Ergonomics

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/terg20

Automation complacency on the road

Yueying Chu & Peng Liu

To cite this article: Yueying Chu & Peng Liu (2023): Automation complacency on the road, Ergonomics, DOI: 10.1080/00140139.2023.2210793

To link to this article: https://doi.org/10.1080/00140139.2023.2210793

ERGONOMICS
https://doi.org/10.1080/00140139.2023.2210793

Taylor & Francis
Taylor & Francis Group

Automation complacency on the road

Yueying Chu and Peng Liu

Center for Psychological Sciences, Zhejiang University, Hangzhou, PR China

ABSTRACT

Given that automation complacency, a hitherto controversial concept, is already used to blame and punish human drivers in current accident investigations and courts, it is essential to map complacency research in driving automation and determine whether current research can support its legitimate usage in these practical fields. Here, we reviewed its *status quo* in the domain and conducted a thematic analysis. We then discussed five fundamental challenges that might undermine its scientific legitimation: conceptual confusion exists in whether it is an individual versus systems problem; uncertainties exist in current evidence of complacency; valid measures specific to complacency are lacking; short-term laboratory experiments cannot address the long-term nature of complacency and thus their findings may lack external validity; and no effective interventions directly target complacency prevention. The Human Factors/Ergonomics community has a responsibility to minimise its usage and defend human drivers who rely on automation that is far from perfect.

Practitioner summary: Human drivers are accused of complacency and overreliance on driving automation in accident investigations and courts. Our review work shows that current academic research in the driving automation domain cannot support its legitimate usage in these practical fields. Its misuse will create a new form of consumer harms.

ARTICLE HISTORY
Received 26 February 2023
Accepted 2 May 2023

KEYWORDS
Traffic crash; driving automation; complacency; overreliance; responsibility attribution

1. Introduction

Driving automation (or vehicle automation) is becoming prevalent on the road, with the promise of yielding huge safety benefits. However, as described in human-automation interaction (HAI) research (Bainbridge 1983; Endsley 2017b; Hancock 2019; Norman et al. 1990; Parasuraman and Manzey 2010; Strauch 2018), it might create certain pitfalls that could compromise traffic safety. One is notorious automation complacency, which describes that human drivers use imperfect vehicle automation in an uncritical way and that complacent drivers fail to notice automation failures and deal with emergencies that vehicle automation cannot deal with. In the driving automation domain, policy makers and regulators have expressed concerns about automation-induced complacency. For instance, the National Highway Traffic Safety Administration's (NHTSA 2016) *Federal Automated Vehicles Policy* stated that 'manufacturers and other entities should place significant emphasis on assessing the risk of *driver complacency* and misuse of Level 2 systems, and develop effective countermeasures to assist drivers in properly using the system as the manufacturer expects' (p. 32; emphasis added). According to the Society of Automotive Engineers (SAE 2021), Level 2 partial automation (i.e. advanced driver assistance systems) can perform lateral and longitudinal control functions to assist a human driver, and the driver plays as a supervisor. In addition, Level 3 conditional automation (i.e. automated driving systems) performs all aspects of the dynamic driving task, thereby freeing the driver's hands and feet. However, the driver should resume control promptly when requested, acting as a backup driver. Please refer to the SAE J3016 standard (SAE 2021) for information about other automation levels.

Originating in aviation automation, pilot complacency has been claimed as a major contributor to aviation accidents and incidents involving automated aircrafts (Funk et al. 1999; Gawron 2019). In driving automation, driver complacency has also been claimed to be responsible for recent traffic crashes involving Level 2 partial automation and Level 3 conditional automation (NTSB 2021; see Section 3). Particularly, only complacency (and its synonym, overreliance) was repeatedly cited as a causal factor in traffic crash

CONTACT P. Liu pengliu86@zju.edu.cn Center for Psychological Sciences, Zhejiang University, Hangzhou, Zhejiang, PR China

causation analyses (NTSB 2021), although there are many other important concepts (e.g. fatigue, workload, and loss of situation awareness) used to explain poor driver performance under automation and these concepts received more scholarly attention than complacency in the literature (see Heikoop et al. 2016). Even, several human drivers are being required to be held liable for their complacency or overreliance on automation (see Avery 2021; Rosenthal 2022).

Given that complacency has been used to blame and punish human drivers who used imperfect automation, this concept should be carefully inspected. Surprisingly, it is not well-documented in the driving automation domain and lacks common understandings of what exactly it is, how it should be measured and detected, and how it influences driver performance and traffic safety. Although the literature has claimed the risk of complacency when drivers use driving automation and advanced vehicle technologies (e.g. Furlan et al. 2020; Navarro 2019; Papadimitriou et al. 2020; Simões et al. 2019), their claims were largely based on those from aviation automation. In our opinion, it means a gap between research and practice: prior to shared understandings and sufficient scientific evidence of driver complacency in the specific domain, it has been already used to blame and punish human drivers. Therefore, it is essential to theorise complacency through rigorous scientific and empirical research and then to guarantee its legitimate usage in crash investigations and court cases. Otherwise, human drivers might be placed undue responsibilities after crashes, which is a new form of consumer harms.

According to the best of our knowledge, there is no review work specific to complacency and overreliance in this domain. We fill this gap, unify academic research on complacency in driving automation, and determine whether current scientific research can support its legitimate usage in practical fields such as crash investigations. In doing so, Section 2 briefs the history of complacency in the Human Factors/Ergonomics (HFE) field and its enduring controversies, to offer a whole picture for those who are not well familiar with them and particularly for its casual consumers. Then Section 3 introduces complacency as a causal factor in recent traffic crashes involving different automation levels and its emerging debates. Section 4 offers a literature review of complacency in driving automation and classifies the identified works in terms of five themes. Section 5 discusses five fundamental challenges associated with this concept. Overall, we find insufficient scientific evidence of complacency in this domain and suggest minimising its usage and increasing its scientific underpinnings through rigorous scholarly efforts in Section 6.

2. Complacency: a hitherto controversial concept

The concept of complacency originated from the practice field of aviation accident investigations rather than academic research. The NASA Aviation Safety Reporting System (ASRS) defines it as 'self-satisfaction, which may result in non-vigilance based on an unjustified assumption of satisfactory system state' (Billings et al. 1976; cited in Parasuraman, Molloy, and Singh 1993). As automation becomes an important research topic in HFE, the concept of automation complacency (or 'automation-induced complacency' or just 'complacency') was then developed and studied in this scientific field. Parasuraman, Molloy, and Singh (1993) invited participants to perform system monitoring, fuel management, and manual tracking in a multi-task flight simulation testbed, and designed the automation to perform system monitoring with different reliability conditions (variable-reliability vs. constant-reliability). They measured complacency as *participants' not detecting or being slow to detect the automation failures*. They claimed to provide the first empirical evidence of complacency in the human performance literature: participants under constant-reliability automation had poorer performance in detecting automation failures than those under variable-reliability automation (as the former was assumed to induce participants' complacency). The seminal work motivated several replications and similar studies.

Among them, Bagheri and Jamieson (2004) replicated Parasuraman et al.'s experiment and finding, but gave an opposite analysis through eye-tracking data: poorer detection performance under constant-reliability automation was not due to complacency, as their participants under this condition still had more time gazing at the system monitoring performed by the automation than those under variable-reliability automation. However, this opposite explanation received less attention as compared to Parasuraman, Molloy, and Singh (1993), and the latter was often cited in practical fields such as policy reports and crash investigations (e.g. NTSB 2019a).

Moray and Inagaki (Moray 2003; Moray and Inagaki 2000) argued that complacency should be measured independently of its assumed outcomes. According to them, Parasuraman, Molloy, and Singh's (1993) way to measure complacency through performance decrement is defective (see more in Section 5.3). Moray and

Inagaki suggested that complacency could be inferred only if an operator's automation monitoring behaviour is below that of an optimal or normative level. They also pointed out that even optimal monitoring cannot detect all abnormal events in a multi-tasking environment, thus a failure to monitor does not necessarily mean the operator is complacent.

Dekker, Woods, and Hollnagel (Dekker 2015; Dekker and Hollnagel 2004; Dekker and Woods 2002) challenged the scientific legitimation of complacency. They regarded it as a case of folk models which are without strong empirical foundations and scientific status and not fundamentally useful. They criticised them from three aspects: (1) while defining such a concept, researchers substitute it for another high-level concept rather than decomposing it into more measurable specifics; (2) it is immune to falsification and so resists the most important scientific quality check; and (3) it easily gets overgeneralised to situations it was never meant to speak about. Dekker (2015) argued that the term complacency puts the blame squarely on the shoulders of the nearest operators and lamented that the HFE realm has always been on the side of human operators but might harm them by what they come up with (e.g. the usage of the term).

Parasuraman, Sheridan, and Wickens (2008) disputed Dekker, Woods, and Hollnagel's criticisms. Regarding complacency, they argued that 'very high levels of trust in automation that are not perfectly reliable can be associated with overreliance and failure to monitor the 'raw' information sources that provide input to the automated system. This is the *complacency* issue.' (p. 148; emphasis in original). They defended its scientific basis by empirical studies, including their seminal work (Parasuraman, Molloy, and Singh 1993) and its replication by Bagheri and Jamieson (2004). They argued that operators' failure to detect automation failures and insufficient monitoring are empirical evidence of complacency. However, they also admitted this term is 'somewhat unfortunate, in that in everyday parlance, complacency tends to suggest willful and ill-advised neglect, whereas the empirical phenomenon of reduced monitoring does not and, in fact, could be considered a rational strategy' (p. 148). Their arguments were further elaborated in Parasuraman and Manzey's (2010) integrated attention model for complacency and automation bias. In the theoretical model, they linked complacency to attentional bias and summarised three features of complacency: human monitoring is required and involved; human monitoring is a deviation from an optimal level and thus fails to detect automation failures; and it results in a negative consequence in system performance. Our present work will challenge their approach (i.e. deviations in behavioural and performance under automation as compared to non-automation) to measuring or confirming the existence of 'complacency' in Sections 5.2 and 5.3 and their laboratory experiments to probe it in Section 5.4.

Recently this concept is critiqued again (Miranda 2019; Smith 2018). Smith (2018) argued that it is a misleading label because it focuses on human motivation as the cause and leads its casual users to have a shallow understanding of the impact of brittle automation technologies on human performance. Such a label cannot help improve system design. Smith (2018) re-interpreted the influential findings and the attentional model by Parasuraman and colleagues (Parasuraman and Manzey 2010; Parasuraman, Molloy, and Singh 1993) and cautioned against the risks of oversimplification and overgeneralisation of their findings. Smith also proposed other theoretical explanations for so-called evidence of 'complacency' and highlighted that complacency (and its attentional model) as an explanation is not sufficient (see more in Section 5.2). Miranda (2019) re-raised the concerns that complacency is not a scientific concept but a convenient label to blame individuals and that its misuse has hurt human operators in investigations and courts. Similar concerns about the concept of 'human error' can be found in HFE (see Read et al. 2021). Consistent with Dekker (2015), Miranda criticised that the misconception of this concept and other concepts in HFE are detrimental to HFE's core mission of improving human operators' well-being.

Overall, its opponents criticised that it is not a scientific, useful concept but a convenient label or mere blame game that leads to undue responsibility on the nearest operators. Its supporters argued that it is a scientific concept (even when there is no a widely-accepted definition) and that there is sufficient empirical evidence to demonstrate its existence and explanatory power. Certain researchers (Moray 2003; Moray and Inagaki 2000) did not challenge it from the conceptual level but that it should not be measured by its outcomes.

3. Complacency in automation-related traffic crashes

This section examines complacency in recent automated-related traffic crashes. The National Transportation Safety Board (NTSB 2021), USA completed six investigations involving a vehicle being operated by automation at the time of the crash: four related to partial automation (NTSB 2017, 2019c, 2020a, 2020b) and two related to developmental automated driving systems (NTSB 2019a, 2019b). Surprisingly, the vehicle drivers were blamed for complacency and its synonym (i.e. overreliance) in five out of the six investigations (see Figure 1). In the exceptional investigation involving a developmental automated shuttle (NTSB 2019b), its attendant was not assigned the role of vehicle driver or operator and thus did not get accused of complacency and overreliance on automation; however, the NTSB concluded 'the attendant's not being in a position to take manual control of the vehicle in an emergency' as a potential contributor to the collision.

We take a close look into the 2018 Uber crash (NTSB 2019a), which caused the first pedestrian fatality in automated vehicle (AV) history. On Sunday night in March 2018, a pedestrian was pushing her bicycle across the road without a crosswalk in Tempe, Arizona. The Uber's automated driving system detected her 5.6 s before the collision, but identified her as a vehicle, an unknown object, and a bicyclist, switched its assessments several times, thus delivered no alert until 0.2 s to impact. The Uber operator grabbed the wheel and wrested the vehicle into manual mode. But it was too late. The accident investigation body (NTSB 2019a) completed the investigation and concluded that the vehicle operator had 'prolonged visual distraction, a typical effect of *automation complacency*,' which 'led to her failure to detect the pedestrian in time to avoid the collision' (NTSB 2019a, p. vii; emphasis added). The vehicle operator had worked for Uber as a test operator for nine months. Before the collision, she had monitored the test for 39 mins and was asked to take over the vehicle just one time, for a few seconds. Uber disabled the vehicle's original safety features (i.e. forward collision warning and automatic emergency braking) to test its automated driving system, thus completely

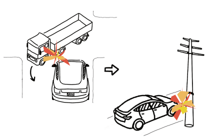
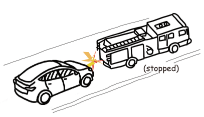
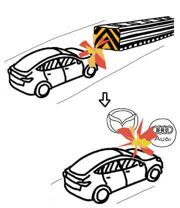
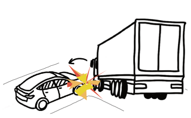
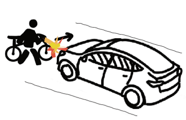
Crash	Probable causes
	**May 7, 2016 (2015 Tesla Model S; NTSB, 2017)** **Driver:** Inattention due to overreliance on vehicle automation; prolonged disengagement from the driving task; using vehicle automation in ways inconsistent with guidance and warnings from the manufacturer. **Automation (vehicle):** Operational design permitted the driver's inappropriate behaviour. **Other road user (truck driver):** Failure to yield the right of way to the car.
	**January 22, 2018 (2014 Tesla Model S; NTSB, 2019c)** **Driver:** Inattention and overreliance on vehicle automation; disengagement from the driving task; using vehicle automation in ways inconsistent with guidance and warnings from the manufacturer. **Automation (vehicle):** Operational design permitted the driver's inappropriate behaviour.
	**March 23, 2018 (2017 Tesla Model X; NTSB, 2020a)** **Driver:** Overreliance on vehicle automation; complacency and inattention; distraction likely from a cell phone game application. **Automation (vehicle):** Mistakenly steering the vehicle into a highway gore area; ineffective monitoring of driver engagement. **Regulator:** The California Highway Patrol's failure to report the damage of the crash attenuator after a previous crash; systemic problems with the California Department of Transportation's maintenance division in repairing traffic safety hardware in a timely manner. **Environment:** A damaged crash attenuator.
	**March 1, 2019 (2018 Tesla Model 3; NTSB, 2020b)** **Driver:** Inattention due to overreliance on vehicle automation; failure to react to the presence of the truck. **Automation (vehicle):** Operational design permitted the driver's inappropriate behaviour. **Manufacturer:** Failure to limit the use of the system to the conditions for which it was designed. **Regulator:** The National Highway Traffic Safety Administration's failure to develop a method of verifying manufacturers' incorporation of acceptable system safeguards for vehicles with Level 2 automation capabilities that limit the use of automated vehicle control systems to the designed conditions. **Other road user (truck driver):** Failure to yield the right of way to the car.
	**March 18, 2018 (Uber's developmental AV; NTSB, 2019a)** **Operator:** Automation complacency; failure to monitor the driving environment and the operation of the automated driving system because of the visual distraction. **Automation (vehicle):** The automated driving system did not accurately classify the pedestrian or predict her path; forward collision warning system and automatic emergency braking system in the Volvo advanced driver assistance systems were not active. **Manufacturer:** The Uber Advanced Technologies Group's inadequate safety risk assessment procedures, ineffective oversight of vehicle operators, and lack of adequate mechanisms for addressing operators' automation complacency. **Regulator:** The Arizona Department of Transportation's insufficient oversight of automated vehicle testing. **Other road user (pedestrian):** Crossing the avenue outside a crosswalk.

Figure 1. Sketches and probable causes related to vehicle driver/operator in five crashes.

relying on its operator to intervene. The NTSB (2019a) concluded that Uber 'did not adequately recognize the risk of *automation complacency* and develop effective countermeasures to control the risk of vehicle operator disengagement, which contributed to the crash' (p. vii; emphasis added).

Complacency with its synonym has been placed at the heart of accident investigations. It is no longer a theoretical explanation for understanding why reliable and high (but still imperfect) automation hurts human performance in academic research. It represents a legal duty of care, the deontological commitment expected of human drivers whose behaviours can influence the lives of other road users (see Dekker 2015). In the Uber case, the vehicle operator—and only her—was charged with negligent homicide with a dangerous instrument in the first trial in September 2020. Uber did not face any liability (McFarland 2020). The operator is awaiting the second trial which has been postponed several times, at the time of our writing. Also, a Tesla driver in the USA was charged with vehicular manslaughter for relying on Autopilot (Level 2 partial automation) when he should have taken over (Rosenthal 2022). Tesla's Chief Executive Officer Elon Musk has blamed their users in traffic crashes for their mistaken belief that Autopilot is capable of fully-automated driving and publicly stated that driver complacency is the issue when they get too used to it (Levin and Beene 2018). These criminal prosecutions raised strong controversies and debates (Zhai et al. 2023). One is whether human drivers should be held culpable for their 'complacency' or 'overreliance' (see Avery 2021; Rosenthal 2022), and if so, it signals that there would be more criminal charges against human drivers who rely on driving automation. It will raise moral and legal concerns.

Of note, the above concerns would be lessened in crashes involving higher automation levels. Under Level 4 high automation, human intervention is not needed as the automated driving system can achieve a minimal risk condition. Under Level 5 full automation, the automated driving system is the sole 'driver' and thus the human acts as a mere passenger. The automated driving system under these two levels takes more operational responsibility and controllability. It implies that the current driver-centric liability system would need a fundamental shift. Normative legal and ethical analyses (e.g. Hevelke and Nida-Rümelin 2015; Marchant and Bazzi 2020; Vladeck 2014) argue that legal responsibility will likely shift from humans to manufacturers if humans do not present any illegal behaviours (e.g. hacking or other improper intervention). Human drivers might not be blamed for 'complacency' in crashes involving Level 4 or Level 5 automation. Our current focus is on the complacency issue under lower automation.

4. Complacency in the driving automation domain: a literature review

4.1. The scoping procedure

We followed the general procedure for conducting a systematic literature review, more specifically, a topic review (Okoli 2019). In the academic literature (Seppelt and Victor 2016) and investigation reports (see Section 3), complacency and overreliance are often used interchangeably. The focus of our topic review was on the concepts of complacency and overreliance in the driving automation domain. The publication search was conducted online via Web of Science and Scopus with three steps (see Figure 2). In its first step, we considered complacency and overreliance and applied the following list of terms for searching: '((autonomous OR automated OR self-driving OR driverless OR smart OR intelligent OR unmanned OR automation) AND (car OR vehicle OR driving) AND (complacency OR overreliance OR over-reliance))' and searched 128 publications, excluding duplicates, for further screening.

In the screening step, done by another researcher, all publications were read and screened by the criterion that the publication should be informative for understanding these concepts. We considered academic works written in English and were accessible in full text (journal papers, conference papers, books, and book chapters). Workshops, patents, or similar were excluded. Among the 128 publications, 67 were unrelated to driving/vehicle automation or drivers; 27 only mentioned these concepts and usually argued them as negative aspects in HAI but did not contribute specific information; in four publications, these concepts only appeared in their reference lists; two publications were not written in English; two publications were patents; and the full papers of three publications were unavailable. Thus, we left 23 publications. Another researcher re-checked this whole process.

We also checked the reference list of these publications and applied Google Scholar (for instance, using the terms of vehicle automation and complacency) for more relevant publications. This snowball search added 14 publications. Finally, we have 37 publications including 32 journal papers, four conference papers, and one book chapter. To guarantee the reproducibility of our literature review, we make its process and

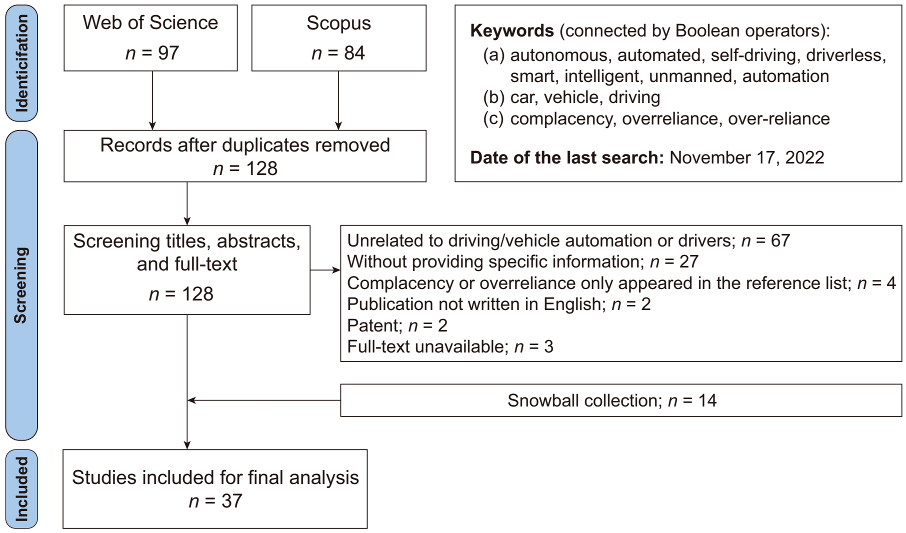


Figure 2. The literature scoping procedure.

result publicly available at https://osf.io/pdgk9/?view_only=14a5ce614d2c4b44bb14606529604e33.

4.2. Results

We read each publication and conducted a thematic clustering and description of their contents relevant to complacency and overreliance (see Figure 3). The analysis was initially conducted by one researcher and its results were checked by another researcher. The consensus was reached finally. Overall, complacency (and its synonym, overreliance) was not a focal concept in driving automation research. The key challenges of complacency research in the growing driving automation domain will be presented in Section 5.

4.2.1. Theme 1: Conceptual analysis ($n = 8$)

Among the eight studies under Theme 1, they can be classified into two types, according to the level of specificity in their conceptual analysis. Two works (Inagaki and Itoh 2013; Ward 2000) focussed on complacency/overreliance and offered detailed conceptual analysis. Other identified works (Baumann, Krems, and Heinrich 2022; Dixon 2020; Gouraud, Delorme, and Berberian 2017; Hoc, Young, and Blosseville 2009; Kunze et al. 2019; Yamani and Horrey 2018) are not specific to them and offer general (and sometimes, limited) conceptual analysis. Next, we review their focal points and core assumptions about the relationship between complacency/overreliance, driver performance, and other key concepts in HAI. Overall, there is no articulated model and theoretical underpinnings for them, in comparison to other important concepts such as situation awareness (see Salmon, Stanton, and Young 2012).

Several conceptual works (Dixon 2020; Kunze et al. 2019; Yamani and Horrey 2018) mainly adopted the insights from Parasuraman, Manzey, Wickens and colleagues who built their understandings of complacency based on the aviation industry or tasks in aviation (Parasuraman and Manzey 2010; Parasuraman, Molloy, and Singh 1993; Wickens et al. 2015). Thus, they usually agreed that complacency occurs when drivers' monitoring behaviour (or attention allocated to the monitoring) becomes suboptimal or below the standard level and then leads to detection failures. They also supported that complacent behaviour is influenced by trust and promoted by the high reliability of the automation system or concurrent task demands (Kunze et al. 2019; Yamani and Horrey 2018). They believed that complacency can be probed by measuring actual (objective) system performance and perceived (subjective) system performance, or by measuring actual attention allocation and required/optimal attention allocation.

Baumann, Krems, and Heinrich (2022) agreed with Endsley (1996) that 'overreliance on automation or complacency are the primary causes for vigilance-related impairments of situation awareness' and 'that complacency and overreliance reduce the operators' efforts for vigilant monitoring and for continuously updating the situation model' (p. 19). They defined complacency as an attitude towards automation and argued that the impairment of situation awareness due to complacency is motivational in nature. But, they also admitted that there is little empirical evidence supporting the assumed causal

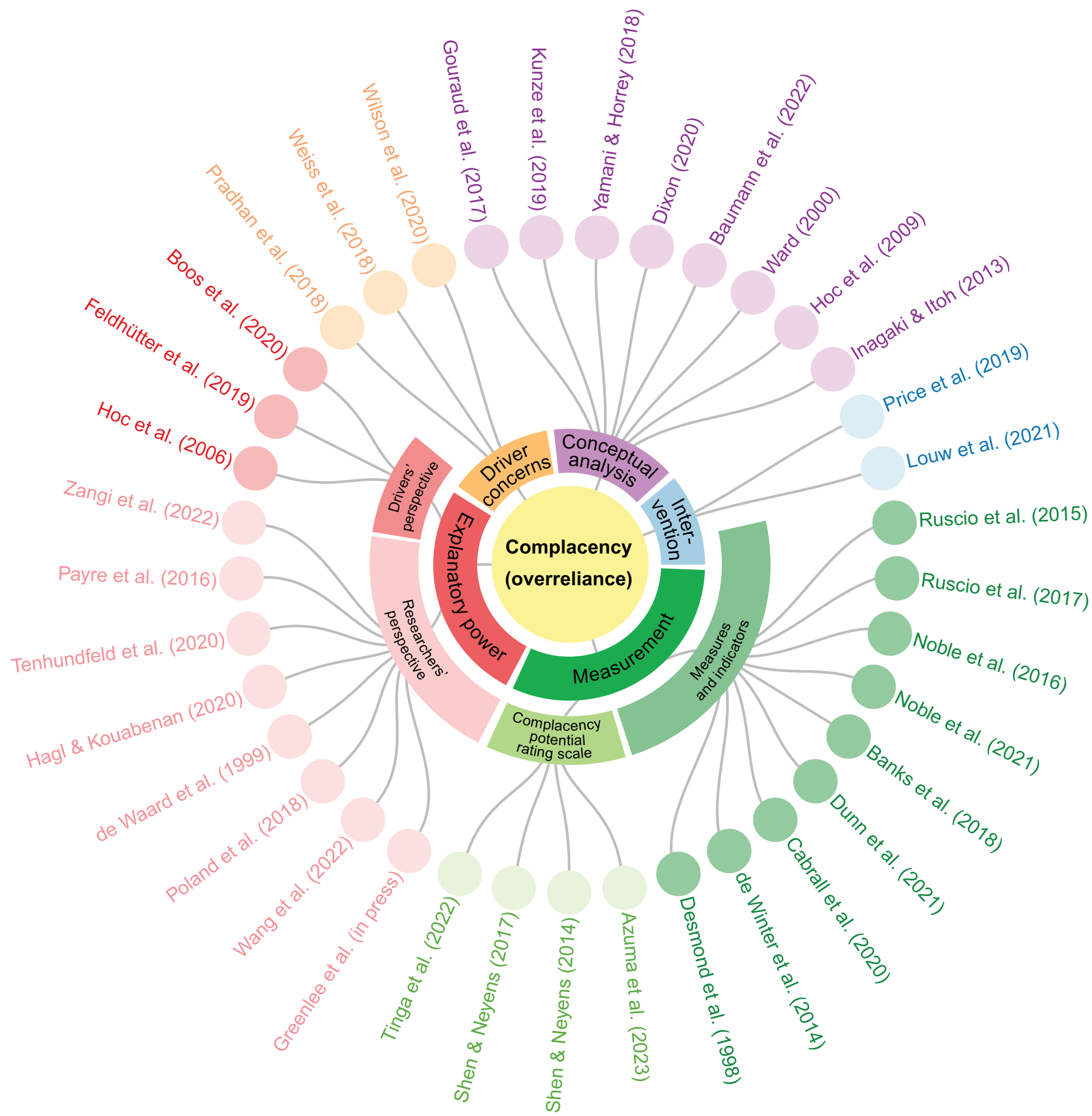


Figure 3. Classification of the included publications by themes.

relationship between complacency and situation awareness, as complacency is not measured directly in the literature.

Other works offered somewhat different views. Ward (2000) proposed a conceptual framework for describing the possible deleterious effects of automated technology in intelligent transportation systems. Ward proposed that automation can damage driver performance through different paths. One path is to make drivers place too much trust in automation and then foster complacency, which then reduces drivers' perceived risk and adjusts their behaviours towards a riskier style; that is, complacency is a mediator between automation and risk compensation. The other path is to simplify driving tasks and decrease arousal or to produce the 'out-of-loop' effect through poor feedback, deskilling, and passive engagement, which then leads to attention fault and vigilance decrement and finally loss of situation awareness. Ward's theoretical model is not empirically examined.

Gouraud, Delorme, and Berberian (2017) described that 'overreliance or complacency is created by an uncritical reliance on the system leading to thinking of it as more competent than it actually is' (p. 3) and expressed several relevant viewpoints. First, similar to Ward (2000), Gouraud et al. thought that automation might influence human performance through different mechanisms, complacency or vigilance decrement. Second, they discussed the potential associations between complacency and mind wandering (i.e. human mind's propensity to generate thoughts unrelated to the task at hand): complacency might lead operators to free cognitive resources and reallocate them to unrelated thoughts and thus produce mind wandering, or mind wandering might also occur prior to complacency and modify its emergency.

Hoc, Young, and Blosseville (2009) described complacency as 'a decrease in human operator performance in failure detection' (p. 140). Beyond this behavioural definition, Hoc et al. argued that complacency can manifest as three successive levels of negligence in terms of cognitive and cooperative activities: the drivers might neglect the information necessary to perform the automated function, neglect the supervision of the automation, and omit to improve the automation performance by some complementary action.

Inagaki and Itoh (2013) rejected the term complacency, because they thought that the term is often used to express a phenomenon that the operator does not monitor the automation, and however that a failure to monitor the automation does not necessarily mean the operator is complacent (Moray and Inagaki 2000). Inagaki and Itoh proposed a theoretical model to describe, analyse, and evaluate the drivers' overreliance on and overtrust in advanced driver assistance systems (ADAS). They described both as psychological states but differentiated them: 'overtrust is an incorrect situation diagnostic decision claiming that the object is trustworthy when it actually is not' (p. 2) and 'overreliance is an incorrect action selection decision based on an incorrect situation diagnostic decision regarding the ADAS (i.e. the overtrust in it)' (p. 3). Thus, they suggested that overtrust and overreliance occur in different decision stages (situation diagnosis vs. action selection). They gave certain behavioural examples of overtrust and overreliance, and an overreliance example is that when the deceleration of the lead vehicle is larger than what the adaptive cruise control (ACC) can manage, if the driver does not apply the brake, the driver is regarded to have an overreliance on ACC.

4.2.2. Theme 2: measurement ($n = 13$)

Publications under this theme were further classified into two sub-themes (eight for Theme 2.1 and three for Theme 2.2).

4.2.2.1. Theme 2.1: measures and indicators for complacency and overreliance. Complacency has been defined as a mental state or psychological state (Billings et al. 1976) or attitude (Baumann, Krems, and Heinrich 2022). Thus, it is not something that we can see, but something we infer from what we see. As certain researchers believe that complacency leads to certain deviations in operators' behaviours and performance in automated driving (manual driving as a reference), they usually use these deviations to measure or indicate complacency. Table 1 summarises the relevant eight studies (Banks et al. 2018; Cabrall et al. 2020; de Winter et al. 2014; Desmond, Hancock, and Monette 1998; Dunn et al. 2021; Noble, Dingus, and Doerzaph 2016; Noble et al. 2021; Ruscio, Bos, and Ciceri 2017; Ruscio, Ciceri, and Biassoni 2015), involved vehicle automation technologies, and specific measures and indicators. These studies collectively reported that vehicle automation (from a specific driver assistance system, partial automation, to an automated driving system) can induce drivers' complacency and encourage drivers to take more risks on roads, which may negate its safety benefits (see Banks et al. 2018; Dunn et al. 2021).

Performance-based measures and indicators refer to performance failures in specific driving activities. For instance, Ruscio, Bos, and Ciceri (2017, Ruscio, Ciceri, and Biassoni 2015) examined the influence of a collision warning system on driver behaviours and performance and suggested the following performance measure for complacency: drivers' failing to press the brake required at the appearance of the unexpected obstacle. Behavioural measures and indicators usually refer to (visually) distracted behaviours, such as reduced visual allocation to driving tasks and increased engagement in non-driving related tasks and drowsiness. For instance, Noble and colleagues interpreted the behaviours of 'eyes off road metrics and secondary task engagement' (Noble et al. 2021) and 'reduced visual scanning' (Noble, Dingus, and Doerzaph 2016) as exemplars of complacent behaviours. In addition, Desmond, Hancock, and Monette (1998) proposed specific subjective measures for driver complacency. They asked drivers to have two drives (manual and automated drives, each lasting for 40 mins) and experienced different perturbing events. After the two drives, driver participants become fatigued and their self-reported task motivation and active coping scores were lowered. The authors then explained that 'the decrement in task motivation and active coping following both drives may be indicative of complacency problems in fatigued drivers' (p. 12).

Overall, there are divergent opinions about the measures and indicators for complacency and overreliance in the literature. We take de Winter et al. (2014) study as an example to discuss it. de Winter et al. (2014) reviewed the effects of ACC and highly automated driving (HAD) on drivers and concluded that certain studies offered evidence of complacent behaviours evoked by ACC and HAD. Such 'complacent behaviours' include drivers do not disengage the HAD system when the vehicle drives above the speed limit

Table 1. A summary of eight studies under Theme 2.1.

Study	Vehicle automation	Measures and indicators
Ruscio, Bos, and Ciceri (2017), Ruscio, Ciceri, and Biassoni (2015)	Collision warning system	Failing to press the brake required at the appearance of the unexpected obstacle
Noble, Dingus, and Doerzaph (2016)	In-vehicle adaptive stop display	Reduced visual scanning
Noble et al. (2021)	Partial automation: driver assistance system	Reduced environmental monitoring (i.e. eyes off road metrics) and increased secondary task engagement
Banks et al. (2018)	Partial automation (i.e. Tesla's Autopilot)	Distracted behaviours (cited in Tenhundfeld et al. 2020)
de Winter et al. (2014)	ACC and HAD	Summarised automation-induced 'complacent behaviours': drivers do not disengage the HAD system when the vehicle drives above the speed limit, do not intervene when required, or have later responses to specified driving stimuli
Desmond, Hancock, and Monette (1998)	Automated driving system	Subjective measures: decrement in task motivation and active coping following both manual and automated drives
Dunn et al. (2021)	Partial automation	Distraction-related behaviours (i.e. secondary task engagement, eye-glance behaviour, and drowsiness)
Cabrall et al. (2020)	Driver monitoring system as a backup under partial automation	Visual distraction

(Merat and Jamson 2009), do not intervene when required (Damböck et al. 2013), or have later responses to specified driving stimuli (Merat and Jamson 2009; Vollrath, Schleicher, and Gelau 2011). However, these studies cited by de Winter et al. (2014) themselves did not link their findings with complacency and overreliance and thus were not identified in our literature scoping process. For instance, regarding their finding of drivers' later responses to critical situations under automated driving (i.e. approaching curves with speed limits or entering fog, which requires manual intervention), Vollrath, Schleicher, and Gelau (2011) admitted that it is hard to determine how this finding comes about, which may either be due to reduced attention under automated driving or simply because of having to shift from automatic to manual control.

4.2.2.2. Theme 2.2: complacency potential rating scale. Certain HAI studies considered individual differences in accepting and relying on automation and developed certain subjective rating scales for measuring people's propensity to monitor and use automation sub-optimally, including the Complacency-Potential Rating Scale (Singh, Molloy, and Parasuraman 1993) and then Automation Induced Complacency Potential-Revised scale (Merritt et al. 2019). Complacency potential measured by these scales is usually taken as a predictor of risky behaviours when people interact with automation. These scales have been used in the driving automation domain (Azuma et al. 2023; Shen and Neyens 2014, 2017; Tinga et al. 2022). As this theme is not our current focus, we do not elaborate on relevant studies.

4.2.3. Theme 3: explanatory power ($n = 11$)

As explained earlier, regarding drivers' behavioural and performance deviations in automated driving from manual driving, certain researchers used them to measure or indicate driver complacency (see Section 4.2.2), whereas others used complacency/overreliance (but without measuring it) to explain them and thus endowed complacency explanatory or causal power. We discuss it from the researchers' perspective (i.e. researchers use complacency or overreliance as an explanation) and drivers' perspective (i.e. drivers' self-explanations about why they fail or perform unwanted behaviours in automated driving are extracted as their complacency or overreliance on vehicle automation).

4.2.3.1. Theme 3.1: researchers' perspective. Eight studies were clustered under this theme (see Table 2). Researchers did not measure complacency/overreliance but implicitly took it as a theory or causal agent to explain their observed negative human sides of vehicle automation. Six studies (de Waard et al. 1999; Greenlee et al. in press; Payre, Cestac, and Delhomme 2016; Poland et al. 2018; Wang et al. 2022; Zangi et al. 2022) reported drivers' objective and subjective differences between automated and manual driving. Hagl and Kouabenan (2020) used complacency to explain a lower traffic-risk perception with ADAS users (vs. non-ADAS users). Tenhundfeld et al. (2020) used low complacency to explain why first-time users, who experienced the automated parking assist in multiple trials, had a higher intervention rate in their first trial versus the last trial.

Among them, certain studies expressed an uncertain attitude towards their theoretical inference, as they meanwhile suspected the possibility of other explanations (de Waard et al. 1999; Greenlee et al. in press; Hagl and Kouabenan 2020). de Waard et al. (1999) found that most drivers using an automated highway system (AHS) did not react or responded fairly late to a surprising situation (i.e. the AHS failed to detect a car

Table 2. A summary of eight studies under Theme 3.1.

Study	Vehicle automation	Explained behaviours and performance
de Waard et al. (1999)	Automated highway system (AHS)	Did not react or responded fairly late to the AHS failure in dealing with a surprised situation
Payre, Cestac, and Delhomme (2016)	Fully automated driving (similar to Level 3 automation)	Longer reaction time in manual control recovery in an emergency for drivers who had high trust in the fully automated driving
Poland et al. (2018)	Tesla's Autopilot	Driver's inattention in a fatal crash
Hagl and Kouabenan (2020)	ADAS	Lower traffic-risk perception with ADAS users (vs. non-ADAS users)
Wang et al. (2022)	In-vehicle intelligent agents	Lower situation awareness when advised by conversational agents (vs. informative agents)
Zangi et al. (2022)	Partial automation	Reductions in visual allocation to driving tasks and increases in engagement in non-driving related tasks
Greenlee et al. (in press)	Partial automation	Reductions in hazard detection performance
Tenhundfeld et al. (2020)	Automated parking assist (Autopark)	First-time users of the Autopark showed a very high intervention rate, a result of their low complacency

that merged extremely close). They explained their finding through both automation-induced complacency and loss of situation awareness. In Greenlee et al. (in press), participants experienced the manual or automated driving conditions and were required to report hazards (a vehicle stopped unsafely and intruded some spaces of the participants' vehicle). Greenlee et al. noted the non-significant differences in hazard detection performance and self-reported workload/stress between the two conditions. But performance decrement was more severe under automated driving versus manual driving. They discussed that automation complacency might account for performance decrement under automated driving, but it cannot account for similar but less severe performance decrement under manual driving. Thus they suggested that 'future research will be needed to determine the reasons for this (performance) decrement in automated vehicles' (p. 13).

4.2.3.2. Theme 3.2: drivers' perspective. Participants in three studies (Boos et al. 2020; Feldhütter et al. 2018; Hoc et al. 2006) were surveyed after their experiments and asked to self-explain why they performed unwanted behaviours while using vehicle automation. Researchers' coding their post-hoc explanations yielded 'causal' human factors, including complacency and overreliance.

Hoc et al. (2006) examined the effect of the automation responsible for lateral control and found its created difficulties in returning to manual control when it was invalid. The authors analysed verbal report contents in relation to human-automation cooperation and reported that 4% of the contents were related to complacency ('Personally, I get used to do nothing … '). A research group (Boos et al. 2020; Feldhütter et al. 2018) examined the interactions between drivers and vehicle automation (Level 2 partial automation and Level 3 conditional automation) and the mode error and awareness associated with the changes in automation levels. Boos et al. (2020) participants' explanations for neglecting the monitoring task under Level 2 were classified into three categories: (1) overreliance (e.g. 'I became more and more trustful with increasing time during which the system worked flawlessly'); (2) non-driving-related activities (NDRA) used as activation (e.g. 'I engaged in an NDRA because I wanted to avoid getting too tired'); (3) NDRA preferred over monitoring (e.g. 'It was too tempting to engage in an NDRA'). In Feldhütter et al. (2018), an ordinary quiz game (a single choice question with four options) was placed in front of the central information display, as a measure of NDRA. Feldhütter et al. summarised the reasons stated as to why participants played the quiz game rather than monitoring partial automation: reliance on the system, uncertainty concerning the automation mode, and boredom due to the passive monitoring task. Therefore, beyond complacency and overreliance, there are other explanations for driver participants' sub-optimal behaviours and performance under automated driving.

4.2.4. Theme 4: driver concerns ($n = 3$)

Real driver users express their concerns about partial automation or ADAS, and some of their concerns are related to complacency (Wilson et al. 2020) and overreliance (Pradhan et al. 2018; Weiss et al. 2018). For instance, Wilson et al. (2020) recruited drivers to drive a vehicle with partial automation on a highway. They noted several issues during their driving, such as mode confusion. In their post-hoc interview, the authors argued that certain risks expressed by the drivers are a result of overtrust and complacency. For instance, some participants reported that they 'switched off' while using the partial automation technology. Drivers' relevant concerns were not strong and they overall expressed positive attitudes towards Level 2 partial automation.

4.2.5. Theme 5: intervention ($n = 2$)

Few studies mentioned certain general measures to prevent complacency or mitigate its impacts. Louw et al. (2021) suggested (but did not validate) that 'drivers should receive explicit training about the potential effects that automation use may have on their manual driving, so that they do not become complacent' (p. 680). Price et al. (2019) examined the influence of the instructions indicating the primary responsible party (the automation or the driver) and found that drivers who were told that they are primarily responsible for vehicle control looked at the road more. Thus, perceived responsibility might prevent complacency.

5. Key challenges

Section 4 provides a systematic review of the *status quo* regarding complacency and overreliance in driving automation. In what follows, we critically assessed extant research, appraised scientific debates and knowledge gaps, and identified several key challenges within the field.

5.1. Conceptual challenge: the individual versus systems distinction

In the literature, complacency has been regarded as a personal trait (Campbell and Bagshaw 1991), a motivation factor (Baumann, Krems, and Heinrich 2022), a process or an intermediate variable such as a 'mental state' (Billings et al. 1976) and 'psychological state' (Wiener 1981), or a human performance phenomenon or issue (Mouloua et al. 2019). It lacks consensus over what really it is (Goddard, Roudsari, and Wyatt 2012). When the same term is used to describe different things and/or in different ways, its utility as a scientific concept is limited (Makov et al. 2023). Developing a shared understanding is a big challenge. But researchers should at least make it clear whether complacency is an individual or systems problem. This conceptual distinction is critical in practice, as it will not only affect how it is prevented and addressed on the road, but also determine how involved human drivers should take causal and legal responsibilities in the event of a crash. HFE has other similar debates between the individual and systems perspectives on certain key concepts including 'human error' (see Read et al. 2021; Woods et al. 2010) and 'loss of situation awareness' (see Salmon, Walker, and Stanton 2015).

Certain definitions or statements of complacency within aviation and road transport and beyond make it appear to be an individual problem. The Merriam-Webster dictionary defines complacency as 'self-satisfaction especially when accompanied by unawareness of actual dangers or deficiencies' (Merriam-Webster 2022), and a very similar definition can be found in aviation (see Section 2). Wickens et al. (2015) described it as a phenomenon 'associated simply with the failure to be vigilant in supervising automation prior to the automation failure' (p. 960). In the driving automation literature, researchers expressed similar arguments (see Section 4.2.1). For instance, Baumann, Krems, and Heinrich (2022) defined complacency as an attitude towards automation and described its influence on situation awareness with a motivational nature. Thus, these definitions used in everyday parlance, academic studies, and practical fields position individuals as the origin of risk. They tend to fixate on a human state, capability, motivation, or attitude as the causal factor.

However, the above perspective is challenged. Stanton and Young (2000) argued that it is unclear whether complacency is situationally induced or an individual difference variable. Furthermore, Parasuraman and Manzey (2010) clearly pointed out that 'complacency and automation bias, although affected by individual differences, cannot be considered as just another type of human error but constitute phenomena that result from a complex interaction of personal, situational, and automation-related characteristics' (p. 403). Thus, they held the complacency-as-a-systems-problem perspective (see also Miranda 2019; Smith 2018).

We support the systems perspective (Parasuraman and Manzey 2010). What we mean by the systems perspective is that taking a deep dive into complacency-related crashes will show that these crashes are attributed to multiple contributing factors, not just the nearest operators. It is consistent with the systems thinking in HFE (Read et al. 2021), which suggests that outcomes (e.g. behaviours and accidents) in complex sociotechnical systems emerge from the interactions between multiple components (i.e. humans, technologies, organisations, and external environments). Take the 2018 Uber AV crash for a close look (see Section 3). Although the crash was attributed to the Uber operator's distraction and complacency, there were underlying automation flaws (e.g. the automated driving system failed to detect the pedestrian timely) and organisational failures (e.g. the Uber disabled the vehicle's original safety features to test the performance of the Uber AV). Blaming human drivers in similar crashes underlies mere several presumptions: they will and can adequately supervise and monitor vehicle automation; they have the capability to regain vehicle control quickly and safely when necessary; and human intervention is the safest option (or at least is not the more dangerous one) if and when the automation malfunctions or encounters challenges on the road (Pearl 2017). These, however, are beyond human capacity or human nature (Shalev 2022). These presumptions would be fallacies or delusions (Emmenegger and Norman 2019; Hancock 2019).

Probably, the real problem is that automation manufacturers and providers fail to commit that complacency would not lead to dangerous situations and consumer harms, or even that the automation is designed to induce 'complacency' (in other words, the human operator is designed to be 'complacent'). This term of 'complacency' (or 'driver complacency' and 'operator complacency') *per se* contains pejorative connotations, puts the blame on the involved individual (Moray and Inagaki 2000; Smith 2018), and thus tempts audiences and casual users to believe it as an individual problem. Its use within and beyond HFE has resulted in untended consequences. Thus, we believe this term *per se* has become a problem in practice.

5.2. Theoretical challenge: the risk of 'uncertainty laundering'

Given current theoretical discussions (see Section 4.2.1), we found that there is no accepted, articulated theory or model of driver complacency about how it is produced, how it is associated with other elements for driver-automation interaction, and how it influences driver performance and traffic safety. For instance, regarding its relationship with trust, different viewpoints exist. One is that complacency is a product of (over)trust (see Borowsky, Zangi, and Oron-Gilad 2022; Cotter et al. 2021; Greenlee et al., in press; Kunze et al. 2019; Payre, Cestac, and Delhomme 2016; Rudin-Brown 2010; Ward 2000; Wickens 2020). However, its opposite viewpoint suggests overtrust as a product of complacency (see Kaber and Endsley 1997). These different viewpoints are not empirically examined yet. Sometimes these terms are also (implicitly) interchangeable (see Papadimitriou et al. 2020; Wulf et al. 2013; Young, Stanton, and Harris 2007).

We do not want to clarify their relationship, but address a more serious theoretical problem. Regarding drivers' behavioural and performance deviations in automated driving as compared to manual driving, they have been used to measure or indicate complacency (Theme 2.1) or explained as the results of complacency (Theme 3.1), in the eyes of complacency researchers (see Figure 4). It reflects the interesting inconsistencies in complacency research in the association between complacency and its behavioural and performance indications. More importantly, it would indicate that complacency research takes their association for granted. However, this mindset should be challenged.

First, taking these behavioural and performance deviations as evidence of complacency may lead to wrong conclusions, because different theoretical inferences may be compatible with the same data (Dekker 2015; Makov et al. 2023; Smith 2018). It has been identified in the driving automation domain but received insufficient attention. For instance, Young and Stanton (2002) observed that 'a handful of experiments have found degraded performance when using vehicle automation, mostly in recovery from automation failure' (p. 365). Regarding their observation, complacency or overreliance has been used as a potential explanation (see de Waard et al. 1999). However, beyond this explanation, Young and Stanton (2002) also summarised other explanations in the literature: expectations about the automation (Nilsson 1995), mobilisation of effort (Desmond, Hancock, and Monette 1998), and mental workload (Stanton, Young, and McCaulder 1997). Recently Greenlee et al. (in press) pointed out that it is currently still unknown what factors (e.g. complacency or general consequences of prolonged monitoring) are responsible for temporal declines in detection performance when drivers are tasked with the monitoring role under automated driving. Also, these behavioural or performance deviations have been referred to as different key concepts in driving research. For instance, visual attention allocated to driving tasks (i.e. redirection of visual attention to non-driving related tasks) has been used to measure or indicate not only complacency (Noble, Dingus, and Doerzaph 2016) and overreliance (Dunn et al. 2021) but also mode awareness (Feldhütter et al. 2018; Forster et al. 2020) and overtrust (Yang et al. 2018). Even when a human driver is fully gazing at driving tasks under automated driving or when the human driver has the same visual allocation behaviours under manual and automated driving, we cannot conclude that the driver is not complacent. This is because visual fixations and attention can be dissociated. The driver may allocate covert attention elsewhere and fail to detect critical events, which refers to the 'inattentional blindness' or 'looking-but-not-seeing' phenomenon (Mack and Rock 1998). Parasuraman and Manzey (2010) explained it, as well as overt redirection of visual attention, as a result of automation complacency. It is an interesting point beyond our current scope. Overall, there are different usage or competing

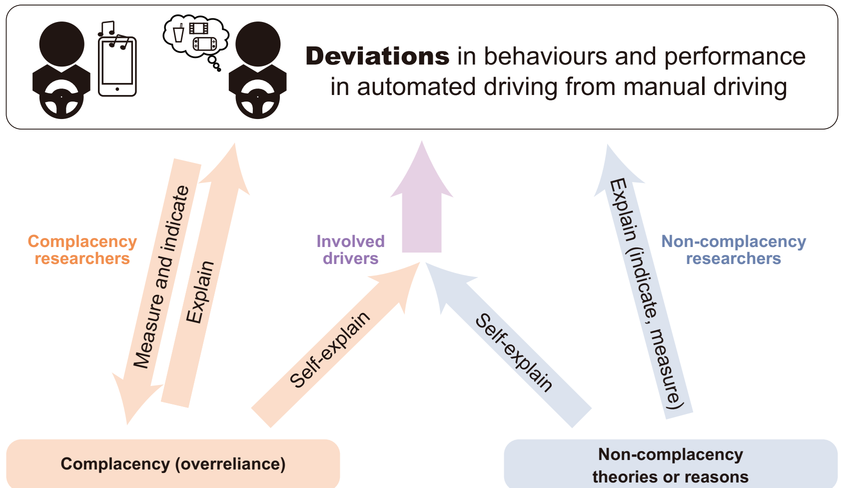


Figure 4. Uncertainties in what explains behavioural and performance deviations in automated driving.

explanations of these behavioural and performance deviations in driving automation research (see Figure 4), largely due to uncertainties in what they really indicate.

Second, the self-explanations from automation users further unfold the uncertainties in what these behavioural and performance deviations map into. For instance, regarding drivers' more engagement in non-driving task activities, researchers (e.g. Dunn et al. 2021; Noble et al. 2021) used complacency (or overreliance) to explain them; however, other researchers (Boos et al. 2020; Feldhütter et al. 2018) after coding the involved drivers' self-explanations found that there are also other reasons for their engagement in non-driving task activities (see Section 4.2.3.2).

It is cognitively unrealistic to expect humans to remain attentive the entire time under automated driving as well as manual driving. Complacency (if it exists) is not necessarily the only causal explanation for drivers' behavioural and performance deviations, regardless of the researchers' ('outside') or drivers' ('inside') perspectives. There are uncertainties in what are the real causes. Given this, using them to measure complacency or taking them as a result of complacency is what we call 'uncertainty laundering.' This issue would threaten the scientific legitimation of this concept and relevant research. It offers a shallow understanding of human performance, with risks of oversimplification and overgeneralisation. It even raises a strong criticism that current evidence of complacency might mean nothing (Dekker 2015): it is a mere retrospective judgement but not an explanation. As Hamlet reminds us, 'ay, there's the rub.'

5.3. Measurement challenge: a lack of valid, specific measures

As explained earlier, the concept complacency originated from the aviation sector and refers to a psychological or mental state such as 'self-satisfaction' and 'low index of suspicion' (Billings et al. 1976; Wiener 1981). This 'hypothetical' state has never been directly measured in aviation and road transport and beyond. Instead, as shown in Section 4.2.2, various behavioural and performance indicators (e.g. increased manual control recovery time, more secondary task engagement, and reduced visual monitoring) were used to measure it or indicate its existence in academic research. In current crash investigations, the 'prolonged visual distraction' behaviour has been regarded as evidence of complacency (NTSB. 2019a). Section 5.2 discusses that complacency is not necessarily the only causal explanation for them from the theoretical perspective. Next, we discuss them from the measurement perspective and challenge the notion that they are valid and effective measures for complacency.

First, as complacency is believed to be causal to these behavioural and performance deviations, it should be measured independently of these assumed outcomes (Bahner, Hüper, and Manzey 2008; Moray and Inagaki 2000). Otherwise, it—using an 'effect' to represent a 'cause'—is unfortunately circular reasoning and muddled thinking (see Dekker 2015; Flach 1995), as shown in Figure 5.

Second, there is lacking objective and usable measures for complacency in driver-automation interaction. Moray and Inagaki (2000) proposed that complacency should be objectively measured as that monitoring or

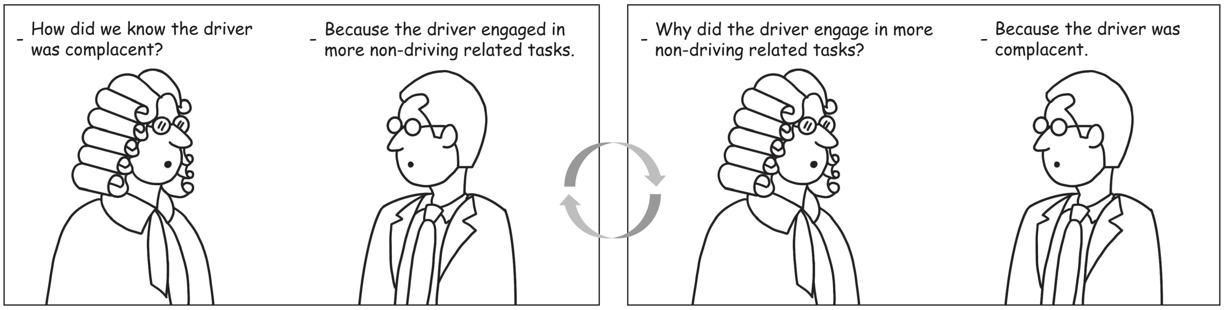


Figure 5. Circular reasoning between complacency and its assumed outcomes.

sampling of automation below the optimal (or standard) level. However, it still has theoretical and practical concerns. The theoretical concern, as explained earlier, the under-sampling behaviour might be due to other factors rather than complacency (see Section 5.2). The practical concern is that it is difficult (if not impossible) to specify its reference (i.e. the optimal sampling behaviour) in advance in real settings such as driving (Parasuraman and Manzey 2010). Further, even a deviation from the optimal sampling behaviour might only describe the degree of *reliance* but cannot be used to label *complacency* or *overreliance* in hindsight (Smith 2018).

The above questions imply the current measurement conundrum for driver complacency. The red-line for judging that a human driver is already complacent prior to the crash occurrence or other negative outcomes, which is required in practical fields such as crash investigations, is uncharted and ambiguous.

5.4. Experimental challenge: short-term laboratory experiments cannot address the long-term nature of complacency

Current empirical evidence pertaining to complacency comes from laboratory experiments with short duration and college students. We next discuss whether laboratory experiments can form complacency in a short timeframe and provide sufficient external validity to confirm and generalise their findings in practice. This issue receives insufficient attention in previous debates.

Researchers and casual users use complacency as reflective of empirical reality: while operators interact with reliable and high automation (but still imperfect), they tend to believe their dependence on automation is warranted, their complacent behaviours then occur, which reduces their likelihood to detect automation failures or leads to their late responses. A long timeframe is needed to develop operators' complacent behaviours naturally. As a reference, Campbell and Bagshaw (1991) stated that 'the higher accident rate for general aviation pilots with between 1000 and 3000 flying hours, compared with those of less flying experience, is often explained by complacency' (p. 156). Thus, the time needed for fostering complacency should be far more than half or one hour, the common timeframe for running a driving experiment (unless there are other non-natural ways to artificially invoke 'complacent' behaviours, such as misleading information).

Complacency has a long-term nature. Unfortunately, current laboratory experiments would not provide enough time for complacency to form (McBride, Rogers, and Fisk 2014) and their validity to test complacency-related theories might not be strong. Caution is warranted in overgeneralising their complacency-related findings in practical fields (Smith 2018). However, current crash investigations (e.g. NTSB. 2019a) mainly rely on the discussions from short-term laboratory experiments with college students (e.g. Parasuraman and Manzey 2010; Parasuraman, Molloy, and Singh 1993).

5.5. Prevention challenge: can we reduce complacency and overreliance?

As complacency (and overreliance) has been considered the critical reason for automated-related crashes occurring in clinical causation analysis, it should be the direct target of crash prevention actions. A close link between a recognised crash cause and its prevention action is essential.

Although previous studies suggested that specific instructions (Price et al. 2019) or training (Louw et al. 2021) might reduce complacency and overreliance, their potency in actual situations would be reduced by many practical factors, such as inaccurate information from salespeople (Endsley 2017a) and improper naming of the vehicle automation system (Abraham et al. 2017; Dixon 2020; Du et al. 2022; Nees 2018; Teoh 2020). As complacency (also overreliance) is difficult to be measured objectively and directly, any detection and mitigation attempts might be ineffective (Drnec et al. 2016). Therefore, even if complacency is recognised as a crash cause, it seems that few effective preventions can be taken to alter it.

Does it mean there is nothing more to do? Here we argue that we do not have to directly target the hypothetical human state or attitude, but to detect relevant observable driver behaviours such as distraction and misuse of vehicle automation (of note, these behaviours might be due to other reasons such as general consequences of prolonged monitoring). That is to say, regardless of which mechanism causes these behaviours, these behaviours should be detected and prevented.

In the 2018 Uber AV crash, there was no system in place to ensure its operator keep the eyes on the road. But that system exists on roads, called the driver monitoring system (DMS), an automated system to monitor human drivers who are required to monitor the driving automation system and the road. DMS is expected to detect unfitted driver states and behaviours such as drowsiness, distraction, and fatigue (Collet and Musicant 2019) and thus mitigate the potential risks of complacency and others. In practice, complacency is taken as a distraction problem by the NTSB (Landsberg 2020), which is expected to be detected by DMS. The regulators and watchdogs require DMS to ensure that the drivers' eyes are directed at the road and their hands are either on the wheel or ready to grab it at all times. When the drivers do not meet these requirements, DMS should send alerts and perform appropriate emergency procedures.

Such requirements over drivers and DMS are appropriate in vehicles with partial automation. However, in vehicles with conditional automation or higher automation, the automated driving system will become the primary responsible party when it is activated (Price et al. 2019). Certain 'complacent behaviours' such as looking at phones and watching movies might become normal, which is what exactly car manufacturers and tech giants in the AV industry promised to make future driving more enjoyable (Deichmann et al. 2023). Thus, there are deeper questions: how these requirements over human drivers and DMS under automated driving should be tailored for this structural change? How safe is safe enough to allow drivers to be 'complacent' in AVs? For these questions, their answers remain completely unclear and deserve further research efforts.

Finally, we want to make it clear that DMS is designed to know certain driver states but not to directly 'read' what are in drivers' mind (e.g. complacency), and thus it is not naturally linked to the business of complacency. Given the notion that if something cannot be changed it is not a cause (Hauer 2020), we might need to re-think whether complacency is a real cause. What is more important is that the vehicle automation designers and manufacturers should make sure that complacency and overreliance would not lead to dangerous situations. Consumers deserve such a commitment. In addition, the manufacturers and dealerships have the responsibility to make the public and consumers aware of the limitations and constraints of the current vehicle automation technologies. They shall design and employ specific self-guided tutorials and training sections prior to drivers' first contact with vehicle automation, in order to calibrate driver trust and prevent potential complacency issues. That said, a systems approach should be adopted for interventions.

6. Conclusions

Complacency (and overreliance) has been defined as operators using and relying on imperfect automation uncritically. We believe it is a real and important issue when operators interact with automation in real settings. We provided an overview of the *status quo* regarding the concept in driving automation. After careful scrutiny, we found its challenges in conceptualisation, theorising, measurement, experiment design, and prevention. This concept is not well defined in driving automation and beyond. This is a clear conflict in whether it is an individual or systems problem. Certain behavioural and performance indicators (e.g. distraction or engagement in secondary tasks) have been used to indicate or measure it; however, these indications are not necessarily due to complacency and they could be the results of other causes. Using complacency to explain them would slip into the risk of 'uncertainty laundering' or oversimplification and overgeneralisation. Valid and objective measurements for complacency are lacking in driving. Concern exists about the realism of current short-term laboratory experiments to form complacency. There is no effective intervention or device directly targeting and preventing complacency. As a corollary, we conclude that current scientific inquiry would not properly support its legitimate usage in investigations, inquests, and court cases.

Using brittle and imperfect vehicle automation makes human drivers be set up to err and then be blamed for automation complacency. It was the only individual factor repeatedly identified in current crash investigations involving different vehicle automation levels. It might be not a coincidence but reflect a hidden but common belief among investigators and researchers: 'To be complacent is human.' However, if there is no consensus about what it is, no clear evidence for confirming its existence and causal power, and no effective device to directly reduce it, can we use this concept—it carries pejorative connotations and puts the blame on automation consumers—to determine drivers' causal and even legal responsibilities in the aftermath of a crash? It is a moral choice amongst crash investigators and HFE researchers. This concept may create new consumer harms.

To reduce potential consumer harms, we argue that it should reduce the temptation to punish and blame drivers for complacency (or overreliance) in research and practice. The term has become a problem *per se*. We suggest that the HFE community has an ethical and moral responsibility to minimise its usage and defend human drivers who buy and use far-from-perfect automation. Of note, this suggestion does not mean to 'throw the baby out with the bathwater.' Researchers need conceptive theoretical debates, strong scientific inquiry, and careful empirical examinations of its causal influence on traffic crashes and its own antecedents, in order to theorise this concept, which is also important for preventing driving automation's safety benefits from being compromised.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work is supported by the National Natural Science Foundation of China [Grant No. T2192932 and 72071143].

ORCID

Yueying Chu http://orcid.org/0009-0007-7757-4554
Peng Liu http://orcid.org/0000-0003-4929-0531

Data availability statement

The procedure of our literature review and its result are publicly available at https://osf.io/pdgk9/?view_only=14a5ce614d2c4b44bb14606529604e33.

References

Abraham, H., B. Seppelt, B. Mehler, and B. Reimer. 2017. "What's in a Name: Vehicle Technology Branding & Consumer Expectations for Automation." In *Proceedings of the 9th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*, September 24–27, 2017, Oldenburg, Germany. doi:10.1145/3122986.3123018.

Avery, J. 2021. "Fumble! Anti-Human Bias in the Wake of Socio-Technical System Failures." *Arizona State Law Journal* 53: 1009–1090.

Azuma, M. C., F. B. Giordano, S. A. Stoffregen, L. S. Klos, and J. Lee. 2023. "It Practically Drives Itself: Autonomous Vehicle Technology, Psychological Attitudes, and Susceptibility to Risky Driving Behaviors." *Ergonomics* 66 (2): 246–260. doi:10.1080/00140139.2022.2076906.

Bagheri, N., and G. A. Jamieson. 2004. "Considering Subjective Trust and Monitoring Behavior in Assessing Automation-Induced "Complacency." In *Human Performance, Situation Awareness and Automation: Current Research and Trends*, edited by D. A. Vincenzi, M. Mouloua, and P. A. Hancock. Mahwah, NJ: Lawrence Erlbaum Associates.

Bahner, J. E., A.-D. Hüper, and D. Manzey. 2008. "Misuse of Automated Decision Aids: Complacency, Automation Bias and the Impact of Training Experience." *International Journal of Human-Computer Studies* 66 (9): 688–699. doi:10.1016/j.ijhcs.2008.06.001.

Bainbridge, L. 1983. "Ironies of Automation." *Automatica* 19 (6): 775–779. doi:10.1016/0005-1098(83)90046-8.

Banks, V. A., A. Eriksson, J. O'Donoghue, and N. A. Stanton. 2018. "Is Partially Automated Driving a Bad Idea? Observations from an On-Road Study." *Applied Ergonomics* 68: 138–145. doi:10.1016/j.apergo.2017.11.010.

Baumann, M., J. Krems, and L. K. Heinrich. 2022. "Automation, Situation Awareness and Mental Workload." In *User Experience Design in the Era of Automated Driving*, edited by A. Riener, M. Jeon, and I. Alvarez. Cham: Springer International Publishing. doi:10.1007/978-3-030-77726-5_1.

Billings, C. E., J. K. Lauber, H. Funkhouser, G. Lyman, and E. W. Huff. 1976. *NASA Aviation Safety Reporting System. TM-X-3445*. Moffett Field, CA: NASA Ames Research Center.

Boos, A., A. Feldhütter, J. Schwiebacher, and K. Bengler. 2020. "Mode Errors and Intentional Violations in Visual Monitoring of Level 2 Driving Automation." In *2020 IEEE 23rd International Conference on Intelligent Transportation Systems (ITSC)*, September 20–23, Rhodes, Greece, 2020. doi:10.1109/ITSC45102.2020.9294690.

Borowsky, A., N. Zangi, and T. Oron-Gilad. 2022. "Interruption Management in the Context of Take-over-Requests in Conditional Driving Automation." *IEEE Transactions on Human-Machine Systems* 52 (5): 1015–1024. doi:10.1109/THMS.2022.3194006.

Cabrall, C. D. D., J. C. J. Stapel, R. Happee, and J. C. F. de Winter. 2020. "Redesigning Today's Driving Automation toward Adaptive Backup Control with Context-Based and Invisible Interfaces." *Human Factors* 62 (2): 211–228. doi:10.1177/0018720819894757.

Campbell, R. D., and M. Bagshaw. 1991. *Human Performance and Limitations in Aviation*. Oxford: Blackwell Science Ltd.

Collet, C., and O. Musicant. 2019. "Associating Vehicles Automation with Drivers Functional State Assessment

Systems: A Challenge for Road Safety in the Future." *Frontiers in Human Neuroscience* 13: 131. doi:10.3389/fnhum.2019.00131.

Cotter, J. E., A. Atchley, B. C. Banz, and N. L. Tenhundfeld. 2021. "Is My User Impaired? Designing Adaptive Automation That Monitors the User's State." In *2021 Systems and Information Engineering Design Symposium (SIEDS)*, April 29–30, 2021, University of Virginia, Virtual Conference. doi:10.1109/SIEDS52267.2021.9483731.

Damböck, D., T. Weißgerber, M. Kienle, and K. Bengler. 2013. "Requirements for Cooperative Vehicle Guidance." In *16th International IEEE Conference on Intelligent Transportation Systems (ITSC 2013)*, October 6–9, 2013, The Hague, Netherlands. doi:10.1109/ITSC.2013.6728467.

de Waard, D., M. van der Hulst, M. Hoedemaeker, and K. A. Brookhuis. 1999. "Driver Behavior in an Emergency Situation in the Automated Highway System." *Transportation Human Factors* 1 (1): 67–82. doi:10.1207/sthf0101_7.

de Winter, J. C. F., R. Happee, M. H. Martens, and N. A. Stanton. 2014. "Effects of Adaptive Cruise Control and Highly Automated Driving on Workload and Situation Awareness: A Review of the Empirical Evidence." *Transportation Research Part F: Traffic Psychology and Behaviour* 27: 196–217. doi:10.1016/j.trf.2014.06.016.

Deichmann, J., E. Ebel, K. Heineke, R. Heuss, M. Kellner, and F. Steiner. 2023. *Autonomous Driving's Future: Convenient and Connected*. McKinsey & Company.

Dekker, S. 2015. *Safety Differently: Human Factors for a New Era*. Boca Raton, FL: CRC Press.

Dekker, S., and E. Hollnagel. 2004. "Human Factors and Folk Models." *Cognition, Technology & Work* 6 (2): 79–86. doi:10.1007/s10111-003-0136-9.

Dekker, S. W. A., and D. D. Woods. 2002. "MABA-MABA or Abracadabra? Progress on Human–Automation Co-Ordination." *Cognition, Technology & Work* 4 (4): 240–244. doi:10.1007/s101110200022.

Desmond, P. A., P. A. Hancock, and J. L. Monette. 1998. "Fatigue and Automation-Induced Impairments in Simulated Driving Performance." *Transportation Research Record: Journal of the Transportation Research Board* 1628 (1): 8–14. doi:10.3141/1628-02.

Dixon, L. 2020. "Autonowashing: The Greenwashing of Vehicle Automation." *Transportation Research Interdisciplinary Perspectives* 5: 100113. doi:10.1016/j.trip.2020.100113.

Drnec, K., A. R. Marathe, J. R. Lukos, and J. S. Metcalfe. 2016. "From Trust in Automation to Decision Neuroscience: Applying Cognitive Neuroscience Methods to Understand and Improve Interaction Decisions Involved in Human Automation Interaction." *Frontiers in Human Neuroscience* 10: 290. doi:10.3389/fnhum.2016.00290.

Du, M., T. Zhang, J. Liu, Z. Xu, and P. Liu. 2022. "Rumors in the Air? Exploring Public Misconceptions about Automated Vehicles." *Transportation Research Part A: Policy and Practice* 156: 237–252. doi:10.1016/j.tra.2022.01.003.

Dunn, N. J., T. A. Dingus, S. Soccolich, and W. J. Horrey. 2021. "Investigating the Impact of Driving Automation Systems on Distracted Driving Behaviors." *Accident; Analysis and Prevention* 156: 106152. doi:10.1016/j.aap.2021.106152.

Emmenegger, C., and D. Norman. 2019. "The Challenges of Automation in the Automobile." *Ergonomics* 62 (4): 512–513. doi:10.1080/00140139.2019.1563336.

Endsley, M. R. 1996. "Automation and Situation Awareness." In *Automation and Human Performance: Theory and Applications*, edited by R. Parasuraman and M. Mouloua. Hillsdale, NJ: Erlbaum.

Endsley, M. R. 2017a. "Autonomous Driving Systems: A Preliminary Naturalistic Study of the Tesla Model S." *Journal of Cognitive Engineering and Decision Making* 11 (3): 225–238. doi:10.1177/1555343417695197.

Endsley, M. R. 2017b. "From Here to Autonomy: Lessons Learned from Human–Automation Research." *Human Factors* 59 (1): 5–27. doi:10.1177/0018720816681350.

Feldhütter, A., N. Härtwig, C. Kurpiers, J. M. Hernandez, and K. Bengler. 2018. "Effect on Mode Awareness When Changing from Conditionally to Partially Automated Driving." In *Proceedings of the 20th Congress of the International Ergonomics Association (IEA 2018)*, August 26–30, 2018, Florence, Italy. doi:10.1007/978-3-319-96074-6_34.

Flach, J. M. 1995. "Situation Awareness: Proceed with Caution." *Human Factors: The Journal of the Human Factors and Ergonomics Society* 37 (1): 149–157. doi:10.1518/001872095779049480.

Forster, Y., V. Geisel, S. Hergeth, F. Naujoks, and A. Keinath. 2020. "Engagement in Non-driving Related Tasks as a Non-intrusive Measure for Mode Awareness: A Simulator Study." *Information* 11 (5): 239. doi:10.3390/info11050239.

Funk, K., B. Lyall, J. Wilson, R. Vint, M. Niemczyk, C. Suroteguh, and G. Owen. 1999. "Flight Deck Automation Issues." *The International Journal of Aviation Psychology* 9 (2): 109–123. doi:10.1207/s15327108ijap0902_2.

Furlan, A. D., T. Kajaks, M. Tiong, M. Lavallière, J. L. Campos, J. Babineau, S. Haghzare, T. Ma, and B. Vrkljan. 2020. "Advanced Vehicle Technologies and Road Safety: A Scoping Review of the Evidence." *Accident; Analysis and Prevention* 147: 105741. doi:10.1016/j.aap.2020.105741.

Gawron, V. 2019. *Automation in Aviation—Accident Analyses. MTR190013*. McLean, VA: MITRE Corporation.

Goddard, K., A. Roudsari, and J. C. Wyatt. 2012. "Automation Bias: A Systematic Review of Frequency, Effect Mediators, and Mitigators." *Journal of the American Medical Informatics Association : JAMIA* 19 (1): 121–127. doi:10.1136/amiajnl-2011-000089.

Gouraud, J., A. Delorme, and B. Berberian. 2017. "Autopilot, Mind Wandering, and the Out of the Loop Performance Problem." *Frontiers in Neuroscience* 11: 541. doi:10.3389/fnins.2017.00541.

Greenlee, E. T., P. R. DeLucia, and D. C. Newton. in press. "Driver Vigilance Decrement is More Severe During Automated Driving Than Manual Driving." *Human Factors: The Journal of the Human Factors and Ergonomics Society*: 001872082211039. doi:10.1177/00187208221103922.

Hagl, M., and D. R. Kouabenan. 2020. "Safe on the Road–Does Advanced Driver-Assistance Systems Use Affect Road Risk Perception?" *Transportation Research Part F: Traffic Psychology and Behaviour* 73: 488–498. doi:10.1016/j.trf.2020.07.011.

Hancock, P. A. 2019. "Some Pitfalls in the Promises of Automated and Autonomous Vehicles." *Ergonomics* 62 (4): 479–495. doi:10.1080/00140139.2018.1498136.

Hauer, E. 2020. "Crash Causation and Prevention." *Accident; Analysis and Prevention* 143: 105528. doi:10.1016/j.aap.2020.105528.

Heikoop, D. D., J. C. F. de Winter, B. van Arem, and N. A. Stanton. 2016. "Psychological Constructs in Driving Automation: A Consensus Model and Critical Comment on Construct Proliferation." *Theoretical Issues in Ergonomics Science* 17 (3): 284–303. doi:10.1080/1463922X.2015.1101507.

Hevelke, A., and J. Nida-Rümelin. 2015. "Responsibility for Crashes of Autonomous Vehicles: An Ethical Analysis." *Science and Engineering Ethics* 21 (3): 619–630. doi:10.1007/s11948-014-9565-5.

Hoc, J.-M., F. Mars, I. Milleville-Pennel, É. Jolly, M. Netto, and J.-M. Blosseville. 2006. "Human-Machine Cooperation in Car Driving for Lateral Safety: Delegation and Mutual Control." *Le Travail Humain* 69 (2): 153–182. doi:10.3917/th.692.0153.

Hoc, J.-M., M. S. Young, and J.-M. Blosseville. 2009. "Cooperation between Drivers and Automation: Implications for Safety." *Theoretical Issues in Ergonomics Science* 10 (2): 135–160. doi:10.1080/14639220802368856.

Inagaki, T., and M. Itoh. 2013. "Human's Overtrust in and Overreliance on Advanced Driver Assistance Systems: A Theoretical Framework." *International Journal of Vehicular Technology* 2013: 1–8. doi:10.1155/2013/951762.

Kaber, D. B., and M. R. Endsley. 1997. "Out-of-the-Loop Performance Problems and the Use of Intermediate Levels of Automation for Improved Control System Functioning and Safety." *Process Safety Progress* 16 (3): 126–131. doi:10.1002/prs.680160304.

Kunze, A., S. J. Summerskill, R. Marshall, and A. J. Filtness. 2019. "Automation Transparency: Implications of Uncertainty Communication for Human-Automation Interaction and Interfaces." *Ergonomics* 62 (3): 345–360. doi:10.1080/00140139.2018.1547842.

Landsberg, B. 2020. "Automation Complacency: Yet Another Distraction Problem." Accessed 11 October 2022. https://safetycompass.wordpress.com/2020/02/10/automation-complacency-yet-another-distraction-problem/

Levin, A., and R. Beene. 2018. "Tesla Model X in California Crash Sped up Prior to Impact." Bloomberg. Accessed 10 October 2020. https://www.bloomberg.com/news/articles/2018-06-07/tesla-model-x-in-california-crash-sped-up-seconds-before-impact

Louw, T., R. Goncalves, G. Torrao, V. Radhakrishnan, W. Lyu, P. Puente Guillen, and N. Merat. 2021. "Do Drivers Change Their Manual Car-Following Behaviour After Automated Car-Following?" *Cognition, Technology & Work* 23 (4): 669–683. doi:10.1007/s10111-020-00658-5.

Mack, A., and I. Rock. 1998. *Inattentional Blindness*. Cambridge, MA: MIT Press.

Makov, S., D. Pinto, P. Har-Shai Yahav, L. M. Miller, and E. Zion Golumbic. 2023. "Unattended, Distracting or Irrelevant": Theoretical Implications of Terminological Choices in Auditory Selective Attention Research." *Cognition* 231: 105313. doi:10.1016/j.cognition.2022.105313.

Marchant, G., and R. Bazzi. 2020. "Autonomous Vehicles and Liability: What Will Juries Do?" *Boston University Journal of Science and Technology Law* 26: 67–119.

McBride, S. E., W. A. Rogers, and A. D. Fisk. 2014. "Understanding Human Management of Automation Errors." *Theoretical Issues in Ergonomics Science* 15 (6): 545–577. doi:10.1080/1463922X.2013.817625.

McFarland, M. 2020. "Uber Self-Driving Car Operator Charged in Pedestrian Death." CNN. Accessed 23 January 2021. https://edition.cnn.com/2020/09/18/cars/uber-vasquez-charged/index.html

Merat, N., and A. H. Jamson. 2009. "How Do Drivers Behave in a Highly Automated Car?." In *Proceeding of the Fifth International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design*, June 22–25, 2009, Montana.

Merriam-Webster 2022. "Complacency." Merriam-Webster Online Dictionary. https://www.merriam-webster.com/dictionary/complacency

Merritt, S. M., A. Ako-Brew, W. J. Bryant, A. Staley, M. McKenna, A. Leone, and L. Shirase. 2019. "Automation-Induced Complacency Potential: Development and Validation of a New Scale." *Frontiers in Psychology* 10: 225–225. doi:10.3389/fpsyg.2019.00225.

Miranda, A. T. 2019. "Misconceptions of Human Factors Concepts." *Theoretical Issues in Ergonomics Science* 20 (1): 73–83. doi:10.1080/1463922X.2018.1497727.

Moray, N. 2003. "Monitoring, Complacency, Scepticism and Eutactic Behaviour." *International Journal of Industrial Ergonomics* 31 (3): 175–178. doi:10.1016/S0169-8141(02)00194-4.

Moray, N., and T. Inagaki. 2000. "Attention and Complacency." *Theoretical Issues in Ergonomics Science* 1 (4): 354–365. doi:10.1080/14639220052399159.

Mouloua, M., J. C. Ferraro, A. D. Kaplan, P. Mangos, and P. A. Hancock. 2019. "Human Factors Issues regarding Automation Trust in UAS Operation, Selection, and Training." In *Human Performance in Automated and Autonomous Systems: Current Theory and Methods*, edited by M. Mouloua and P. A. Hancock. London: CRC Press.

Navarro, J. 2019. "Are Highly Automated Vehicles as Useful as Dishwashers?" *Cogent Psychology* 6 (1): 1575655. doi:10.1080/23311908.2019.1575655.

Nees, M. A. 2018. "Drivers' Perceptions of Functionality Implied by Terms Used to Describe Automation in Vehicles." In *Proceedings of the Human Factors and Ergonomics Society 2018 Annual Meeting*, October 1–5, 2018, Philadelphia, PA. doi:10.1177/1541931218621430.

NHTSA 2016. *Federal Automated Vehicles Policy: Accelerating the Next Revolution in Roadway Safety*. Washington, DC: National Highway Traffic Safety Administration (NHTSA), U.S. Department of Transportation.

Nilsson, L. 1995. "Safety Effects of Adaptive Cruise Control in Critical Traffic Situations." In *Proceedings of the 2nd World Congress on Intelligent Transport Systems*, November 9–11, 1995, Yokohama, Japan.

Noble, A. M., T. A. Dingus, and Z. R. Doerzaph. 2016. "Influence of In-Vehicle Adaptive Stop Display on Driving Behavior and Safety." *IEEE Transactions on Intelligent Transportation Systems* 17 (10): 2767–2776. doi:10.1109/TITS.2016.2523438.

Noble, A. M., M. Miles, M. A. Perez, F. Guo, and S. G. Klauer. 2021. "Evaluating Driver Eye Glance Behavior and Secondary Task Engagement While Using Driving Automation Systems." *Accident; Analysis and Prevention* 151: 105959. doi:10.1016/j.aap.2020.105959.

Norman, D. A., D. E. Broadbent, A. D. Baddeley, and J. Reason. 1990. "The 'Problem' with Automation: Inappropriate Feedback and Interaction, Not 'Over-Automation'." *Philosophical Transactions of the Royal Society of London. B, Biological Sciences* 327: 585–593. doi:10.1098/rstb.1990.0101.

NTSB. 2017. *Collision between a Car Operating with Automated Vehicle Control Systems and a Tractor-Semitrailer Truck near Williston, Florida, May 7, 2016. NTSB/HAR-17/02*. Washington, DC: National Transportation Safety Board.

NTSB. 2019a. *Collision between Vehicle Controlled by Developmental Automated Driving System and Pedestrian Tempe, Arizona, March 18, 2018. NTSB/HAR-19/03*. Washington, DC: National Transportation Safety Board.

NTSB. 2019b. *Low-Speed Collision Between Truck-Tractor and Autonomous Shuttle, Las Vegas, Nevada, November 8, 2017. HAB-19-06*. Washington, DC: National Transportation Safety Board.

NTSB. 2019c. *Rear-End Collision between a Car Operating with Advanced Driver Assistance Systems and a Stationary Fire Truck, Culver City, California, January 22, 2018. NTSB/HAB-19/07*. Washington, DC: National Transportation Safety Board.

NTSB. 2020a. *Collision between a Sport Utility Vehicle Operating with Partial Driving Automation and a Crash Attenuator Mountain View, CA, March 23, 2018. NTSB/HAR-20/01*. Washington, DC: National Transportation Safety Board.

NTSB. 2020b. *Collision between Car Operating with Partial Driving Automation and Truck-Tractor Semitrailer Delray Beach, Florida, March 1, 2019. NTSB/HAB-20/01*. Washington, DC: National Transportation Safety Board.

NTSB. 2021. "Automated Vehicles - Investigations." National Transportation Safety Board. Accessed 3 January 2022. https://www.ntsb.gov/Advocacy/safety-topics/Pages/automated-vehicles-investigations.aspx

Okoli, C. 2019. "Developing Theory from Literature Reviews With Theoretical Concept Synthesis: Topical, Propositional and Confirmatory Approaches." *SSRN Electronic Journal*. doi:10.2139/ssrn.3452134.

Papadimitriou, E., C. Schneider, J. Aguinaga Tello, W. Damen, M. Lomba Vrouenraets, and A. ten Broeke. 2020. "Transport Safety and Human Factors in the Era of Automation: What Can Transport Modes Learn from Each Other?" *Accident; Analysis and Prevention* 144: 105656. Art doi:10.1016/j.aap.2020.105656.

Parasuraman, R., and D. H. Manzey. 2010. "Complacency and Bias in Human Use of Automation: An Attentional Integration." *Human Factors* 52 (3): 381–410. doi:10.1177/0018720810376055.

Parasuraman, R., R. Molloy, and I. L. Singh. 1993. "Performance Consequences of Automation-Induced 'Complacency'." *The International Journal of Aviation Psychology* 3 (1): 1–23. doi:10.1207/s15327108ijap0301_1.

Parasuraman, R., T. B. Sheridan, and C. D. Wickens. 2008. "Situation Awareness, Mental Workload, and Trust in Automation: Viable, Empirically Supported Cognitive Engineering Constructs." *Journal of Cognitive Engineering and Decision Making* 2 (2): 140–160. doi:10.1518/155534308X284417.

Payre, W., J. Cestac, and P. Delhomme. 2016. "Fully Automated Driving: Impact of Trust and Practice on Manual Control Recovery." *Human Factors* 58 (2): 229–241. doi:10.1177/0018720815612319.

Pearl, T. H. 2017. "Fast & Furious: The Misregulation of Driverless Cars." *NYU Annual Survey of American Law* 73: 24. doi:10.2139/ssrn.2819473.

Poland, K., M. P. McKay, D. Bruce, and E. Becic. 2018. "Fatal Crash Between a Car Operating with Automated Control Systems and a Tractor-Semitrailer Truck." *Traffic Injury Prevention* 19 (sup2): S153–S156. doi:10.1080/15389588.2018.1532211.

Pradhan, A. K., E. Pulver, J. Zakrajsek, S. Bao, and L. Molnar. 2018. "Perceived Safety Benefits, Concerns, and Utility of Advanced Driver Assistance Systems Among Owners of ADAS-Equipped Vehicles." *Traffic Injury Prevention* 19 (sup2): S135–S137. doi:10.1080/15389588.2018.1532201.

Price, M., J. Lee, A. Dinparastdjadid, H. Toyoda, and J. Domeyer. 2019. "Effect of Automation Instructions and Vehicle Control Algorithms on Eye Behavior in Highly Automated Vehicles." *International Journal of Automotive Engineering* 10 (1): 73–79. doi:10.20485/jsaeijae.10.1_73.

Read, G. J. M., S. Shorrock, G. H. Walker, and P. M. Salmon. 2021. "State of Science: Evolving Perspectives on 'Human Error'." *Ergonomics* 64 (9): 1091–1114. doi:10.1080/00140139.2021.1953615.

Rosenthal, E. 2022. "When a Tesla on Autopilot Kills Someone, Who is Responsible?" New York University. Accessed 10 October 2022. https://www.nyu.edu/about/news-publications/news/2022/march/when-a-tesla-on-auto-pilot-kills-someone–who-is-responsible–.html

Rudin-Brown, C. M. 2010. "'Intelligent' In-Vehicle Intelligent Transport Systems: Limiting Behavioural Adaptation Through Adaptive Design." *IET Intelligent Transport Systems* 4 (4): 252–261. doi:10.1049/iet-its.2009.0151.

Ruscio, D., A. J. Bos, and M. R. Ciceri. 2017. "Distraction or Cognitive Overload? Using Modulations of the Autonomic Nervous System to Discriminate the Possible Negative Effects of Advanced Assistance System." *Accident; Analysis and Prevention* 103: 105–111. doi:10.1016/j.aap.2017.03.023.

Ruscio, D., M. R. Ciceri, and F. Biassoni. 2015. "How Does a Collision Warning System Shape Driver's Brake Response Time? The Influence of Expectancy and Automation Complacency on Real-Life Emergency Braking." *Accident; Analysis and Prevention* 77: 72–81. doi:10.1016/j.aap.2015.01.018.

SAE 2021. *Taxonomy and Definitions for Terms Related to Driving Automation Systems for on-Road Motor Vehicles*. Washington, DC: SAE International/ISO.

Salmon, P. M., N. A. Stanton, and K. L. Young. 2012. "Situation Awareness on the Road: Review, Theoretical and Methodological Issues, and Future Directions." *Theoretical Issues in Ergonomics Science* 13 (4): 472–492. doi:10.1080/1463922X.2010.539289.

Salmon, P. M., G. H. Walker, and N. A. Stanton. 2015. "Broken Components Versus Broken Systems: Why It is Systems Not People That Lose Situation Awareness." *Cognition, Technology & Work* 17 (2): 179–183. doi:10.1007/s10111-015-0324-4.

Seppelt, B. D., and T. W. Victor. 2016. "Potential Solutions to Human Factors Challenges in Road Vehicle Automation." In *Road Vehicle Automation 3*, edited by G. Meyer and S. Beiker. Cham: Springer International Publishing. doi:10.1007/978-3-319-40503-2_11.

Shalev, N. 2022. "Mackworth's Clock Is Still Ticking." *Nature Reviews Psychology* 1 (4): 190–190. doi:10.1038/s44159-022-00036-0.

Shen, S., and D. M. Neyens. 2014. "Assessing Drivers' Performance When Automated Driver Support Systems Fail With Different Levels of Automation." In *Proceedings of the Human Factors and Ergonomics Society Annual*

Meeting, October 27–31, 2014, Chicago, IL. doi:10.1177/1541931214581435.

Shen, S., and D. M. Neyens. 2017. "Assessing Drivers' Response During Automated Driver Support System Failures With Non-Driving Tasks." *Journal of Safety Research* 61: 149–155. doi:10.1016/j.jsr.2017.02.009.

Simões, A., L. Cunha, S. Ferreira, J. Carvalhais, J. P. Tavares, A. Lobo, A. Couto, and D. Silva. 2019. "The User and the Automated Driving: A State-of-the-Art." In *International Conference on Applied Human Factors and Ergonomics*, July 24–28, 2019, Washington D.C.

Singh, I. L., R. Molloy, and R. Parasuraman. 1993. "Automation-Induced "Complacency": Development of the Complacency-Potential Rating Scale." *The International Journal of Aviation Psychology* 3 (2): 111–122. doi:10.1207/s15327108ijap0302_2.

Smith, P. J. 2018. "Making Brittle Technologies Useful." In *Cognitive Systems Engineering: The Future for a Changing World*, edited by P. J. Smith and R. R. Hoffman. Boca Raton, FL: CRC Press.

Stanton, N. A., M. Young, and B. McCaulder. 1997. "Drive-by-Wire: The Case of Driver Workload and Reclaiming Control With Adaptive Cruise Control." *Safety Science* 27 (2-3): 149–159. doi:10.1016/S0925-7535(97)00054-4.

Stanton, N. A., and M. S. Young. 2000. "A Proposed Psychological Model of Driving Automation." *Theoretical Issues in Ergonomics Science* 1 (4): 315–331. doi:10.1080/14639220052399131.

Strauch, B. 2018. "Ironies of Automation: Still Unresolved After All These Years." *IEEE Transactions on Human-Machine Systems* 48 (5): 419–433. doi:10.1109/THMS.2017.2732506.

Tenhundfeld, N. L., E. J. de Visser, A. J. Ries, V. S. Finomore, and C. C. Tossell. 2020. "Trust and Distrust of Automated Parking in a Tesla Model X." *Human Factors* 62 (2): 194–210. doi:10.1177/0018720819865412.

Teoh, E. R. 2020. "What's in a Name? Drivers' Perceptions of the Use of Five SAE Level 2 Driving Automation Systems." *Journal of Safety Research* 72: 145–151. doi:10.1016/j.jsr.2019.11.005.

Tinga, A. M., D. Cleij, R. J. Jansen, S. van der Kint, and N. van Nes. 2022. "Human Machine Interface Design for Continuous Support of Mode Awareness During Automated Driving: An Online Simulation." *Transportation Research Part F: Traffic Psychology and Behaviour* 87: 102–119. doi:10.1016/j.trf.2022.03.020.

Vladeck, D. C. 2014. "Machines without Principals: Liability Rules and Artificial Intelligence." *Washington Law Review* 89: 117–150.

Vollrath, M., S. Schleicher, and C. Gelau. 2011. "The Influence of Cruise Control and Adaptive Cruise Control on Driving Behaviour–a Driving Simulator Study." *Accident; Analysis and Prevention* 43 (3): 1134–1139. doi:10.1016/j.aap.2010.12.023.

Wang, M., S. C. Lee, G. Montavon, J. Qin, and M. Jeon. 2022. "Conversational Voice Agents Are Preferred and Lead to Better Driving Performance in Conditionally Automated Vehicles." In *Proceedings of the 14th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*, September 17–20, 2022, Seoul, Republic of Korea. doi:10.1145/3543174.3546830.

Ward, N. J. 2000. "Automation of Task Processes: An Example of Intelligent Transportation Systems." *Human Factors and Ergonomics in Manufacturing* 10 (4): 395–408. doi:10.1002/1520-6564(200023)10:4 < 395::AID-HFM3 > 3.0.CO;2-3.

Weiss, E., M. Fisher Thiel, N. Sultana, C. Hannan, and T. Seacrist. 2018. "Advanced Driver Assistance Systems for Teen Drivers: Teen and Parent Impressions, Perceived Need, and Intervention Preferences." *Traffic Injury Prevention* 19 (sup1): S120–S124. doi:10.1080/15389588.2017.1401220.

Wickens, C. D. 2020. "Automation Lessons from Other Domains." In *Handbook of Human Factors for Automated, Connected, and Intelligent Vehicles*, edited by D. L. Fisher, W. J. Horrey, J. D. Lee, and M. A. Regan. Boca Raton, FL: CRC Press.

Wickens, C. D., B. A. Clegg, A. Z. Vieane, and A. L. Sebok. 2015. "Complacency and Automation Bias in the Use of Imperfect Automation." *Human Factors* 57 (5): 728–739. doi:10.1177/0018720815581940.

Wiener, E. L. 1981. "Complacency: Is the Term Useful for Air Safety?" In *Proceedings of the 26th Corporate Aviation Safety Seminar,* March 29–31, 1981, Denver, CO.

Wilson, K. M., S. Yang, T. Roady, J. Kuo, and M. G. Lenné. 2020. "Driver Trust & Mode Confusion in an On-Road Study of Level-2 Automated Vehicle Technology." *Safety Science* 130: 104845. doi:10.1016/j.ssci.2020.104845.

Woods, D. D., S. Dekker, R. Cook, L. Johannesen, and N. Sarter. 2010. *Behind Human Error*. Burlington, VT: Ashgate.

Wulf, F., K. Zeeb, M. Rimini-Döring, M. Arnon, and F. Gauterin. 2013. "Effects of Human-Machine Interaction Mechanisms on Situation Awareness in Partly Automated Driving." In *16th International IEEE Conference on Intelligent Transportation Systems (ITSC 2013)*, October 6–9, 2013, Hague, Netherlands. doi:10.1109/ITSC.2013.6728525.

Yamani, Y., and W. J. Horrey. 2018. "A Theoretical Model of Human-Automation Interaction Grounded in Resource Allocation Policy During Automated Driving." *International Journal of Human Factors and Ergonomics* 5 (3): 225–239. doi:10.1504/IJHFE.2018.10016994.

Yang, Y., B. Karakaya, G. C. Dominioni, K. Kawabe, and K. Bengler. 2018. "An HMI Concept to Improve Driver's Visual Behavior and Situation Awareness in Automated Vehicle." In *2018 21st International Conference on Intelligent Transportation Systems (ITSC)*, November 4–7, 2018, Maui, HI. doi:10.1109/ITSC.2018.8569986.

Young, M. S., and N. A. Stanton. 2002. "Malleable Attentional Resources Theory: A New Explanation for the Effects of Mental Underload on Performance." *Human Factors* 44 (3): 365–375. doi:10.1518/0018720024497709.

Young, M. S., N. A. Stanton, and D. Harris. 2007. "Driving Automation: Learning from Aviation About Design Philosophies." *International Journal of Vehicle Design* 45 (3): 323–338. doi:10.1504/IJVD.2007.014908.

Zangi, Noa., Rawan Srour-Zreik, Dana Ridel, Hadas Chasidim, and Avinoam Borowsky. 2022. "Driver Distraction and Its Effects on Partially Automated Driving Performance: A Driving Simulator Study Among Young-Experienced Drivers." *Accident; Analysis and Prevention* 166: 106565. doi:10.1016/j.aap.2022.106565.

Zhai, S., S. Gao, L. Wang, and P. Liu. 2023. "When Both Human and Machine Drivers Make Mistakes: Whom to Blame?" *Transportation Research Part A: Policy and Practice* 170: 103637. doi:10.1016/j.tra.2023.103637.