). The study recommended visual notifications that are large enough, use strong colour contrast, and are visible in the driver's peripheral vision to support awareness during mode transitions. One study proposed showing important information through augmented reality heads-up displays (HUD) that project onto the windscreen, to highlight objects that the system is responding to (Landry, et al., 2022). Continuous or dynamic displays could provide real-time, detailed feedback on system performance, further helping drivers stay informed.

One study recommended that HMI icons should be more unique to help drivers distinguish ADAS functions from other vehicle features (Landry, et al., 2022). They suggested using consistent and more distinctive colours for ADAS icons, since some standard symbols are currently used for both conventional and ADAS functions, which can confuse drivers. They also noted that different car brands use these icons inconsistently, despite some symbols being standardised. However, they advised against fully standardising displays, as this could limit innovation and reduce the system's functionality.

Multimodal feedback

Several sources suggested multimodal feedback, such as auditory, visual and haptic feedback, may improve trust, acceptance, situational awareness (Neuhuber, et al., 2022; Kim, et al., 2024), and overall safety (Landry, et al., 2022).

One study recommended adding audio notifications to existing visual feedback to improve drivers' trust and acceptance (Kim, et al., 2024). Although a small sample size (n=22), the study found that user interfaces offering detailed information through both sound and visuals ranked highest in trust and lowest in perceived risk.

Another study investigated the design of active vehicle roll motions - slight tilting or rolling of the vehicle's body - to signal a lane change (Cramer & Klohr, 2019). Participants tested different roll motion scenarios on a test track and found them useful for announcing lane changes. The study outlined several optimal parameters for roll motion, such as time to reach the maximum angle, and recommended time for announcing the lane change. It found that an announcement time of 2.0 seconds was suitable, providing a total of approximately 4 seconds from initial announcement to lane change.

However, not all studies concluded that additional modes of communicating between the vehicle and the driver are beneficial. One study found that verbal communication between the system and driver did not increase situational awareness (Uchida, et al., 2019). As a result, they did not recommend using verbal communication to address human factors challenges in ADAS.

Driver monitoring systems

Several studies recommended changes to the driver monitoring systems to address human factors challenges with ADAS. These systems assess the driver’s current state, for example, if they are showing signs of drowsiness. Suggestions included monitoring systems based on the driver’s physiological state, rather than driving performance (Ahlström, et al., 2021), monitoring using cameras (Ahlström, et al., 2021; Lee et al., 2013 cited in Neuhuber, et al., 2022; Hwang, et al., 2025), and methods of physical monitoring, such as tracking brain responses (Solís-Marcos, et al., 2017).

Multiple studies supported using cameras and physiological data to monitor driver attentiveness and performance (Ahlström, et al., 2021; Wilson et al. 2020; Hwang, et al., 2025). For example, including eye, head, and body-tracking systems, as well as steering wheel sensors to check if hands are on the wheel (Mousel and Treis, 2017 cited in Wilson, et al., 2020). Physical symptom tracking systems were also suggested by other sources (Ahlström, et al., 2021; Lee et al., 2013 cited in Neuhuber, et al., 2022; Solís-Marcos, et al., 2017; Hwang, et al., 2025). While physiological monitoring systems reliably tracked driver state, steering wheel torque sensors showed limited success in monitoring driver engagement (NTBS, 2017 cited in Wilson, et al., 2020).

One driving simulator study suggested that monitoring drivers' brain responses could effectively track attention (Solís-Marcos, et al., 2017). The study found that driver attention decreased due to underload and, over longer periods, mental fatigue affected attention during both ADAS and manual driving. This study used event-related potentials (ERPs), which are brain responses indicating cognitive processes, to measure driver attention. ERPs are measured using EEG, which involves placing electrodes on the scalp to monitor brain activity and observe reactions to stimuli. The researchers noted that ERPs could monitor driver attention more accurately than traditional indicators like speed or lane position. Researchers have called for further investigation into ERPs as a monitoring tool.

The use of EEG to monitor driver attention presents not only risks around data security, but also practical and ethical issues. Placing electrodes on the scalp could be impractical for everyday use and potentially intrusive as it involves continuous monitoring of a driver's brain activity. While EEG could offer a promising method for effectively monitoring driver attention, addressing these practical and ethical concerns is crucial.

Adaptive vehicle behaviour

Adaptive systems that respond to driver performance could enhance ADAS safety. A simulator study revealed that auditory distractions can delay driver takeover response times, thereby increasing the risk of collisions (Hwang, et al., 2025). To mitigate this, the study recommended that future ADAS vehicles adjust their behaviour, such as reducing speed or changing lanes, when driver performance declines.

Wider education and training

Several studies point to the importance of driver education and training about the capabilities of ADAS systems, although there were different recommended approaches. Suggested approaches included: detailed theory-based training (educating drivers about the fundamental principles, concepts, and theories behind ADAS) (Itoh, et al., 2018; Lee, et al., 2020; DeGuzman & Donmez, 2021), increasing drivers' self-awareness of gaps in their knowledge of ADAS systems (DeGuzman & Donmez, 2024; Walker, et al., 2018), redefining safety guidelines/thresholds to be suitable for vehicles with ADAS (Gaspar & Carney, 2020), gaining hands-on experience of using ADAS technologies (Walker, et al., 2018), and tailoring education for various driver groups (Neuhuber, et al., 2022; DeGuzman & Donmez, 2024).

Information about the system

Evidence suggests that detailed information and training are needed to improve drivers' trust and mental models of ADAS technology. Itoh et al's (2018) simulator study found that drivers who were provided with knowledge about the HMI system before the experiment had quicker takeover times. Another study showed that detailed information and training can increase driver trust following system failures (Lee, et al., 2020).

Research also emphasised that it may be beneficial to focus driver education and training on improving drivers' overall understanding of the limitations of ADAS rather than just its capabilities. DeGuzman and Donmez (2021) argued that it is impractical for drivers to learn and remember all possible limitations of ADAS systems while driving. Therefore, training should help drivers understand that ADAS can make mistakes and reinforce their own role in using the system safely, to build appropriate trust and reliance.

Several sources also stress the importance of building drivers' awareness of the gaps in their knowledge about ADAS (DeGuzman & Donmez, 2024; Walker, et al., 2018). Walker et al. (2018) found that on-road experience with ADAS improves drivers' trust calibration and helps shape their mental models. They suggested that early interactions, such as test drives with someone knowledgeable about the system, like a car dealer, can enhance understanding of the vehicle's capabilities and support appropriate trust.

Additional research underscores the need to update existing guidelines for ADAS vehicles (Gaspar & Carney, 2020; Ebel, et al., 2023). Gaspar and Carney (2020) suggested that distraction guidelines and safety thresholds, such as how long drivers look away from the road, may need to be changed to address the human factors challenges introduced by ADAS.

Tailored information

Some studies concluded that tailored information and training for different driver groups can better improve understanding and trust of ADAS systems (Neuhuber, et al., 2022; Zhang, et al., 2024). Zhang et al. (2024) identified three driver groups with varying awareness and trust levels and recommended customising training to fit each group's characteristics. Similarly, Neuhuber et al. (2022) categorised drivers into five groups based on trust, behaviour, and system use, and recommended tailored training, especially for highly trusting or sceptical drivers who often misuse ADAS. They also emphasised that education and training should be continuously adapted as drivers' behaviour changes over time.

8. Methodological limitations

While the reviewed studies offer valuable insights into human factors associated with ADAS, several methodological limitations should be acknowledged.

Sample limitations

Many studies had relatively small sample sizes, limiting their statistical power and representativeness of the wider population. The absence of a reported power analysis across studies makes it unclear whether the sample sizes used were adequate to detect meaningful effects, raising the possibility that non-significant findings may be due to insufficient statistical power rather than a true lack of effect.

Across many studies the participant pool was drawn from specific populations such as university students and staff, employees of automotive companies or other employee groups. In several cases, participants were recruited through flyers, referrals or company portals, which can introduce self-selection bias. As a result, participants may not reflect typical users of the vehicle technologies being studied (e.g., ADAS users in the general population) and the real-world applicability of the results may be constrained.

The studies did not consistently report on participant characteristics, such as gender and age. Some of the samples were also skewed towards particular groups, such as being male dominated or skewed towards younger age groups, which might limit the generalisability of the findings. The studies also did not consistently report on driving-related factors, such as years of driving or experience with automation.

Additionally, only one study was conducted in the UK, with the majority of research based in North America. While this may reflect market conditions, given that North America had the largest ADAS market in 2024 (Mordor Intelligence, n.d.), findings from other countries may not be entirely applicable due to contextual differences. These differences include driving cultures, which refer to the behaviours and attitudes of drivers within a particular region or country (Gray, 2023); regulations that influence the design, testing, and approval of ADAS; and the driving environment, such as signage, lane markings, and speed limits. All these factors can impact the performance of ADAS and drivers' responses to them, thereby limiting the generalisability of the findings to the UK context. While some findings in this report may not be directly applicable to the UK, it is hypothesised that human factors are generally consistent across different countries. However, this hypothesis needs to be rigorously tested.

Study design limitations

The majority of studies, whether real-world or using a simulator, were conducted in controlled settings, often with the presence of researchers, which may have influenced participants' responses. Participants were typically instructed to use ADAS in specific ways rather than choosing to use it naturally, which could affect engagement and decision-making.

Many studies involved a single drive or short-duration exposure, limiting the ability to observe driver adaptation over time. This is particularly important as many human factors challenges may only become apparent after prolonged use of automation. In some cases, the experimental design introduced sequence effects, potentially biasing results due to the order in which tasks or conditions were presented. The driving scenarios used in these studies did not cover the full range of situations which drivers encounter in real life, such as driving in different road types, weather conditions, and traffic densities.

The lack of a longitudinal perspective also prevents understanding of how driving behaviour and trust evolve with extended system use, as highlighted in several studies discussed in the 'Levels of trust in ADAS' chapter.

Many studies used subjective measures such as questionnaires which rely on participants' self-reports, which can be influenced by social desirability bias or inaccurate self-assessment.

Recommendations for future research designs

Future studies should ensure larger sample sizes and more diverse participant samples to ensure that the results are generalisable across a broader population of drivers.

Studies should incorporate a wider range of driving scenarios, including motorways, B-roads, and varied conditions such as daytime versus nighttime and different traffic flow levels. Testing under multiple highway conditions and longer practice sessions will help better reflect the complexities of real-world driving.

To enhance real-world relevance, future research should prioritise naturalistic driving studies which allow for the observation of driver behaviour in authentic environments. These studies should be specific to the UK to accurately reflect driving styles, UK regulations, and driving environments (e.g. road types). Longitudinal designs would further contribute by capturing changes in behaviour and adaptation over time.

9. Conclusions

The evidence review explored the human factors implications of Level 2 ADAS, in particular driver understanding of system capabilities and driver responsibilities, trust levels and cognitive and behavioural challenges.

This section outlines suggestions for further research, recommendations for policy and implications of the review's findings for emerging ADAS capabilities, such as Driver Controlled Assistance Systems (DCAS) and system-initiated manoeuvres (SIM).

Suggestions for further research

Understanding driver responsibilities and system capabilities

The review demonstrated that when using Level 2 ADAS, drivers experienced challenges related to understanding their responsibilities and the system's capabilities. Further research is therefore required into effective methods to improve drivers' understanding of the system's capabilities and limitations, and the responsibility to monitor the vehicle at all times. Additionally, it would be beneficial to investigate why drivers often overestimate their understanding of these systems.

Trust in Level 2 ADAS

Many studies examined drivers' trust of Level 2 ADAS. In general, they trusted the technology but trust levels varied depending on the type of ADAS technology used, human factors, and driving conditions. Inappropriate levels of trust could lead to reduced attention and monitoring, impacting driver safety and encouraging engagement in secondary tasks. Therefore, further research should explore strategies for trust calibration to ensure that this trust in ADAS is appropriately aligned with the system’s actual capabilities and limitations.

Cognitive and behavioural challenges

Evidence also demonstrated that drivers using Level 2 ADAS experienced a range of cognitive and behavioural challenges compared to manual driving, such as lower levels of attention, situational awareness, monitoring, and vigilance, and higher levels of fatigue. Readiness, responsiveness, and arousal were generally lower when using ADAS, while other evidence on workload levels was inconclusive and requires further investigation. These results are in line with previous literature showing that, in general, individuals struggle at monitoring a task over extended periods of time.

System design

The reviewed studies also emphasised that a transparent system design is crucial to support users. This involves intuitive HMIs that clearly communicate system status and functionality, as well as the integration of multimodal feedback (audio-visual and haptic) and driver monitoring systems. While these areas were identified as important mitigation strategies, the reviewed papers did not provide detailed solutions for their design. Further research can explore the specific design elements that improve driver understanding and interaction with ADAS.

Driver training

The reviewed studies emphasised that tailored training should be provided to drivers so that they understand their ongoing responsibilities when using ADAS, reinforcing that these systems are designed to assist and not replace them. Future research should investigate the most effective training delivery methods and evaluate whether it can support visual scanning behaviours comparable to those in manual driving. Additionally, long-term studies are needed to assess whether prolonged ADAS use leads to skill fading and if ongoing support is required to maintain driving skills.

User acceptance and data privacy

Given the reliance of these systems on personal and physiological data, user acceptance of data collection should be investigated. Acceptance often depends on perceived benefits and risks, for example users may be comfortable sharing physiological data to enhance safety but not if it could raise insurance premiums. Another concern from a user perspective is modern vehicles' vulnerability to cyberattacks. Understanding these nuances is vital to developing ethical and user-centred data practices.

Methodological considerations for future studies

Methodologically, future on-road studies which include a broader range of driving contexts, such as motorways, B-roads, varied lighting and traffic conditions are needed. These studies would require robust methodologies, including adequate sample sizes, case-control comparisons, and extended practice sessions to simulate real-world driving more accurately.

The studies in this review focus on immediate cognitive and behavioural challenges, so longitudinal studies would be beneficial to understand the long-term effects of using Level 2 ADAS and track behavioural adaptation over time across diverse user groups, considering variables such as age, gender, and driving experience.

Given limited UK-specific research, regionally relevant studies are essential to examine how Level 2 ADAS perform under local road conditions, infrastructure, and regulatory environments. Naturalistic studies, in which participants voluntarily use ADAS in everyday settings, would yield more authentic insights into real-world usage patterns.

Finally, more empirical evidence on the safety outcomes of ADAS will be essential to evaluate the technology's true impact on road safety. This could include comparative analyses of accidents, incidents, and near-misses between ADAS and non-ADAS users—ideally conducted in collaboration with organisations such as the British Transport Police and insurance providers.

Policy discussion points

The policy implications from this review suggest a multifaceted approach that includes enhanced driver education, improved system design, robust data protection, and comprehensive research to ensure the safe and effective use of Level 2 ADAS technologies. Findings underscore the necessity for enhanced communication and education about their limitations and proper use. Policymakers should consider creating comprehensive, evidence-based educational programmes that inform drivers about their responsibilities and the system's assistive nature.

As part of this effort, it is recommended to engage with automotive manufacturers such as Original Equipment Manufacturers (OEMs) to promote clearer and more accurate communication regarding ADAS capabilities and driver responsibilities in their marketing and advertising materials.

Moreover, policymakers should advocate for the development and implementation of more intuitive and transparent HMIs and encourage automotive manufacturers to design systems that balance standardisation for safety with user comfort.

The reliance on personal data by ADAS systems also necessitates policy considerations around data privacy and acceptance. Policymakers should ensure that regulations are in place to protect drivers' personal data and address concerns about its use, particularly in contexts that could negatively affect insurance premiums.

Government funding and partnerships with manufacturers should support commissioning of further research on Level 2 ADAS in the UK, such as long-term naturalistic driving studies in diverse driving environments.

Implications for Emerging Driver Controlled Assistance Systems (DCAS) and System-Initiated Manoeuvres (SIM)

The evidence on human factors in Level 2 ADAS provides a critical foundation for understanding the challenges posed by emerging ADAS capabilities, such as Driver Controlled Assistance Systems (DCAS) and system-initiated manoeuvres (SIM). These new features, where the vehicle initiates manoeuvres without explicit driver input, represent a significant step toward higher levels of automation. However, they also raise complex questions about driver roles, system transparency, and shared control.

Evidence from the studies reviewed showed that driver uncertainty about their level of control or overestimation of system capabilities (i.e. poor trust calibration) could lead to inappropriate use of Level 2 ADAS systems. Emerging ADAS systems taking a more proactive role in managing driving tasks may help reduce driver errors, but they could also create new safety risks if drivers become increasingly passive or disengaged. There is a risk drivers might wrongly believe the vehicle can handle situations beyond its design limitations. Without transparent communication of the system's intentions and limitations, drivers using DCAS/SIM systems are likely to experience similar challenges in understanding when and how to intervene, potentially compromising safe and effective system use. The evidence review also found that when using existing ADAS systems drivers often struggle with mode awareness, making it difficult to understand what the system is doing and what is expected of them. Emerging ADAS, such as DCAS and SIM, differs by introducing additional complexity through automated decision-making and action initiation, which places even greater demands on timely and sophisticated feedback from the human-machine interface (HMI).

The findings suggest that similarly to existing ADAS, successful deployment of these systems will require not only reliable technology, such as HMIs and monitoring systems, but also comprehensive driver training programs that support the development of accurate and resilient mental models from the outset.

Existing Level 2 ADAS research offers valuable insights into user trust, system comprehension and boundaries. However, DCAS/SIM introduces distinct human factors challenges, particularly in areas such as attention management and driver-system interaction. The operational differences between existing and emerging forms of Level 2 ADAS mean that these issues cannot be addressed by simply extending existing frameworks; instead, dedicated research is needed to explore DCAS/SIM-specific impacts.

For example, this review found limited evidence on hands-on versus hands-off driving, a distinction that becomes more relevant with DCAS/SIM systems. As hands-off operation becomes more common, it is crucial to investigate its implications for driver readiness, trust calibration, and control transitions—especially given that DCAS/SIM often involves the system taking control without prior driver input.

DCAS/SIM features are currently limited in availability on public roads, so there remains a relatively small body of empirical evidence covering how drivers interact with and respond to these systems in real-world conditions. Further research should investigate drivers' use of DCAS/SIM, for instance via a longitudinal on-road study where participants answer short safety-related surveys on a weekly basis. Alternatively, studies on closed and controlled track environments could provide further insights on driving performance and safety when using DCAS/SIM. A closed, controlled environment allows to investigate corner-cases, which is much more challenging on public roads from a safety and ethical perspective.

Annex 1: Search strategy

Search strategy

Inclusion and exclusion criteria

The inclusion criteria were developed to narrow the search to the papers most relevant to the research questions. These are set out below.

Table X: Inclusion criteria

	Inclusion	Exclusion
Populations and geographies	No restrictions	No restrictions
Technologies	Advanced driving assistance systems (ADAS) that can control steering and speed for prolonged periods of time whilst the driver is expected to be attentive and involved with the possibility of taking over control of the vehicle. This could involve manoeuvres that are confirmed or initiated by the driver, but also "system-initiated manoeuvres". These systems may or may not be hands-free. The driver is always responsible when these systems are being used. These could be labelled as SAE Level 2.	Less advanced ADAS technologies. These could temporarily take control of steering or speed. Includes things like cruise control, lane keeping, speed limiters, parking assistance, etc. The driver is always responsible when these systems are being used. These technologies are classified as SAE Level 1. Fully self-driving technologies, where the vehicle/system is responsible, not the driver. All Level 4 and above vehicles would be in this category, so are out of scope.
Human factors	'Human factors', broadly defined: This includes issues like attention, situational awareness, attentional processing, attention allocation, engagement, monitoring, vigilance, preparedness, readiness, cognitive demand/load, distraction, tiredness, fatigue, understanding of responsibilities, trust in the system, misuse, mental models, mental workload, underload. Takeovers (time/ response/ performance) are in scope, but only in the context of the relevant technologies.	Studies that specifically look at takeovers when the driver is completing a non-driving task, like reading or playing a game.
Study Designs	Simulation-based and real-world studies. High-quality evidence reviews. Surveys	Studies that only test different ways of monitoring driver attention.

		Studies that assess the technical feasibility of different technologies. Studies that only test the impact of driver education/training on how they use/interact with technologies. Studies that only focus on drivers' views and experiences of using the relevant technologies, such as enjoyment or feelings of safety. qualitative studies, or other observational or attitudinal studies. Conceptual studies that aim to develop frameworks or systems for thinking about issues. Opinion pieces and literature reviews.
Time period	2017 onwards	Pre 2017
Language	English	Other languages
Publication	Published academic literature	Anything else

Academic database search and search strings

The scoping phase identified that there was a large volume of academic evidence published on this topic, but little or no non-academic (grey) literature. For this reason, we proposed that the review focused only on academic literature. We used complex search strings to search academic databases informed by our Information Specialist. These were developed based on the inclusion criteria set out above. We searched for suitable evidence in the following academic databases:

- Scopus
- IEEE Xplore
- Applied Science & Technology
- TRID (Transport Research International Documentation)

DfT provided a useful list of potential search terms, which acted as a starting point for our search. We developed a detailed search string in Scopus, refining it through several iterations until it was performing well. The string was then translated into the syntax of the other databases, and the search was run. The results from all databases were merged and deduplicated. Additionally, we carried out citation tracking using Citation Chaser. In total, the search yielded 6,210 papers.

Table X: Academic database search string

1	TITLE-ABS(((driver) W/0 (assist* OR "control assistance system" OR monitoring OR notification* OR override OR supervision OR warning* OR "disengagement monitoring" OR "state monitoring")) OR ((drive* OR driver* OR driving OR vehic* OR car OR cars OR automobile* OR truck*) AND ("eyes off" OR "eyes on" OR "gaze monitoring" OR "hands free" OR "hands off" OR "hands on " OR "human automation teaming" OR "human autonomy teaming" OR "human confirmation" OR "human intervention" OR "level 2" OR "human machine interface" OR "lateral control" OR "lateral motion control assist*" OR "longitudinal control" OR "longitudinal motion control assist*" OR "operational design domain" OR "partial* automat*" OR "semi-automat*" OR automated OR autonomous OR "system boundaries" OR "system confirmed" OR "system initiated" OR "copilot" OR "cooperative steering" OR "autopilot")) OR (((SAE OR automated OR autonomous) W/2 "level 2") OR "automated valet" OR "advanced vehicle technolog*" OR "L2 autonomy" OR "Driver-initiated lane change*" OR "highway assist*" OR "lane change" OR "lane keep assist*" OR "lane keeping assist*" OR "traffic jam assist")) OR AUTHKEY(((driver) W/0 (assist* OR "control assistance system" OR monitoring OR notification* OR override OR supervision OR warning* OR "disengagement monitoring" OR "state monitoring")) OR ((drive* OR driver* OR driving OR vehic* OR car OR cars OR automobile* OR truck*) AND ("eyes off" OR "eyes on" OR "gaze monitoring" OR "hands free"

	OR "hands off" OR "hands on " OR "human automation teaming" OR "human autonomy teaming" OR "human confirmation" OR "human intervention" OR "human machine interface" OR "lateral control" OR "lateral motion control assist*" OR "longitudinal control" OR "longitudinal motion control assist*" OR "operational design domain" OR "partial* automat*" OR "semi-automat*" OR "level 2" OR automated OR autonomous OR "system boundaries" OR "system confirmed" OR "system initiated" OR "copilot" OR "cooperative steering" OR "autopilot")) OR (((SAE OR automated OR autonomous) W/2 "level 2") OR "automated valet" OR "advanced vehicle technolog*" OR "L2 autonomy" OR "Driver-initiated lane change*" OR "highway assist*" OR "lane change" OR "lane keep assist*" OR "lane keeping assist*" OR "traffic jam assist"))
2	TITLE-ABS("Attention reminder" OR "Cognitive load" OR "Cognitive overload" OR "Cognitive underload" OR "Cognitive workload" OR "Disengagement detection" OR "Human factors" OR "Human trust" OR "Mental load" OR "Mental overload" OR "mental model*" OR "Mental underload" OR "Mental workload" OR "Mode confusion" OR "Situational awareness" OR "Visual disengagement" OR ((driver*) W/0 (awareness OR vigilance OR preparedness OR readiness OR overconfiden* OR attentive* OR capability OR confidence OR confirmed OR confus* OR drowsi* OR fatigue OR tiredness OR gaze OR misuse OR overreliance OR performance OR responsibilit* OR responsive* OR trust* OR workload OR behavior* OR behaviour* OR attention OR disengagement OR engagement OR mistrust))) OR AUTHKEY("Attention reminder" OR "Cognitive load" OR "Cognitive overload" OR "Cognitive underload" OR "Cognitive workload" OR "Disengagement detection" OR "Human factors" OR "Human trust" OR "Mental load" OR "Mental overload" OR "mental model*" OR "Mental underload" OR "Mental workload" OR "Mode confusion" OR "Situational awareness" OR "Visual disengagement" OR ((driver*) W/0 (awareness OR vigilance OR preparedness OR readiness OR overconfiden* OR attentive* OR capability OR confidence OR confirmed OR confus* OR drowsi* OR fatigue OR tiredness OR gaze OR misuse OR overreliance OR performance OR responsibilit* OR responsive* OR trust* OR workload OR behavior* OR behaviour* OR attention OR disengagement OR engagement OR mistrust)))
3	#1 AND #2
4	2017 to present and English only

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Glossary

Term	Definition
Advanced Driver Assistance Systems (ADAS)	ADAS technologies provide support to the driver for tasks such as keeping the vehicle inside the lane, but do not replace them as drivers of the vehicle.
Driver Controlled Assistance Systems (DCAS)	DCAS technology is a more advanced form of ADAS that can manage both speed and steering for extended periods of time. While the driver remains fully responsible for the vehicle, DCAS blends aspects of both driver assistance and fully autonomous systems
SAE Levels	These describe the different levels of autonomous vehicles, established by the Society of Automotive Engineers (SAE). SAE Level 0 is used to describe manual driving with no ADAS technologies, whilst SAE Level 5 described fully automated vehicles, which do not need human intervention.
SAE Level 2	This is also known as partial driving automation, meaning systems in vehicles that can control steering and acceleration/deceleration under certain conditions. With SAE Level 2 systems, the driver must remain fully engaged at all times, continuously monitor the driving environment, and be ready to take over immediate control when required. Unlike higher levels of automation, the responsibility for safe driving remains entirely with the human driver.
Human-Machine Interfaces (HMIs)	HMIs are systems in the vehicle that drivers can interact with, such as touchscreens or buttons on the vehicle's dashboard.
Takeover request	This is when the vehicle using ADAS capabilities requests that the driver take over control of the vehicle. This request may be given for reasons such as
Simulator study	A study where participants do not drive a vehicle on the road but drive a stationary, car-like simulator indoors. These simulators have most of the components of a typical vehicle (such as the driving wheel, gear sticks, and dashboard) but often have screens in place of car windows that show videos of real or illustrated roads. The drivers' actions are monitored, often by researchers or using cameras.

Real world study	A study where participants drive a real vehicle, with or without in-built ADAS capabilities, on a real road or on a test track. The drivers' actions are monitored, often by researchers or using cameras.
Situational awareness	Situational awareness is the awareness that a driver has of what is happening around them.
Feedback	Feedback refers to the way the system sends information or notifications to the driver, such as displaying an image to convey a change in the ADAS state of the vehicle.
Physiological monitoring system	Monitoring the driver's state using physiological indicators, such as their pupil diameter or eye movement
Adaptive Cruise Control (ACC)	ACC is similar to standard cruise control, but it also assists with acceleration and/or braking to maintain a distance from the vehicle in front.
Lane Keeping Assist (LKA)	LKA provides steering support to prevent the vehicle from departing the lane. Some systems also assist to keep the vehicle centred within the lane.
Underload	Where the driver is paying less attention to the driving tasks/their surroundings or putting less effort into monitoring the vehicle.
Misuse	Misuse is the inappropriate use of ADAS technologies, for example, drivers engaging in NDRTs whilst ADAS is engaged, rather than monitoring the vehicle.
Disuse	Disuse is where drivers the reject, or do not use, the ADAS technologies available.
NDRTs - Non-Driving Related Tasks.	These are tasks that a driver might do that are not directly related to driving the vehicle. For example, using a mobile phone.
Mental workload	Mental workload is the amount of mental demand required to operate a vehicle that uses ADAS systems.