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# Systematic Review of Driver Distraction in the Context of Advanced Driver Assistance Systems (ADAS) & Automated Driving Systems (ADS)

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SYSTEMATIC REVIEW OF DRIVER DISTRACTION IN THE  
CONTEXT OF ADVANCED DRIVER ASSISTANCE SYSTEMS (ADAS)  
& AUTOMATED DRIVING SYSTEMS (ADS)

By

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## **ABSTRACT**

# **SYSTEMATIC REVIEW OF DRIVER DISTRACTION IN THE CONTEXT OF ADVANCED DRIVER ASSISTANCE SYSTEMS (ADAS) & AUTOMATED DRIVING SYSTEMS (ADS)**

SEPTEMBER 2022

APOORVA PRAMOD HUNGUND, B.E., K. J. SOMAIYA COLLEGE OF  
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Advanced Vehicle Systems promise improved safety and comfort for drivers.

Steady advancements in technology are resulting in increasing levels of vehicle automation capabilities, furthering safety benefits. In fact, some of these vehicle automation systems are already deployed and available, but with promised benefits, such systems can potentially change driving behaviors. There is evidence that drivers have increased secondary task engagements while driving with automated vehicle systems, but there is a need for a clearer scientific understanding of any potential correlations between the use of automated vehicle systems and potentially negative driver behaviors.

The aim of my thesis is therefore to understand the state of knowledge on automated vehicle systems and its possible impact on drivers' distraction behaviors. I have conducted two systematic literature reviews to examine this question. This thesis reports these reviews and examines the effects of secondary task engagement on driving behaviors such as take-over times, visual attention, trust, and workload, and discusses the implications on driver safety.

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## LIST OF ACRONYMS

<b>Acronyms</b>	<b>Expansion</b>
ADAS	Advanced Driver Assistance Systems
ADS	Automated Driver Systems
SAE	Society of Automotive Engineers
FCW	Forward Collision Warning
LDW	Lane Departure Warning
ACC	Adaptive Cruise Control
ODD	Operational Design Domain
LKA	Lane Keeping Assist
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta Analyses
CINAHL	Cumulated Index to Nursing and Allied Health Literature
TRID	Transport Research International Documentation
AS	Active Steering
LKS	Lane Keeping System
NDRT	Non-Driving Related Task
SuRT	Surrogate Reference Task
PRC	Percent Road Center
TQT	Twenty Questions Task
PERCLOS	Percentage of Eyelid Closure over the Pupil Over Time

KSS	Karolinska Sleepiness Scale (KSS)
TOR	Take Over Request
GSR	Galvanic Skin Responses
TTC	Time to Collision
HUD	Heads-Up Display
DSM	Driver State Monitoring

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# **CHAPTER I**

## **SYSTEMATIC REVIEW OF DRIVER DISTRACTION IN THE CONTEXT OF ADVANCED DRIVER ASSISTANCE SYSTEMS (ADAS) & AUTOMATED DRIVING SYSTEMS (ADS)**

The first chapter of this thesis discusses Automated Vehicle Systems, briefly exploring its history, the advances made in recent years, potential safety benefits, and prevailing issues, including human factors issues with automated vehicles. We will also discuss the issue of driver distraction, including a historical perspective on this topic. The next chapter, Chapter II describes the first systematic review, which was conducted to examine the impact of Advanced Driver Assistance Systems (ADAS) on distraction. Chapter III describes the systematic review of Automated Driving Systems and the impact of their use on distraction behaviors. Chapter IV offers a conclusion and discussion about the findings and key takeaways from both systematic reviews.

### **1.1 Automated Vehicle Systems**

#### **1.1.1 History of Automated Vehicle Systems**

Automation is defined as “a technology concerned with performing a process by means of programmed commands. Combined with automatic feedback control to ensure proper execution of the instructions” (Groover, 2020). Automation is a widely used concept in manufacturing but is now also applied outside manufacturing, where there's a significant distribution of human and mechanical effort (Groover, 2020). With advances and technology, today's automated systems are highly sophisticated and complex. A vital field concerned with automation is Robotics - a specialized branch in which the machine possesses specific human-like characteristics. Such machines can work alongside humans

or take-over specific tasks that human beings used to perform initially. Another important field where automation has significantly changed is the aviation industry. One of the best examples of automation in the aviation industry is autopilot. These systems make it easier for pilots to fly aircrafts easily and smoothly with minimal human interaction.

More recently, there has been a significant level of advances in automated systems in the automotive domain. Here, automation comprises different control and safety systems or the different vehicle features providing additional support to the driver. Automated Vehicle Systems does this either by taking over some of the driving tasks or taking control of the vehicle completely. SAE's report (SAE, 2021) on automation can be used to contextualize the levels of automation and create a guide to the different automation capabilities of a system. According to the SAE taxonomy and definitions, Level 0 or fully manual vehicle is defined as a system in which the driver has complete control; Level 1 & 2 are defined as systems where the vehicle can take-over some part of the driving task, but the driver has to remain in control; Level 3 is defined as an automation system where vehicles can make informed decisions for themselves, however, human override may be required conditionally; and finally, Level 4 & 5 are defined as systems that do not require human intervention. These levels help us define and understand these features, and while not prescriptive, can offer up a useful vocabulary for us to describe and discuss vehicle automation.

Based on the defined levels, we can thus broadly define Levels 1 and 2 as Advanced Driver Assistance Systems (ADAS), and Levels 3 to 5 as Automated Driving Systems (ADS).



## SAE J3016™ LEVELS OF DRIVING AUTOMATION™

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	SAE LEVEL 0™	SAE LEVEL 1™	SAE LEVEL 2™	SAE LEVEL 3™	SAE LEVEL 4™	SAE LEVEL 5™
What does the human in the driver's seat have to do?	You <b>are</b> driving whenever these driver support features are engaged – even if your feet are off the pedals and you are not steering			You <b>are not</b> driving when these automated driving features are engaged – even if you are seated in “the driver’s seat”		
	You <b>must constantly supervise</b> these support features; you must steer, brake or accelerate as needed to maintain safety			When the feature requests, you must drive	These automated driving features will not require you to take over driving	

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	These are driver support features			These are automated driving features		
What do these features do?	These features are limited to providing warnings and momentary assistance	These features provide steering <b>OR</b> brake/acceleration support to the driver	These features provide steering <b>AND</b> brake/acceleration support to the driver	These features can drive the vehicle under limited conditions and will not operate unless all required conditions are met	This feature can drive the vehicle under all conditions	
Example Features	<ul style="list-style-type: none"> <li>• automatic emergency braking</li> <li>• blind spot warning</li> <li>• lane departure warning</li> </ul>	<ul style="list-style-type: none"> <li>• lane centering <b>OR</b></li> <li>• adaptive cruise control</li> </ul>	<ul style="list-style-type: none"> <li>• lane centering <b>AND</b></li> <li>• adaptive cruise control at the same time</li> </ul>	<ul style="list-style-type: none"> <li>• traffic jam chauffeur</li> </ul>	<ul style="list-style-type: none"> <li>• local driverless taxi</li> <li>• pedals/steering wheel may or may not be installed</li> </ul>	<ul style="list-style-type: none"> <li>• same as level 4, but feature can drive everywhere in all conditions</li> </ul>

**Figure 1: SAE Levels of Automation**

Note: This image was published by SAE International in April 2021 as a summarization of terminologies and terms in driving automation. From SAE J3016 LEVELS OF AUTOMATION, SAE International, April 2021. (<https://www.sae.org/blog/sae-j3016-update>)

Of these systems, Level 1 and 2 automation features are readily available in modern vehicles and are almost commonplace on public roadways. Some of the most commonly available ADAS features are lane keep assist, lane centering, adaptive cruise control, Blind Spot Assist, Auto Park, etc., and their combinations. Level 3 features have slowly become available on larger scales, and it is only inevitable that these systems will soon have a prominent role to play in driving. These systems will be able to conditionally take-over the task of driving from the driver periodically allowing the driver to simply monitor, for example, Honda Sensing Elite (*Honda Launches Honda SENSING Elite*,

2021) or Mercedes-Benz's updated Drive Pilot (Ramey, 2022) systems, both of which can handle conditional control of the vehicle.

However, an important caveat about vehicle automation is that, with evolving automation use, drivers' role will change from operating vehicles to the management of automated driving systems. The operator will progressively play a reduced role in driving vehicles; that is, the operator will no longer actively control but provide supervisory control, especially for partially automated vehicles (Bainbridge, 1982; Sheridan, 2002). Eventually, Automated Vehicle Systems will have changed the role of humans in driving from the driver to partially driving, to monitoring, and finally to just being the passenger.

### **1.1.2 Potential Benefits of Automated Vehicle Systems**

Automated vehicles are already on our roads today, with lower level automation available in vehicles available to the consumer, and higher levels of automation being deployed by manufacturers for testing or for limited public deployment. The advances in these technologies provide more opportunities for increased safety while driving. These systems can either provide warnings for external obstructions, control/aid braking, acceleration, position on the road, and to some extent, monitor driver behavior as well. Lindgren et al. (2008) stated that at the highest level of intervention, Automated Vehicle Systems can either act independently or even override the driver's action. The task of driving no longer involves the simple interaction of humans on vehicles but affects humans and vehicles interacting together. The primary aim of using Automated Vehicle Systems is to reduce human driving errors and increase safety on the road.



For example, Farmer (2008) and Jermakian (2011) found that FCW could have potentially reduced 69 - 81% of rear-end crashes compared to driving without FCW. FCW could have prevented 70% of rear-end crashes even with accounting for its limitations. Highway Loss Data Institute (2015a, 2015b, 2015c, 2018) estimated that Honda's FCW and LDW reduced physical injuries by 24% and found that Subaru's ADAS system reduced the frequency of physical injury by 35%. Cicchino (2017) studied crash data for FCW and AEB and found that FCW reduced rear-end striking crashes by 27%, AEB by 43%, and both by 50%. Farmer (2008) estimates that LDW could potentially reduce 66 – 88% of head-on crashes, 55-67% of sideswipe crashes involving vehicles traveling in the same direction, and 57-74% of vehicles traveling in opposite directions. HLDI (2015c) found no statistical change or effect of LDW, whereas Cicchino (2017) estimated that LDW systems reduced crash injuries by 21%. This was supported by Sternlund (2017), who estimated that LDW and LKA systems reduced all single vehicle and head-on crashes by 30%.

Another widely available and used ADAS feature is Adaptive Cruise Control (ACC). Similar to conventional cruise control, ACC uses sensors to estimate the velocity and distance of the vehicle in front to maintain a set headway time (Fancher et al., 1998). ACC is designed to automate the driving process partially and is more of a convenience system, but it is also known to provide additional safety benefits to drivers. For example, a literature review found ACC to provide increased situational awareness while driving with ACC engaged (de Winter et al., 2014). ACC can partly take-over longitudinal control, reducing mental workload and providing more opportunities for the driver to monitor their surroundings and increase their situational awareness. However, using secondary tasks while engaging with automation may decrease their overall situational awareness (de

Winter et al., 2014; Rogers et al., 2011). Drivers may inadvertently cancel out the safety benefits by misusing Automated Vehicle Systems.

### **1.1.3 User Perceptions and Trust in Automated Vehicle Systems**

The safety benefits of Automated Vehicle Systems can only be realized when these systems are used properly and efficiently. It also depends on drivers' willingness to use and trust towards these systems. Drivers need to understand the system – functional capabilities, limitations, and operations - to use them within their operating design domain (ODD) in situations the systems can work in. Differences in levels of understanding can lead to the systems being used in situations outside of their intended design and can cause drivers to have false impressions about a system's abilities (Beggiato & Krems, 2013) leading to over trust (Inagaki & Itoh, 2013) and could also lead to disusing the system (Parasuraman & Riley, 1997).

A survey study (Penmetsa et al., 2019) examined the perceptions of vulnerable road users toward automated vehicles. Respondents who had direct experience interacting with the automated vehicles had significantly higher expectations of safety benefits than respondents with no interaction. This indicates that as people increasingly interact with automated vehicles, their attitudes towards technology may be positive. A simulator study (Gold et al., 2015) examining the effect of experience on trust and user perception of Automated Vehicle Systems found that the driving experience increased self-reported trust among drivers and led to positive attitudes toward using Automated Vehicle Systems, specifically in older drivers. Studies have also indicated that the experience in using Level 2 systems such as Lane Keep Assist or Adaptive Cruise Control is likely to

influence the acceptance of highly automated vehicles among drivers (Molnar et al., 2018; Zeeb et al., 2016).

Trust in Automated Vehicle Systems is one of the most important factors toward Automated Vehicle Systems use and acceptance. Such systems are specifically to help prevent crash injuries and increase safety. However, unless ADAS and ADS systems are trusted and thus, actually used, the safety benefits will not be realized.

## **1.2 Driver Distraction**

While Driver Distraction is an important theme of this thesis, it is important to first understand the context and the state of driver distraction research that has been conducted in the past. This will help us understand the potential implication and identify potential outcomes of distraction in the domain of vehicle automation. To that end, this section will provide an abbreviated history of driver distraction in the form of a brief literature review.

Driver Distraction is a recognized driver safety problem and has been significantly addressed in literature over the decade. Distraction has been defined as engaging in any activity that takes away driver's attention from the main task of driving (Lee, 2014). Driving is a complex activity, consisting of various cognitive, physical, sensory, and psychomotor skills (Young et al., 2007). Despite being an extremely involved activity, drivers often tend to engage in distractions while driving. Such activities may include using electronic devices, conversing with passengers, listening to the radio., etc. Driver Distraction can be broadly classified into three categories – manual, visual, and cognitive (Gazder & Assi, 2022; D. Strayer et al., 2011). Manual distraction

can be defined as drivers taking their hand(s) off the steering wheel to engage in distractions, visual distractions refer to any activity that requires drivers to take their visual attention away from the main roadway whereas cognitive distraction refers to distractions that shift driver's attention away from the main activity of driving (D. L. Strayer et al., 2013).

A large naturalistic study (the 100-car naturalistic study) found driver inattention as a factor in 78% of all crashes (Dingus et al., 2006). Multiple studies conducted with different age groups have found the use of mobile phones as one of the most common modes of distraction (Beanland et al., 2013; Fofanova & Vollrath, 2012; Foss & Goodwin, 2014; McDonald & Sommers, 2015; Papantoniou et al., 2015). Other activities include grooming, eating, radio control, passenger interactions, etc. (Fofanova & Vollrath, 2012; Foss & Goodwin, 2014; Shaaban et al., 2020). Focus is placed on cellphone interactions while driving as there are significant decremental effects observed in multiple studies. Two studies (Choudhary & Velaga, 2019; Saifuzzaman et al., 2015) found drivers' average speed decreased and the probability of causing a crash increased while driving with cell phones. Drivers increase their attention off road by almost 400% while texting (Hosking et al., 2009), which may ultimately lead to them missing hazards (Horberry et al., 2006), having increased reaction times (Irwin et al., 2015) to take-over events and situations.

Previous research has focused on mitigating distraction using training and intervention or feedback methods. Training has resulted in better hazard anticipation, attention maintenance, and hazard mitigation (Fisher et al., 2015) specifically in younger drivers. Training aims to provide information to drivers about the systems they use,

increase their understanding and knowledge, and make drivers aware of the system's limitations.

Most of the engagement in secondary tasks is preventable, and participants may decide not to engage and focus only on the task of driving. For example, Beanbeld et al. (2013) found that the most common distractions were involuntary, non-driving related tasks inside the vehicle. However, in some cases, having a secondary task has helped drivers maintain their attention and kept them alert. With the advent of driver assistance and automation technologies, drivers may soon have long, continuous periods of inactivity leading to fatigue or inattention. Still, they will have to be alert enough to take back control from automation if needed quickly (Neubauer et al., 2012). Such passive driving may give rise to driver fatigue (May & Baldwin, 2009). It has also been found that maintaining or stimulating the drive with a secondary task can help drivers maintain situational awareness, perhaps mitigating the adverse effects of engaging in a secondary task (Chandrasekaran et al., 2019; Drews et al., 2008). In a study into drivers' multitasking influence on driving performance (Nijboer et al., 2016), drivers found that engaging in a single task (using a tablet) over listening to the radio or answering questions leads to worse driving habits. Engaging in a low cognitive workload secondary task has helped keep drivers active and avoid fatigue.

### **1.3 Thesis Objective and Statement**

In the previous sections, we discussed the potential benefits of Automated Systems (Section 1.1) and the potential negative impacts of driver distraction (Section 1.2). From these previous sections, it is clear that, while automated systems are designed to improve

comfort, convenience, and safety, the risk of driver distraction is still real, and may, in fact potentially reduce safety benefits. This is not very clear yet, and researchers have now started examining the interaction between the use of vehicle automation and the impact of this use on secondary task engagement. The objective of this thesis is to understand this interaction as well as the outcomes of this interaction.

Literature shows that Automated Vehicle Systems promise an increase in safety benefits and create situations in which drivers may engage in secondary tasks (Carsten et al., 2012; de Winter et al., 2014; Hergeth et al., 2016; Naujoks et al., 2016). However, engaging in secondary tasks with the automation technology available today can cause drivers to be distracted in safety-critical situations, thus, erasing the benefits of Automated Systems. However, at the same time, there is some evidence that engaging in a low cognitive task can increase situational awareness in drivers and help them take back control quicker in case of safety-critical situations (Chandrasekaran et al., 2019; Drews et al., 2008). Since there is no clear relationship between the usage of Automated Vehicle Systems and engagement of secondary tasks, it becomes difficult to understand the effect it can have on the changing driver behaviors. Therefore, to properly understand this association, a systematic review of all literature related to Automated Vehicle Systems and driver distraction was conducted.

These systematic reviews will be reported in two phases - Phase I will consist of the review of literature related to level 1 & 2 automation levels, and Phase II will consist of literature on Level 3 and higher. The categorization for Phase I and II depends on the level of control of the driving task. Automation Level 1 and 2 has a driver in control, whereas Level 3 and higher are shared/vehicle system in control. Both phases were

undertaken with a similar methodology – a systematic search of five databases, with the presence of a secondary task while driving with automation active. Phase I had keywords and search terms specific to Levels 1 & 2 of automation, and Phase II had keywords and search terms specific to Level 3 of automation.

The first phase of the review discusses the effects of driver distractions in the presence of advanced driver assistance systems (ADAS) or Level 1 and 2 of automation (SAE, 2021). For this phase, I conducted a systematic review of all published literature on the use of advanced driver assistance systems in the presence of secondary tasks and any observed changes. This is reported in Chapter 2 of this thesis. For phase two, I applied the same process and observed effects on driving behavior while driving with Level 3 and higher automation in the presence of secondary tasks. This will be reported in Chapter 3 of this document.

## **CHAPTER II**

### **PHASE I SYSTEMATIC REVIEW –**

#### **ADVANCED DRIVER ASSISTANCE SYSTEMS (ADAS) AND DISTRACTION**

This chapter discusses the Phase I Review, which reviews Level 1 and Level 2 Automation & the engagement in secondary tasks, as well as any observed changes in driving behavior caused by this engagement. The chapter starts with an introduction to the presence of Level 1 and 2 automation features in use today, with a brief description of the possible issues and why engaging with secondary tasks while driving with automation may lead to hazardous situations. The chapter then discussed the research questions around which the research articles are synthesized and discussed. The discussion chapter examines all research articles selected for final synthesis and the implications of this review. Finally, the conclusion chapter provides a summation and some important considerations about the findings of Phase I review.

#### **2.1 Introduction**

In the previous section, we briefly discuss the benefits of using ADAS features including reduced crash injuries and fatalities and improved driving performance (Kusano & Gabler, 2012; Kusano & Gabler, 2015; Cicchino et al., 2017). The objective of these features is to improve driver comfort and driver safety by providing support while driving. Since ADAS falls under Level 1 and Level 2 Automation (SAE, 2021), they can assist drivers with monitoring their surroundings, maintaining, or adjusting speeds and trajectories, and providing necessary alerts to the driver.

However, research indicates that incomplete knowledge or understanding of these systems can lead to over trusting or an over-reliance on the system's capabilities and



cause the drivers to consider them to be of higher automation levels. While driving with ADAS, the driver's role becomes more passive and supervisory rather than an active, hands-on task with manual driving. ADAS takes over certain driving tasks, and with every addition of an ADAS feature in the vehicle or with the increased capabilities and scope of automated systems in vehicles, there exists an increased risk of drivers becoming less aware and attentive toward the driving task, especially because of the increased possibility of involvement in non-driving-related secondary tasks.

Adaptive cruise control (ACC) and lane-keeping assist (LKA) are prominent ADAS features in vehicles today. These systems respectively control the longitudinal and lateral movements of the vehicle and assume control of the vehicle from the driver when the systems are engaged. However, taking control from drivers for prolonged periods of the drive may increase the likelihood of drivers engaging in secondary tasks, such as in-vehicle infotainment or the use of portable manual devices (Carsten et al., 2012). This may significantly affect their ability to anticipate and mitigate hazards, react to safety-critical situations, and take back control of the car at necessary times. Given that the function of using ADAS is to aid in driving, drivers can justify their engagement in secondary tasks if there is no necessary input or help needed to complete the trip.

Driver perceptions of the ADAS system also play an important role in how drivers use the systems and how comfortable they can be in engaging in secondary tasks. Two survey studies that examined drivers' perceived trust found that most of the drivers agreed that they would engage more in secondary tasks if they were driving with an ADAS feature and that there was a possibility of them over-relying on the system (Hannan et al., 2018; Weiss et al., 2018). Another important consideration is driver

workload. A literature review (de Winter et al., 2014) compiled literature detailing the effects of ACC and highly automated driving on drivers' workload and situation awareness. The study examined the change in workload and situation awareness when driving with ACC engaged and when they were manually driving. The study found that when drivers were properly motivated or instructed to be aware of hazards in their immediate surroundings, both ACC and highly automated driving improved their situation awareness compared with manual driving. However, it was also found that when drivers were distracted or engaged in secondary tasks, their situation awareness decreased for ACC or highly automated driving compared with manual driving.

Despite significant research on distracted driving in the presence of active ADAS use, there is no definite established association. This review aims to organize all relevant literature by means of a systematic review and conduct a synthesis of this literature to understand any association between secondary task engagement & ADAS use and to clearly understand the nature of this association.

## **2.2 Research Objective**

In Phase I, we aimed to understand changes in drivers' secondary task engagement, their performance in those tasks, their attention and driving performance, in the context of Advanced Driver Assistance Systems (ADAS). This phase of the review focuses on published empirical research that examined driving behavior while driving with ACC, LKA, related warning systems, or a combination of two or more of these ADAS features, in the presence of a secondary task.

Based on the objective, we examined the literature to address the following four research questions:

*Research Question 1: Is there an association between ADAS use and secondary task engagement?*

For this research question, engagement was defined as driver interactions or behaviors that could be measured and observed through reactions, eye movements, hand movements and behavior.

*Research Question 2: Is there an association between ADAS use and secondary task performance?*

This research question studied the association with how well drivers performed a secondary task while driving with ADAS active. Task performance in these cases was measured by scores, time to completion, hit or miss rate, or other related task metrics.

*Research Question 3: Is there an association between ADAS use and drivers' attention?*

This research question addressed association between ADAS use and driver attention. Attention was broadly defined to include visual and cognitive attention, measured by eye movement metrics and other related metrics, such as situational awareness.

*Research Question 4: Is there an association between ADAS use and changes in driving behavior?*

This research question studied changes in driver behavior while actively using ADAS and engaging in a secondary task. Driver behavior here is defined as vehicle management behaviors, as well as trust and acceptance.

### 2.3 Methodology

Phase I Systematic Review was conducted as per the Preferred Reporting Items for Systematic Reviews and Metal Analyses (PRISMA) (Page et al., 2020) guidelines.

#### 2.3.1 Keywords

A search of databases was conducted (Academic Search Premier, CINAHL, PubMed, PsychINFO, and TRID) for relevant studies between 1990 and March 1<sup>st</sup>, 2020. The two key concepts used for keywords were related to Driver Distraction and Automated Vehicle Systems (L2 and L1) level of automation.

**Table 1: Phase I Database Search Keywords**

Driver Distraction Keywords (OR)	(AND)	Advanced Driver Assistance Systems Keywords (OR)
"drive", "drives", "driver", "driving", "drivers", "distract", "distracts", "distracted", "distraction", "mind off road", "mind-off road", "eyes-off road", "eyes off road", "secondary task", "secondary tasks", "non- driving relevant task", "non-driving relevant tasks", "non-driving relevant task", "non- driving relevant tasks"		"ADAS", "advanced driver assistance system", "advanced driver assistance systems", "ACC", "adaptive cruise control", "LKA", "lane keeping assist", "lane keeping", "ADS", "automated driving system", "automated driving systems", "autonomous system", "autonomous systems"

#### 2.3.2 Inclusion and Exclusion Criteria

Only studies that met the following criteria were included in phase I review: (1) full text, original research in a peer reviewed journal; (2) published in English; (3) human studies; (4) included drivers aged 16 years and older; (5) used quantitative methods for data collection and analysis, supported by statistical analysis; and (6) examined driver

behaviors in the context of distraction and of ADAS systems. Studies that reported one or more of the following outcomes were eligible for inclusion: driver performance, safety outcomes, secondary task engagement and performance, distraction behaviors, driver trust, or situation awareness. All other studies were considered irrelevant and excluded from the review.

### **2.3.3 Study Selection and Data Extraction**

Studies were screened based on titles, abstracts, and full texts. Following the inclusion and exclusion criteria, and the research questions papers that were relevant for ADAS were identified and selected. Only papers that used an active longitudinal speed control system (ACC), an active lateral displacement control (LKA), active steering (AS), alerts for longitudinal and lateral location or object detection (i.e., FCW, forward collision warning; or LDW, lane departure warning), or a combination of these features were included.

Each included study underwent a full text review, and data points such as date of publication, study location and population, study aim, experiment type, participant sample size, research design and method, dependent variables, independent variables, outcomes, and findings salient to review's research questions were extracted onto a spreadsheet.

## **2.4 Results**

### **2.4.1 Database Search Results:**

The literature search, screening, review, and selection process is described in Figure 2.4.1 using the PRISMA flow chart. The combined searches from the five databases yielded 10,319 records. The titles were first screened for these articles to determine inclusion according to the abovementioned criteria. There were 9641 records that did not meet the criteria and were excluded. The abstracts were screened for the 678 remaining records, and a further 505 were excluded resulting in 173 articles that were relevant to driver distraction and Automated Vehicle Systems. Seventy-two duplicate records were then removed, yielding 101 papers relevant to the broader topic of distraction and Automated Vehicle Systems. Of these, 29 papers were finally identified as being relevant to the specific topic of ADAS and were included in the final synthesis.

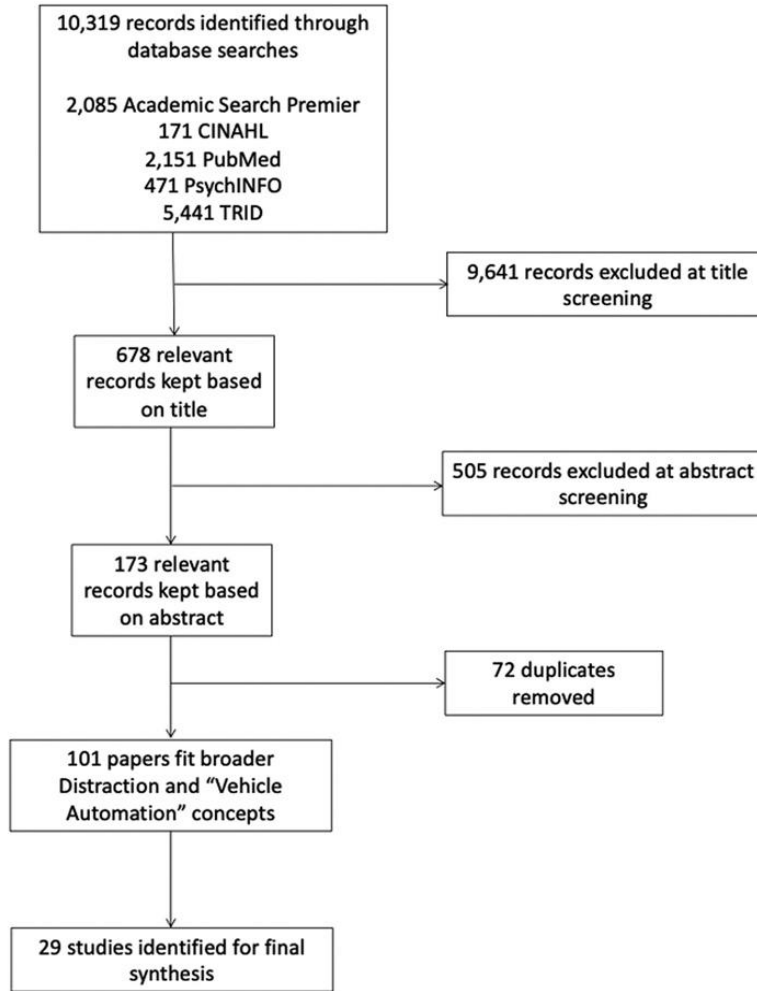


Figure 2: Systematic Review Process for Phase I

Table 2: Phase I Database Search Results

Database	Search Results	Title Cull Results	Abstract Cull Results
Academic Search Premier	2,085	175	35
CINAHL	171	75	33
PsychINFO	471	125	34
PubMed	2,151	124	32
TRID	5,441	179	39
<b>Total</b>	<b>10,319</b>	<b>678</b>	<b>173</b>



**Figure 3: Paper count by publication year – Phase 1**

From the above plot of publication count by years, it can be seen that in the years after 2010, the research conducted on this topic increased. In 2019, around ten papers were published over the year.

#### **2.4.2 Research Question-based Results:**

For the final 29 studies, the distribution of vehicle technology was examined and found as follows: ACC and LKA—14 studies; ACC and AS—three studies; ACC— six studies; LKA or lane keeping system (LKS)—three studies; warning systems such as FCW and LDW—two studies; ACC and FCW—one study.

Furthermore, of the 29 studies, 19 were driving simulator experiments, six on- road experiments, one a closed test-track experiment, and four were naturalistic driving studies.

The secondary tasks presented to participants in these studies varied considerably across studies. Of the 29 studies, 20 used visual-manual tasks, five had visual-manual and verbal tasks, two had only manual, one had only verbal, and one had a visual-spatial task.

This distribution of papers by research questions is detailed below:

*Research Question 1: ADAS Use and Secondary Task Engagement.*



This topic was discussed by 15 of the 29 papers. Of these, seven studies had a focus on ACC and LKA; two on ACC and AS; one on ACC only; two on LKA/LKS only; one on FCW; one LDW, and one on ACC and FCW as their ADAS feature.

Of the studies examining this question, 11 were experimental simulator studies, one was an on-road study, and two were naturalistic driving studies.

*Research Question 2: ADAS Use and Changes in Secondary Task Performance.*

The topic of changes in secondary task performance was discussed in 13 of the 29 papers.

Of these, four examined ACC and LKA; two examined ACC and AS; three discussed LKS/LKA; three discussed ACC; and one examined FCW. Of the 13 studies, 10 were conducted in a simulator, one on a closed track, and two as on-road studies.

*Research Question 3: Relationship between ADAS Use and Drivers' Attention.*

The question of change in drivers' attention was addressed by 10 papers. Of these, six papers discussed studies conducted with ACC and LKA; and four with ACC only.

Five of these studies were conducted in a simulator, one on a closed track, one as an on-road study, and three as a naturalistic driving study.

*Research Question 4: ADAS Use, Secondary Task Engagement, and Changes in Driver Behavior.*

The majority of the papers discussed this research question in some capacity. Overall, 16 of the 29 papers discussed changes in driving behavior in either reaction time to events, trust, workload, takeover behavior, or lane deviations.

Of these, nine studies were conducted with a combination of ACC and LKA; two with ACC and AS; three with ACC only; one with LKS/LKA only; and one with LDW.

Of the 16 studies, 10 were conducted in simulators, four on a roadway, one as naturalistic driving, and one on a closed track.

## **2.5 Discussion**

This review was conducted to help understand the association between use of ADAS & engaging in secondary task on driving behavior. Using the PRISMA guidelines, a final selection of 29 papers was synthesized. The section discusses the 29 papers based on research questions established in Section 2.2.

### **2.5.1 Research Question 1: ADAS Use and Secondary Task Engagement**

This research question examines drivers' engagement in secondary tasks while driving with ADAS. Of the 29 studies, 15 discuss this association across different ADAS features. Nine studies use visual-manual secondary tasks, three visual-manual and verbal, one with verbal only, and one with visual-spatial task. Overall, a majority of the studies reported increased secondary task engagement, measured by actual task involvement or glance behavior toward the task, when driving with some level of ADAS.

Borowsky et al. (2016) found that the use of ACC and AS gave the drivers more mental capacity and drivers increased their secondary task engagement. The same paper

also discusses that in the presence of secondary tasks and automation failures, drivers had more crashes than when there was no automation failure. Three simulator studies (Payre et al., 2017; Miller and Boyle, 2019; Shen and Neyens, 2017) found that drivers increased eye glances toward the secondary tasks while driving with ACC and LKA or with LKA (Miller and Boyle, 2019; Shen and Neyens, 2017) in a driving simulator. Carsten et al. (2012) and Naujoks et al. (2018) conducted driving simulator studies with ACC and LKA and found that drivers increased their secondary task engagement during ADAS drives. Merat et al. (2012) found drivers increasing their secondary task engagement, only in the absence of a critical event. Naujoks et al. (2016), in an on- road study, found that drivers with more experience with ACC engaged more in secondary tasks when driving with ACC + AS. Two studies conducted with warning systems FCW (Reinmueller and Steinhauser, 2019) and LDW (Miller and Boyle, 2017) found that drivers frequently performed secondary tasks with the systems engaged.

Dunn et al. (2019) found some contrasting results when analyzing two naturalistic datasets. For the first dataset, drivers engaged in secondary tasks while driving with ADAS active, but for the second dataset, drivers preferred not to engage in secondary tasks and did so only while driving manually. The authors attributed this to trust, that is, drivers who did not trust the system did not engage in secondary tasks. Vollrath et al. (2010) and Sayer et al. (2005) found no difference in secondary task engagement between ADAS drives and manual drives, although Vollrath et al. (2010) found decreased engagement in cruise control drives compared with either ACC or manual drives, but not significantly so.

### **2.5.2 Research Question 2: ADAS Use and Secondary Task Performance**

This research question aimed at examining associations between ADAS usage and any significant change in the performance of secondary tasks while driving. 13 papers addressed this association, with nine studies using visual-manual tasks, two using manual, one verbal, and one visual-manual and verbal tasks. Ten of the thirteen papers agree that driving with an ADAS feature was directly or indirectly associated with drivers' improvement in the performance of a secondary task.

Naujoks et al. (2016) in an on-road study found improved performance in secondary tasks when driving with ACC + AS in younger drivers as compared to older. Two studies conducted with ACC (Rudin-Brown and Parker, 2004; Ma & Kaber 2005) conducted in a closed track (Rudin-Brown and Parker, 2004) and a simulator (Ma & Kaber 2005) found an improvement in secondary task performance. A second simulator study (Shen and Neyens, 2017) found driving with ACC and LKA improved secondary task performance. Miller and Boyle conducted a series of simulator studies with LKA (Miller & Boyle, 2017; Miller & Boyle 2019a; Miller & Boyle, 2019b) and their results showed increase in secondary task performance as measured by miss rate (Miller & Boyle, 2017), by miss rates and response times (Miller & Boyle 2019a), and by number of completed tasks (Miller & Boyle 2019b). Interestingly, younger drivers showed better performance measures than did older ones (Miller & Boyle 2019a), and, despite improved task completion, there were no significant differences in task accuracy in (Miller & Boyle 2019b). Petersen et al. (2019) found in a driving simulator study that drivers performed better in ACC and LKA drives than they did in drives with only ACC or only LKA, an effect attributed to improved situation, which in turn moderated the impact of trust in the system. In contrast to this,

Borowsky et al. (2016) found that drivers performed better in AS-only drives as compared with AS and ACC or ACC only. In another driving simulator study, Deng and Kaber (2018) found that drivers performed better in manual tasks as compared with visual tasks while driving with ACC.

Some articles found contrasting results. Merat et al. (2012) and Reinmueller and Steinhauser (2019) found no difference in secondary task performance from the manual drive to the ADAS-active drive, and Biondi et al. (2018) in an on-road study, found that decreased reaction times and performance in the peripheral task as they drove with ADAS active.

### **2.5.3 Research Question 2: ADAS Use and Changes in Drivers' Visual Attention**

This research question examined the relationship between ADAS-use and changes in drivers' attention towards the driving task, as measured by eye glances or situation awareness. Of the included papers, ten addressed this topic, with seven using a visual-manual task, two with visual-manual and verbal, and one with a verbal task alone.

For this question, the literature points towards decreased attention when using ADAS. Merat et al. (2012) conducted a driving simulator study with ACC and LKA found drivers looked away from the forward roadway more during automation. Dogan et al. (Dogan et al., 2017) also found increased visual gaze toward the dashboard in a simulator study with ACC+LKA. Similarly, a simulator study by Carsten et al. (2012 with ACC + LKA and found decreased attention towards the driving task when ADAS was active. Similarly, Payre et al (30) found that drivers had more eye glances towards the secondary tasks while driving with ACC + LKA on a driving simulator.

Stanton & Young (2005) found that drivers had lower situation awareness when driving with ACC on a driving simulator. Ma & Kaber (2005) found that drivers had lower situation awareness and paid less attention towards the driving task by focusing on the secondary task in an ACC only simulated drive. Rudin- Brown & Parker (2004) and Grove et al (2019) conducted closed track and naturalistic studies respectively, and found that with ACC active, drivers had more off-road glances. In another naturalistic study, Dunn et al (2019) found that drivers' attention was away from the roadway when driving with ACC + LKA. Similarly, Gaspar & Carney (2019) conducted a naturalistic study with ACC and LKA where they found that although drivers paid attention towards the roadway, they had longer and more frequent off-road glances.

#### **2.5.4 Research Question 4: ADAS use and Changes in Driver Behavior**

This research question examined changes in driver behavior in the context of ADAS usage and secondary task engagement. Here, driver performance was defined as actual vehicle handling (speed, lane keeping, etc.) as well as driver characteristics such as workload or driver trust. Overall, 16 papers addressed this change in driving behavior either in terms of reaction times to events, trust, lane or lateral deviations, takeover behavior and workload. 11 of the 16 papers included a visual-manual task, three included visual-manual and verbal tasks, one a verbal task and one a visual-spatial task. These results can be discussed in the context of four broad driver behaviors related to safe driving - reaction time, vehicle handling, driver workload, and drivers' trust.

Broadly, the evidence suggests an increase in reaction time, a decrease in driver workload except at critical events, an increase in lane variability, and some speed

decreases, and that trust and perception of safety seem to improve after use and/or experience. Specifically, for reaction times, Payre et al (2017) measured drivers' reaction times and found that drivers had longer reaction times to takeover events while driving with ADAS. They also found that drivers had longer reaction times for the first failure than the second failure. Similar results regarding delayed responses to takeover when driving with ADAS were found by Shen & Neyens (2017), Zeeb et al (2016), and Louw et al (2019). Rudin-Brown et al (2004) found that when drivers drove with ACC, the reaction times to lead vehicle's brake lights increased and drivers reacted slower and less often at a safe distance from the lead vehicle.

In terms of workload, three studies, Rudin-Brown & Parker (2004), Heikoop et al (2019), and Stanton & Young (2005) found that driving with ADAS decreased drivers' workload. In contrast, Merat et al (2012) found that drivers had increased workload when they had to navigate a critical incident and engage in the secondary task.

For vehicle handling, five studies (Young & Stanton, 2005; Zeeb et al., 2016; Blaschke et al., 2009; Miller & Boyle, 2017) showed increased lane keeping variability or lane departures when engaged in a secondary task during ADAS drives, including Rudin-Brown & Parker, (2004), who found that the increased lane position variability was more prominent in high sensation-seekers. Merat et al (2012) reported a decrease in speed during secondary task engagement. In contrast to these, in an on-road study, Naujoks et al (2016) found no effect of ADAS on driver performance as measured by speed or acceleration.

In terms of driver reported trust in the automation systems, Schwarz et al (2019) found that drivers tended to trust the system more when a more capable automated system was driven first, and Petersen et al (2019) found that drivers trusted the system more when a

status report and feedback were provided rather than the drivers who were provided low support or drove manually. A closed track study by Rudin-Brown & Parker (2004) found that drivers' trust in ACC increased significantly after using the system and drivers trusted the system to maintain the vehicle's position, allowing them to engage more in secondary tasks. Vollrath et al (2011), found that drivers felt the safest while drive with ACC. In contrast, a naturalistic driving study by Dunn et al (2019) found that drivers who had little, or no experience did not trust the system and subsequently did not engage in any secondary tasks.

## **2.6 Conclusion**

This section discusses a systematic review of research related to engaging in secondary tasks in the context of ADAS. Keyword searches were conducted on 5 databases, resulting in 10,319 results, of which 101 were eligible for a broader review of Distraction and Automation. These articles were further narrowed based on relevance to ADAS, resulting in 29 papers used for the systematic review and synthesis.

The papers and the research provide important insight into the role of the driver in the ADAS context, especially when considering driver distraction. The discussion about engagement in secondary tasks show that a majority of the studies provide evidence that drivers increase engagement in secondary tasks while driving with ADAS. While this is unsurprising, this is important to note because based on the literature discussed, majority of the papers also show an improvement in secondary task performance while driving with active ADAS features. Use of ADAS is known to decrease workload and drivers seem willing to engage more or perform better in NDRTs when this occurs. With respect to attention, the papers discussed show that drivers have more off-road glances, i.e., take



their visual attention away from the roadway and from the main task of driving to focus, and exhibited decreased situation awareness when using ADAS. These findings support the hypothesis that drivers tend to decrease their attention towards driving and instead focus on either secondary tasks or their in-vehicle environment. This is important because the last research question shows an important impact of ADAS-use and presence of secondary tasks on driving behavior. Drivers have longer response times to critical events or take-over events, and show more variability in lane keeping, despite an increase in trust and safety and a decrease in workload.

These results offer important insight into distraction issues with the advent of ADAS, and further strengthen the evidence that drivers can engage in secondary tasks while they have the support of ADAS features, and this behavior could further be carried over into higher levels of automation. To understand if these behaviors are also displayed in Automated Driving Systems (ADS) or Level 3 to Level 5 automation, a systematic literature review of research related to ADS and the use of secondary tasks was also conducted. The search and subsequent results and synthesis are discussed in the next chapter.

**CHAPTER III**  
**PHASE II SYSTEMATIC REVIEW –**  
**AUTOMATED DRIVING SYSTEMS AND DISTRACTION**

This chapter discusses the Phase II Review, which reviews Level 3 and above Automation & the engagement in secondary tasks, as well as any observed changes in driving behavior caused by this engagement. The chapter starts with an introduction to automated driving systems and how they may affect or change the way we drive today. The chapter then discusses the methodology and synthesis for the selection of research articles. The discussion chapter examines all research articles selected for final synthesis and the implications of this review. Finally, the conclusion chapter provides a summation and some important considerations about the findings of the Phase II review.

**3.1 Introduction**

Automated Driving Systems (ADS) are expected to play an important role in the future of transportation systems. An NHTSA Study (Singh, 2015) identified recognition error and decision error as being responsible for highest number of crashes. Higher levels of vehicle automation may have the ability to potentially reduce these statistics and provide safer driving capabilities. Some of the potential benefits ADS has to offer are related to mobility, economic and societal gain, increased productivity in humans and the environment.

However, with increases in ADS technologies, the role of the driver changes from being responsible for monitoring and driving to simply monitoring. ADS systems of the future will not require human interventions to safely commute. The highest level of automation available today - Level 3 systems (SAE, 2021), do not have such capabilities.

With the systems engaged, drivers may partially hand over control of the driving task to the system. Although the system handles some aspects of driving, the driver must be available to back control if necessary. But with delegation of control to the system, drivers may have free cognitive abilities, which they may use to engage in secondary tasks. This may introduce a risk of becoming less attentive and longer reaction times to take-over situations. Since ADS technologies are here to stay, it is essential that we understand any associations between use of higher automation level vehicles and engagement of secondary tasks.

This systemic review aims to therefore address this association by reviewing literature that focuses on studies conducted with Level 3, 4, 5 and 6 of automation and engagement in secondary tasks to examine any behavioral changes in driver attention, trust, workload, perceptions, etc., and establish an association as synthesized by literature.

### **3.2 Research Objective**

In Phase II, I aim to understand the changing relationship between automated vehicle systems and the driving behavior of humans by studying published literature on driving with Automated Vehicle Systems in the presence of a secondary task. The review focuses on examining published empirical research on driving with automated vehicle systems (ADS) or systems with Level 3 and above automation, in the presence of a secondary task.

Unlike Chapter II (Phase I), which discusses the association between ADAS and changing driver behavior with specific research questions, the study of the effect of ADS is broader and consists of multiple considerations. As such, we will focus more on

understanding the themes and topics that emerge from the synthesis and not based on research questions.

### 3.3 Methodology

This systematic review was conducted as per the guidelines from Preferred Reporting Items for Systematic Reviews and Metal Analyses (PRISMA) (Page et al., 2020).

#### 3.3.1 Keywords

A search of databases (Academic Search Premier, CINAHL, PubMed, PsychINFO, and TRID) for relevant studies between the years of 1990 and March 1<sup>st</sup>, 2021, was conducted. The two key concepts used for keywords were related to Driver Distraction and Automated Vehicle Systems (L3 and above).

**Table 3: Phase II Database Search Keywords**

Driver Distraction Keywords (OR)	(AND)	Automated Driving Systems Keywords (OR)
"drive", "drives", "driver", "driving", "drivers", "distract", "distracts", "distracted", "distraction", "mind off road", "mind-off road", "eyes-off road", "eyes off road", "secondary task", "secondary tasks", "non- driving relevant task", "non-driving relevant tasks", "non-driving relevant task", "non- driving relevant tasks"	(AND)	"ADS", "automated systems", "autonomous systems", "automated vehicles", "autonomous vehicles", "automated driving", "autonomous driving", "autonomous driving systems", "automated driver systems", "vehicle automation", "highly automated driving"

#### 3.3.2 Inclusion and Exclusion Criteria

Only studies that met the following criteria were included in phase II review: (1) full text, original research in a peer reviewed journal; (2) published in English; (3) human studies; (4) included drivers aged 16 years and older; (5) used quantitative methods for data collection and analysis, supported by statistical analysis; and (6) examined driver

behaviors in the context of distraction and of ADS. All other studies were considered irrelevant and excluded from the review.

### **3.3.3 Study Selection and Data Extraction**

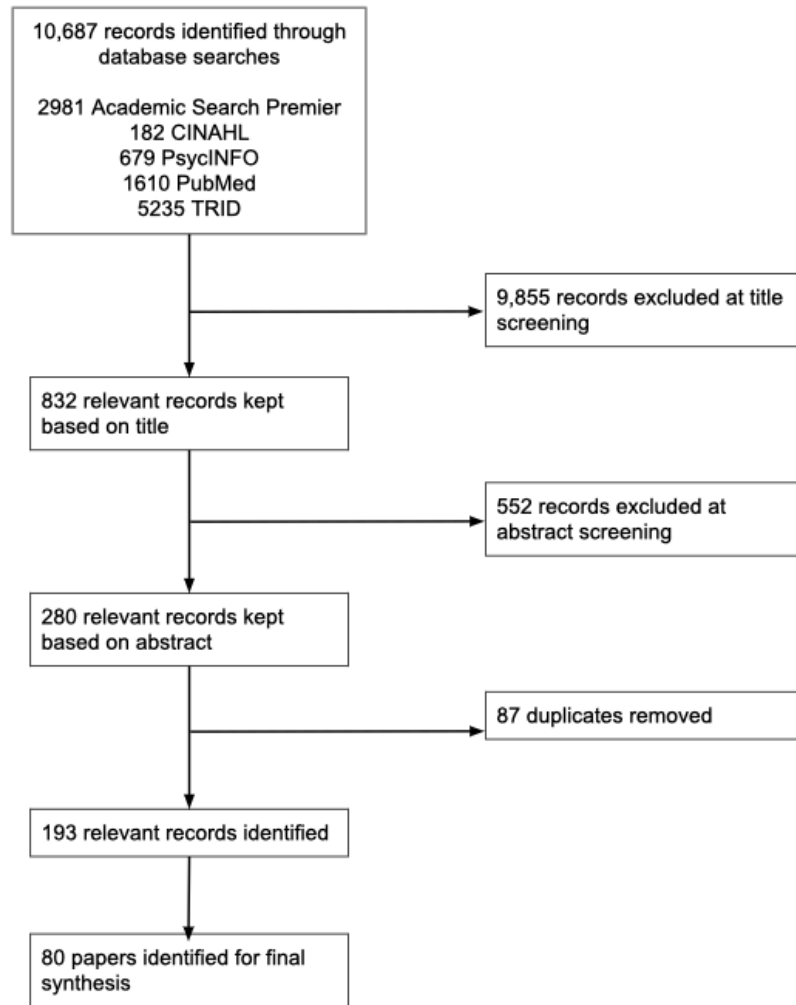
Studies were screened based on titles, abstracts and full texts, in this order. Following the inclusion and exclusion criteria, the research questions papers that were relevant for ADS were identified and selected. Papers that indicated the automation to be Level 3 of Highly Automated Driving and conducted driving sessions in the presence of one or more secondary tasks were included.

Each included study underwent a second full text review, and data points such as date of publication, study location and population, study aim, experiment type, participant sample size, research design and method, dependent variables, independent variables, outcomes, and findings salient to review's research questions were extracted onto a spreadsheet.

## **3.4 Database Search Results**

The literature search, screening, review, and selection process is described in Figure 3 using the PRISMA flow chart. The combined searches from the five databases yielded 10,687 records. The titles were first screened for these articles to determine inclusion according to the abovementioned criteria. There were 9855 records that did not meet the criteria and were excluded. The abstracts were screened for the 832 remaining records, and a further 552 were excluded resulting in 280 articles that were relevant to driver distraction and Automated Vehicle Systems. 87 duplicate records were then removed, yielding 193 papers relevant to the of distraction and Automated Vehicle

Systems. Of these, 80 papers were finally identified as being relevant to the specific topic of ADAS and were included in the final synthesis.



**Figure 4: Systematic Review Process for Phase II**

**Table 4: Phase II Database Search Results**

Database	Search Results	Title Cull Results	Abstract Cull Results
Academic Search Premier	2,981	198	86
CINAHL	182	44	27
PsychINFO	679	217	54
PubMed	1,610	97	4
TRID	5,235	276	109
<b>Total</b>	<b>10,687</b>	<b>832</b>	<b>280</b>



**Figure 5: Paper count by publication year – Phase 2**

Figure 4 describes the frequency by which the studies were published. There is an increase in research after 2014, with 19 papers being published in 2019. Although the literature search was conducted for years between 1990 and 2021, studies relevant to this review were only conducted in the past decade.

### **3.5 Discussion**

This section will discuss and synthesize the outcomes of 80 papers based on the following categories. First, we discuss the methods or approaches used, i.e., experimental studies, observational studies, etc. Second, we discuss the type of secondary tasks used in studies, whether they were visual-manual or verbal, etc. Third, the results of the synthesis on the findings of each paper are discussed. We discuss the observations on takeover behavior, visual attention, secondary task engagement, workload, trust, differences in younger and older drivers, physiological behaviors, changes due to interventions or feedback, and performance in NDRTs.

### **3.5.1 Experimental Methods & Approaches**

From the 80 articles selected for final review, most of the studies were conducted in a driving simulator (N=77). Forty-seven of these studies were conducted on fixed-base or static simulators and the rest on motion or moving base simulators. All studies were conducted using Level 3 automation. The three remaining studies were conducted on road, with all studies conducted using Level 3.

### **3.5.2 Secondary Task Types Examined in Literature**

Looking at secondary tasks specifically, most of the tasks examined in the studies were visual-manual tasks, which require the participants to both pay attention to the task visually and interact with the task manually. An example of this is the Surrogate Reference Task (SuRT), a standardized visual-manual task where drivers are presented with a number of circles of the same size and one larger “target” circle (ISO, 2016). SuRT was used as a secondary task in 11 of the 80 studies included in this review. Studies also used “N-back” (Mehler et al., 2011; Kane & Conway, 2016) tasks, which is a memory recall task of verbally presented digits or the Arrows task (Jamson & Merat., 2005), a task that required the drivers to make a manual yes/no response if “target” arrow was present. These tasks were presented usually along with a monitoring task, i.e., driver would be asked to observe their surroundings and in-vehicle environment. A significant number of studies have also used secondary tasks that would be considered naturalistic, or tasks that drivers would voluntarily engage in, such as interacting with the IVIS system, using smartphones, etc.



### 3.5.3 Takeover Behavior

In this section, we discuss the observed takeover behavior, specifically, metrics such as take-over time and take-over quality as drivers transition from driving with automation to manual driving. Of the 80 papers, 30 papers discuss the change in takeover behaviors while driving with automation. 29 of the studies were conducted in simulators, with 14 on fixed-base and 13 on moving or motion-base with the last as an On-Road study.

Eriksson & Stanton, (2017a) studied change due to engagement in visual tasks and found that when compared to drives without secondary tasks, drivers took longer to react and take back control from the system. Merat et al. (2010) found that drivers had a longer headway and higher response times while engaging in the secondary task, indicating that it took them longer to take appropriate action while engaging in the task, irrespective of the level of automation. In comparison to driving without ADS, drivers in fully automated mode (Level 3) took longer to take back control even in the absence of secondary task. Ko & Ji, (2018) conducted a study where participants that performed self-selected tasks in comparison to low level tasks, or higher demand tasks had the longest gaze-on time, road-fixation time, hands-on time, and take-over time. A study on bicyclist presence (Fleskes & Hurwitz, 2019) found that as compared to drivers that did not engage in secondary tasks, participants that did missed the bicyclist and did not always take-over in time, leading to two collisions. A study (Roche et al., 2019) found that engaging in visual tasks leads to fewer glances on the road than verbal tasks, although drivers got better at responding to take-over requests over the drive. Similarly, Muller et al (2021) that participants took significantly longer take back control while

engaged in a visual task (reading) as compared to visual manual or audio tasks. Reading task was also found to affect take-over times as participants engaging in this task took longer to take back control as compared to manual or just monitoring group (Kuehn et al., 2017). Similar results were also found in a study (Wan & Wu, 2018) on the effect of different seat vibration patterns for take-over requests which found that participants engaging in watching a video and reading had higher response times as compared to participants that engaged in monitoring the environment. Drivers monitoring the environment also had shorter reaction times as compared to engaging in secondary tasks in a study on truck drivers (Zhang et al., 2019), further displaying that simply monitoring a task can help drivers react better and quicker to take-over scenarios. A study (Wandtner et al., 2018a) on different secondary tasks found that participants engaging in visual-verbal tasks and handheld visual-manual tasks took longer to react. In a study on takeover performance (Wu et al., 2019) drivers engaging in secondary tasks (n-back) reacted slower and had the highest take-over time as compared to the letter game. Gold et al. (2016) examined the effect of traffic density and found that although not significant, drivers engaging in secondary tasks had longer take-over durations as compared to participants not engaging. Wintersberger et al. (2018), used attentive user interfaces to send a TOR request directly on participants' cellphones and found that it helped drivers take-over better. Contrary to this, Yoon et al. (2019) used multiple takeover requests to help manage distractions and found that drivers failed to safely take control of the vehicle when given visual takeover requests while engaging in either a phone conversation or smartphone interaction although engaging in secondary tasks in any conditions lead to higher takeover times. Similarly, Lin et al. (2020) found no significant differences

between different secondary tasks, although engagement of any kind had a significant adverse effect on the safety of take-over time by delaying response times and increasing the percentage of crashing. Louw et al., (2015) found that engaging in secondary tasks while driving with automation led to an increase in time to the first reaction compared to drivers driving manually, supporting Vogelpohl et al. (2018) finding of higher take-over times in drives with secondary tasks with higher than drives. A study (Lee et al., 2020) on cognitive, physical, and visual NDRTs found that as cognitive loads increased, participants take-over quality degraded (minimum time and distance to avoid collision), even though participants' hands and eyes returned to the wheel and road. Comparable to this, Zeeb et al. (2016) also found that the quality of take-over was determined by cognitive load, even though they may take proper motor actions for taking over. Participants experiencing the news and video tasks had larger lateral deviations even after disengaging from the task. Along the same lines, Zeeb et al. (2017) found handheld cognitive tasks degraded take-over quality and increased reaction times. Participants of this group had higher time to hands on steering wheel, higher time to first steering as well as higher lateral deviations after control was taken back.

Four of the 30 papers used Surrogate Reference Task as a secondary task in their study. The first study, an on-road study, (Naujoks et al., 2019) used SuRT and Level 3 automation with additional secondary tasks and found that regardless of the task, participants engaging in visual-manual tasks took longer to take back control of the car. Gold et al (2015) found that in comparison to 2 - Back, textual, and monitoring task, participants engaging in SURT responded slower and had a shorter time to collision than participants engaging in 2 – Back tasks. Related to this, Radlmayr et al. (2014) used

SuRT and n-back as secondary tasks and found that drivers were more distracted by the SuRT task and had higher collision rates. The fourth study, also by Gold et al. (2013) used advanced warning times for take-over requests and found that with shorter take-over periods, participants made decisions faster, but not accurate.

Contrary to these results, not all studies observed negative effects on driver behavior. Two studies on truck drivers (Lotz et al., 2019; Lotz et al 2020) found no effect of secondary tasks on take-over time or time to first reaction. Since participants were not given any instructions to engage in secondary tasks, it is possible that self-motivated engagement was lower (Lotz et al 2020). A simulator study on car-following behavior also found similar results (Louw et al., 2020) as engaging in secondary tasks had no effect on time headway. The secondary task (Arrows task) was placed in the center console, and it is possible that drivers could have made quick, shorter glances towards the road, thus noticing the lead vehicle and maintaining a safe distance from it. Kaye et al (2021) and Dogan et al. (2019) both found that irrespective of the task, there were no significant differences in take-over time. In Kaye et al. (2019), the authors also surveyed participants' past mobile phone use and behavior and found that 48.5% answered a phone call while driving, 42.5% sent a text, and 63.5% engaged in social networking sites while driving. These findings suggest mobile phone use is common for the participants. The sample of drivers in this study were young, aged 17 – 25 years. Based on the synthesis reported in Section 3.5.9, younger drivers have a quicker reaction time to take over events. These two outcomes together could simply indicate that younger drivers are better at managing distractions and the task of driving together. Dogan et al. (2019) provided participants with detailed information about the automated vehicle, followed by a training

drive of 8 -10 minutes. Participants also had a time budget of 10s to react to takeover situations. Since participants had experienced the automation system and the process of takeover situations in the practice drive, participants could have had a learning effect, which led to them managing distraction and transition to manual driving more smoothly. A second study from Eriksson & Stanton (2017b) examined the effect of self-paced, nonurgent take-over requests and found this helped in making smoother transitions, irrespective of the secondary task, and drivers managed to maintain manual control of their vehicle without any detrimental effects. As the requests are not urgent, this could prevent additional load on drivers' cognitive abilities, allowing them to process the requests smoother.

The review of the research conducted on this topic indicated a significant increase in take-over times, irrespective of the differences in secondary task types and differences in simulator types. This implies that while driving with automation active, drivers will tend to engage in distraction, which may lead to them reacting later to events or situations that require intervention. Of the kinds of distraction, secondary tasks that require both visual and manual engagement tend to get drivers more involved in the task than just visual, manual or verbal tasks and is accompanied by a consequent delay in takeover time. Further studies on driving with ADS and visual-manual tasks may be required to fully understand the effects on takeover behavior and the implications of these effects. However, this review does provide an understanding into this behavior, with more drivers getting losing focus towards the driving task which ADS is active. One possible method of helping drivers reorient themselves towards driving would be to maximize use of interventions and feedback in-cab. Drivers may need simple instructions, easy

communication, and time to react better to takeover requests. This review also expands on the role of interventions and feedback in driving with automation in Section 3.5.10.

#### **3.5.4 Visual Attention towards during driving task:**

Eye-tracking behavior is a major metric for attention as well as the way in which drivers simultaneously manage driving and distraction. Therefore, in this section, we examine the metrics of visual attention to understand this behavior while driving with automated driving systems. All of the 16 studies are simulator studies, with nine conducted on a moving base simulator and seven on fixed-base or static driving simulator.

In a simulator study (Carsten et al., 2012), where drivers could either drive manually, with L2 or L3 engaged, drivers focused and paid less visual attention to the main roadway and indicated an increase in attention towards the secondary task. Similarly, Naujoks et al. (2018), with the use of L2 or L3 systems while driving found drivers focused less on the main roadway and more on the secondary task, however, the driver's attention toward the main roadway increased after a takeover event. In a study on critical driving scenarios Merat et al., (2012) found drivers to have more crashes while driving with L3, as they were focused more on secondary tasks – measured by slower blink rates and higher response times. Similar to this, in a study examining effect of automation failure, Borowsky and Oron-Gilad (2016) found drivers engaging in secondary tasks and looking toward the task experienced more crashes.

A study (McCarty et al., 2016) found that participants took 33% longer to react to braking cues when they were driving with a secondary task as participants were visually

more focused on the task than the front roadway and missed at least one braking cue. They also found that the longer the driver spent with automation, the less attention was paid to the forward roadway. In a study observing the transfer of control, (Schwarz et al., 2017), participants driving with automation trusted the system and took up to 20s to pay attention back to the main road after the takeover request was initiated. Zeeb et al., (2015) conducted a simulator study analyzing the influence of visual attention on taking over behavior while engaging in a visual secondary task and found that participants categorized as high risk (less frequent glances at the central display, but longer maximum eyes-off-road time) reacted late to take over events and often more inappropriately to the takeover situations. A study into the effects of engaging in secondary tasks (Du et al., 2020a) used 1-back and 2-back memory tasks and found drivers had shorter eyes-on-road, and lower gaze dispersion levels when engaged in 2 back memory tasks. Although there was no significant difference in their findings, drivers had fewer eye movements while engaged in high-level secondary task driving with L3 automation. Two studies by Jamson et al., (2011; 2013) used Percent Road Centre (PRC) to identify attention towards the roadway. The first study found PRC decreased significantly (74% to 54%) as participants drove in fully automated mode and engagement in secondary tasks (use of radio increased from 41 to 54% & watching a video from 2.5% to 32.5). Vlakveld et al., (2018) found drivers with shorter take-over request time (4s) had shorter gazes towards main road and slower blink rate while engaging in the secondary task.

Korber et al., (2018a) investigated the influence of trust on takeover performance, drivers with more trust had more eye glances and engagement towards secondary task and less attention to the road. Kunze et al., (2019) observed the influence of different

displays while driving with automation found drivers engaging in secondary tasks more while driving with automation before critical events occurred. Drivers reporting lower trust scores did not engage in secondary tasks. Similarly, Walker et al., (2019) examined real time changes in driver's trust and attention found that higher the self-reported trust, the less time participants spent on viewing the road and more time on the secondary task.

In comparison, Lotz et al., (2019) found no influence of secondary tasks on visual behavior. Secondary tasks were not considered engaging enough and therefore, had no effect on takeover performance. As a result, driver's visual attention and duration of glances remained constant. A study (DeGuzman et al., 2021) on the effect of system failures and malfunctions found that drivers actually paid more attention to the roadway in drives where take-over requests were made. However, in the absence of take-over requests for malfunctions, drivers looked more at the secondary task. The takeover request may have acted as an alert or an intervention, despite that not being the focus of the takeover request.

Most of the studies observe that while driving with automation, there is a decrease in driver's visual attention towards the roadway while driving with ADS. In almost all the studies discussed in this section, a decrease in visual attention towards the road is followed by an increase in visual attention towards the secondary tasks. Three papers (Korber et al., 2018; Kunze et al., 2019; Walker et al., 2019) also discuss an association with trust and visual attention, with higher trust associated with more glances away from the road. It is important to note that role trust in the system also plays as it may affect way the system is used (Section 3.5.6).



### 3.5.5 Workload

In this section, we discuss the drivers' workload, and changes in workload as drivers adapt to using the automation system. Twelve of the 80 papers discuss observed changes in workload while driving with ADS and an NDRT. Six of the twelve studied were conducted on static or fixed-base simulators and six on motion-base simulators.

Two of the studies were conducted with twenty questions task (TQT) and studied the effects on workload (Merat et al., 2010; Alrefaie et al., 2019). Merat et al., (2010) found that engaging in an NDRT increased workload and drivers took longer to take back control of the vehicle, irrespective of the automation mode (either manual, semi-automated or fully automated). This study also discussed the reliance on the system as drivers driving in fully automated mode took longer to take back control, even if they did not engage in secondary tasks. The second study (Alrefaie et al., 2019) recorded increased workload while engaging in NDRTs and driving with L3 automation and that engaging in a visual manual task (emailing) increased the workload more as compared to verbal (TQT) task.

Muller et al., (2021) measured the effect of naturalistic secondary tasks and found that visual manual tasks (reading or texting) had the highest workload, and participants engaging in these tasks took longer to take back control. A similar study (Yoon & Ji, 2019) conducted with naturalistic secondary tasks, found that over time, the fastest response was recorded for a visual task (watching videos), followed by a manual task (entertainment console interaction), and lastly by a visual and manual task (texting). In terms of workload and mental demand, manual task scored significantly lower than visual-manual task, followed by a visual task. Wu et al. (2019) investigated the effect of

roadway environments and secondary tasks on take-over performance and safety and found that in general, driving with secondary tasks increased workload and impacted safety by reducing reaction times during critical scenarios. Participants also reacted slower and had higher workload and takeover times while engaging in n back tasks. However, in comparison, a study by Choi et al. (2020) measured workload while engaging in n-back and SuRT tasks and found participants experienced lower workload with n-back task. Another study (Yun et al., 2020) measured the effect of different levels of takeover request lead times and found that shorter lead times imposed a higher workload on drivers. As request lead times, increased workload decreased, indicating as drivers had more time to assess their surroundings and take back control, they reacted better. Korber et al., (2015) measured the driver's ability to take back vehicle control while engaging in multiple secondary tasks. Take-overtime for all participants decreased linearly with every takeover situation, indicating that drivers became better at managing workload with experience. Participants completing only one task concentrated their gaze more on secondary task and less on the road, and participants concentrating on more than one task had higher takeover times.

Conversely, Schomig et al, (2015) studied the interaction between highly automated driving & drowsiness and asked participants to drive with automation while performing a quiz task. In drives without a secondary task, there was a definite increase in drowsiness over the drive. However, in the drive with secondary tasks, the engagement clearly decreased the drowsiness level and stayed low throughout the drive. Three studies by Jarosch et al (2017; 2019a; 2019b) studied the effect on drowsiness and fatigue while driving with automation. The first (Jarosch et al., 2017) found that a verbal task (quiz)

was more engaging than a visual-manual task (selection task). The second (Jarosch et al., 2019a), found that PERCLOS and subjective KSS increased while driving with conditional automation and a monotonous (monitoring task) and PERCLOS was highest for this group. The third (Jarosch et al., 2019b) studied the effect on task-induced fatigue while driving with automation found that simply monitoring the system or engaging in a no-response task caused drivers to be fatigued (measured using PERCLOS) as compared to driving with a task that actively required a response from drivers. All four studies found an increase in drowsiness or fatigue while driving with ADS without a secondary task. With ADS, drivers have less control of the task of driving as compared to manual. The transition from actively in charge of the driving task to monitoring may lead to increased levels of fatigue or drowsiness due to boredom. As observed by the four studies, the presence of a low-effort secondary task actually helped mitigate the effects of drowsiness and helped drivers remain alert throughout drives.

In this section, seven of the studies reviewed discuss an increase in workload while driving with ADS active. This indicates that while participants may hand over part of the driving task to the system, their cognitive abilities are immediately occupied by secondary tasks which is associated with an increase in workload. However not all report the same association. In cases where the system has a larger role in driving, participants may experience driver fatigue and drowsiness. Four studies indicate that driving with secondary tasks may help drivers manage fatigue or drowsiness better. Tasks that require responses can keep drivers alert toward the driving task in case they need to take back control and in the absence of these participants may actually end up drowsy, thus endangering their safety. Based on the review conducted in sections 3.5.3 and 3.5.5, there

is a fine line between over and under driver interactions, with too much impairing drivers' attention and takeover abilities and too less leading to drivers becoming drowsy and fatigued. More research would have to be conducted to actually understand the transferability of this association to real-world driving but using low-response or low-interaction secondary tasks may actually help keep drivers' cognitive abilities active and help take control easier.

### **3.5.6 Changes in Trust, or Perceptions**

We discuss the drivers' trust and perceptions regarding ADAS and any observed changes in metrics related to vehicle automation, whether self-observed or through collected data. Of the 80 articles, 11 papers discuss the trust, experience, or perceptions due to engaging in secondary tasks while driving with automation active. Of these, ten were conducted on fixed-base or static simulators and one on a moving or motion-based simulator.

A simulator study (Azevedo-Sa et al., 2021) on the correlation between Trust in automation and performance in secondary tasks found that people driving with reliable automation trusted the system more and had better performance than people driving with unreliable automation. A similar study (Korber et al., 2018a) in which drivers drove in the simulator as part of either a trust promoted or trust lowered group found that drivers in the Trust promoted group engaged more with the secondary task and paid less attention towards the road. Kunze et al., (2019) on uncertainty communication participants with lower trust scores - even when exposed to critical or uncertain situations, participants with low trust scores did not engage in secondary tasks, even though other groups engaged freely in secondary tasks. A study on loss of automation (Mok et al., 2015) had

drivers take back control to mitigate a hazard in either 2s, 5s, or 8s. Participants in the 2s group were not able to safely negotiate the hazard and rated the vehicle to be less trustworthy than the other two groups. Schwarz et al., (2017) studied the transfer of control and found that drivers' trust in the system was based on the order in which they experienced automation capabilities and that irrespective of trust, drivers took approximately 15 to 20s to take back control of the car. Along the same lines, Kraus et al. (2020) observed that automation malfunctions lead to a decrease in trust, although if high transparency is maintained, the decrease was not significant. Walker et al., (2019) used electrodermal activity and eye glances as an objective measure of drivers' trust and found drivers with high self-reported trust and lower electrodermal activity to spend more time on secondary tasks than other drivers. Beggiato et al. (2015) used multiple levels of automation to study information needs and participants indicated highly automated drive as more pleasant. This could possibly be attributed to the fact that drivers had to monitor continuously in partially automated or manual drives. Participants also required less information over the course of the drive as their trust increased with experience.

Two studies utilized the Surrogate Reference Task (SuRT) as a secondary task in the study and both found that over time, drivers' trust in ADS increased over time (Hergeth et al., 2015; Hergeth et al., 2016) and that participants with higher trust in the system monitored the system less frequently than participants with lower trust, although low trust participants also monitored the system less while they were engaging in NDRT. Korber et al., (2018b) also found that when provided explanations about the automation failures, although there was no change in drivers trust, their understanding about the system increased.

A majority of the articles describe a positive relation between trust and use of automation, with trust increasing drivers use automation more. With development of trust, essential points seem to be the reliability, capabilities and communication between driver and system. The review in this section indicates that if a better reliable, capable and easy-to-communicate system is used, drivers will trust the system better. However, this increase in trust in ADS is sometimes associated with an increase in engagement in secondary tasks and decreased monitoring of the road, indicating that as drivers got used to ADS, drivers preferred assigning partial control to ADS and engaging in secondary tasks. The ease in communication is also preferred in take-over requests, with an intervention or warning provided.

### **3.5.7 Secondary task engagement and performance:**

In this section, we discuss the changes in secondary task engagement or the observed engagement in secondary tasks as drivers use vehicle automation. Of the 80 papers, 14 papers discuss the change in secondary task engagement and performance while driving with automation. Of the papers, 13 studies are conducted using simulators (8 on motion-based simulators and five on fixed-base) and one on-road.

A simulator study by Carsten et al. (2012) found that when given a choice of secondary tasks, drivers will engage more in the tasks and pay less attention to the main roadway. Naujoks et al. (2016) studied the effect of different levels of automation on road and found participants previously experienced in ACC engaged more in the secondary tasks overall, irrespective of the level of automation. Wandtner et al. (2018b) used texting as their secondary task and found more participants engaging in the automated drive as

compared to the manual drive. Once they began the task, participants of this group continued to engage even after they took back control and were driving manually. Three studies of the 14 papers used Twenty Questions Task (TQT) in their studies. All studies found an increase in secondary task engagement while driving with automation (Merat et al., 2012; Naujoks et al., 2018, Merat et al., 2010), with more NDRT engagement and better task performance in the noncritical incident section of the drive (Merat et al., 2012). Choi et al. (2020) studied performance using n-back and SuRT and found participants performed better in n-back. Forster et al., (2019) studied the ease with which participants engaged in secondary tasks while transitioning between different levels of automation. Generally, there was a trend towards higher engagement in secondary tasks while driving with automation. The highest engagement was observed with drivers that started driving with L3 automation and were either prompted or to complete a transition to lower level of automation when compared to drives preceding with L2 automation. Maggi et al., (2020) found engagement in secondary task to be higher in automated drive. Wintersberger et al., (2018) studied the influence of takeover requests given at different times during NDRTs and found that when participants were given TORs on cellphones, their performance degraded. This could be due to the fact that they had to shortly stop engaging in the task, participants rushed to complete and made mistakes. This was observed mainly with drivers deemed “risky”, that is, drivers that had a 25% higher reaction time in within task condition. Rauffet et al., (2019) found that drivers were highly engaged in the secondary task (Gaming) during automated driving sessions (more than 70% of the time). Driving-related areas of interest were significantly altered by this engagement, i.e., drivers paid more attention towards the game than to the task of

driving. Azevedo-Sa et al. (2021) used a visual search task and found better NDRT performance while driving with reliable ADS as compared to unreliable, as participants trusted the reliable system more and paid more attention to the task. A study on different levels of automation (de Winter et al., 2016), found that higher levels of automation were associated with faster reaction times for the secondary task and also had better performance in the task. Related to this, Beggiato et al. (2015) also studied the effect of different automation levels, and participants of the highly automated drive spent more time looking (73.5% of glance time) at the secondary task and not on the main roadway, engaging more than any other groups. This group also trusted automation more and engaged mostly when complex situations did not occur.

Based on the studies discussing engagement in secondary tasks, there is an increase in engagement while driving with ADS. In case of manual driving, drivers engaged in secondary tasks have to multitask concurrently. Engaging in secondary tasks while driving with automation is different, as drivers have to multitask sequentially, engaging in one task at a time, even if it is a secondary task. For drives with Level 3 automation, which provide both longitudinal and lateral support while driving, drivers engaged twice more than in Level 2 or manual driving (Forster et al., 2019). A point of interest would also be the intention and the level of engagement in secondary tasks. In Wandtner et al. (2018b), participants tended to continue engaging in the secondary tasks even after they took back control and were driving manually. In Wintersberger et al., (2018), risky participants rushed to finish the secondary task before performing the lane change maneuver. Although this paper shows better performance in takeover behaviors using attentive user interfaces, there is still a question of safety. Since Level 3 automation



is not full automation, sequential multitasking is hazardous and had implications on visual attention (Section 3.5.4), takeover behaviors (Section 3.5.3), and workload (Section 3.5.5)

### **3.5.8 Changes in Drivers' Physiological Responses**

The papers discussed in this section examine the observed changes in participants' physiological responses, specifically, metrics related to heart rate, arousal levels, emotional valence, etc. Of the 80 papers, five papers discuss this change and are addressed below.

The first study (Alrefaie et al., 2019) studied correlations between physiological behavior (heart rate and pupil diameter) and take-over performance and reported increased heart rate during engaging in secondary tasks. Carsten et al. (2012) found the opposite and found decreased heart rate while driving with automation active and engaging in secondary tasks. Two papers by Du et al. (2020a, 2020b) discuss the effect of physiological measures and found that participants had less heart rate variability during high cognitive load (2020a). The first paper also reported larger maximum and mean GSR (Galvanic Skin Responses) for driving with shorter lead time and a higher heart rate acceleration pattern when driving in heavy traffic. The second paper studied the effects on emotional valence and arousal on takeover performance and found that although high arousal does not indicate associations takeover times, positive valence does provide an indication of better takeover quality (Du et al., 2020b). Wintersberger et al. (2018) measured GSR as a variable for stress and found that when a TOR was provided in the

middle of a task, participants had higher arousal as compared to between tasks (TOR provided at the boundary of a task).

Two main physiological behaviors have been explored in this section of the review. In case of GSR, at times of high cognitive load, studies report increased arousal. In case of heart rate measures, we have contrasting reports. Two papers report decreased heart rate and less heart rate variability when driving with ADS active and engaging in secondary tasks, whereas one study reports increased heart rate while doing the same. This may indicate that further studies need to be conducted in order to add to the research and conclusively state the effect on heart rate measures.

### **3.5.9 Younger vs Older Drivers**

In terms of age, it is important to understand if younger vs older drivers interact differently with automated driving systems. Research has described younger drivers as more likely to engage in risky driving and be more involved in crashes (Zador et al., 2000), whereas older drivers have been known to have slower response times to hazards and road safety concerns (Fildes et al., 2007; Romoser et al., 2014). In this section, we discuss the change in driving behavior based on age of drivers. Of the four studies, two studies were conducted on fixed-base simulators, one on motion-base and the last on-road. Only two papers explicitly discuss the change in secondary task performance while driving with automation active. Both studies are simulator studies (one fixed and one motion-based) and indicate an increase in performance of secondary tasks.

A study (Wu et al., 2020) investigating the differences in takeover behavior and drivers' drowsiness level while driving with Level 3 system and NDRTs (none, watching

video clips, switching between watching video clips and gaming). For younger drivers, both single and multiple secondary tasks countered drowsiness during automated drive, and their takeover performance was equivalent to or better than their performance without secondary task. For older drivers, secondary task engagement did not affect the development of drowsiness, but degraded take-over performance, especially under the multiple secondary task engagement. An on-road study (Naujoks et al., 2016) found that when driving with partial or high automation, younger drivers were better at secondary tasks. A comparison study (Korber et al., 2016) of behavior in a critical event found that older drivers braked more often and had a higher time to collision (TTC), although no significant differences were observed. The study also found that irrespective of age, takeover time decreased, minimum TTC increased and maximum lateral acceleration decreased between the first and the last situation of the experiment. Clark & Feng, (2017) studied the influence of age differences in take-over behavior and let drivers participate in secondary tasks voluntarily, without prompting. Based on their level of engagement, participants were grouped into low or high activity. Older drivers of the low activity group spend the lowest time on secondary tasks while younger drivers in the high activity group spent the longest time in secondary tasks. Younger drivers had more eyes off road, although the mean duration of each glance off road was not different between younger or older drivers.

Studies indicate that in general, younger drivers tended to engage more and perform better at secondary tasks than older drivers. Even in cases where engaging in secondary tasks is voluntary, younger drivers tend to freely engage in secondary tasks. Although older drivers do engage in secondary tasks all that often, the time spent in

secondary tasks degrades their performance leading to harsher braking patterns and delayed takeover times.

### **3.5.10 Impact of Interventions or Feedback**

This section discusses studies that used interventions or feedback systems inside the vehicle in order to help drivers manage distractions. These studies deal with an important topic as previous sections have helped understand how driving behaviors may change when drivers engage in secondary tasks. Nine papers addressed the change in take-over times due to engaging in secondary tasks while driving with automation engaged and attempted to provide interventions or mitigation methods to prevent negative effects. All nine studies were conducted in a simulator, with seven using fixed-base and the remaining using motion-base.

The first study (Chen et al., 2021) was conducted with three levels of feedback systems. Participants either received continuous feedback, intermittent feedback, or no feedback while driving with automation active and engaging in a reading task. Participants of the continuous feedback group spent more time looking at the forward roadway, and they had a greater number of long glances. The second study (Cohen-Larzy et al., 2019) tested directional designs (mode of alert) for TORs in time-critical situations and found that participants receiving compatible Direction (away from hazard) reacted faster and accurately as compared to those with incompatible alert (towards hazard). A study by the same research group (Cohen-Larzy et al., 2020) tested the effect of auditory feedback in takeover situations over two experiments. The first experiment indicated that participants receiving the continuous feedback group had significantly higher on road

glances and significantly lower scores in the secondary task as compared to the no feedback group. The second experiment had similar results, however, participants with no feedback had scored significantly higher than all participants in the secondary task indicating that participants that did not receive any form of feedback engaged in secondary tasks until a take-over request was issued. Similar to these studies, Lu et al., (2019) used a verbal monitoring cue before a take-over request was issued to prepare the drivers. Drivers receiving the cue had a better take-over performance as compared to participants that did not receive the cue. This also reduced workload and helped in acceptance and trust in automation. Brandenburg & Roche (2020) also used a two-step take-over request and found that participants preferred this process as it gave them time to get better acclimatized to the request and respond. Drivers also got better at take-over requests and had increased minimum time to collision when receiving the two-step request. Li et al (2020), studied the effects of different NDRT display modes on eye-movement patterns during take-over and found that drivers engaged more in mobile display secondary tasks while driving with automation active. Pupil diameter was smaller and glance duration towards the front scenario was smaller as compared to HUD and baseline modes. Although the takeover request redirected driver's visual attention back to the driving task away from the secondary task, the distracting effect of the mobile display secondary task continued even after the takeover request after NDRT was terminated. Forster et al. (2017) studied the effect of different auditory outputs to help easier take-overs and found that participants performed better when given speech and warning tone as compared to warning only.

Hergeth et al. (2017) used multiple levels of information and found drivers that had prior familiarization had a longer minimum time to collision and shorter take-over times. Similarly, Sportillo et al. (2018) also examined the effect of education using Virtual Reality (VR) and user manuals. For participants that experienced driving and mock take-over before the actual drive, take-over was much quicker.

From the synthesis of previous sections, studies report increased engagement in secondary tasks while driving with ADS active. The implications this engagement has on driver behaviors has also been previously discussed. In this section, methods of helping participants maintain attention by providing feedback or interventions are discussed. Two studies report success in getting participants to pay attention towards the main road by using continuous feedback, in which participants are constantly monitored and are gently nudged to pay attention towards the road when they spend too long looking away or looking at the secondary tasks. Additional support is provided by Li et al., (2020) which reports that although drivers looked away from the secondary task and refocused their attention, without continuous feedback the distracting effect of the secondary task continued. Two studies also discuss training, with a learning effect leading to shorter take-over time (Hergeth et al., 2017; Sportillo et al., 2018).

### **3.6 Conclusion**

We discuss a systematic review of literature conducted on engaging in secondary tasks in the context of ADS. Similar to ADAS and Distraction review, keyword searches were conducted on 5 databases, resulting in 10,687 results, of which 193 were eligible for a broader review of Distraction and Automation. These articles were further narrowed

based on relevancy to ADS, resulting in 80 papers used for the systematic review and synthesis.

The literature discussed provides an understanding into the changing behaviors of drivers using ADS. An important aspect of using higher levels of automation is that unless using Level 4 or Level 5 of automation, drivers are required to be ready to take back control of the vehicle if necessary. All studies discussing take-over behaviors found a significant increase in take-over times while engaging in secondary tasks and driving with automation active. Studies also discuss a decrease in driver's visual attention, with more focus given to secondary tasks as compared to the front roadway. However, in certain cases, the fatigue or drowsiness caused due to monotonous drives can be managed better with low-workload secondary tasks. Studies have also discussed trust and perceptions of drivers towards vehicle automation and a majority of the papers describe a positive relation between trust and use of automation, with trust increasing with experience. Previous research has shown that drivers with incomplete knowledge may end up over trusting automation and may need help in re-orienting themselves to the task of driving. Some studies have conducted research on this topic and in general, participants do engage in secondary tasks while driving with automation and receiving some amount of feedback will help drivers manage distractions better. Lastly, similar to the previous review, drivers do end up engaging more in secondary tasks and performing better at them while driving with automation. Studies concentrating on younger vs older driver have found that younger drivers tend to engage in secondary tasks more, although any engagement in secondary tasks is related to negative change in older drivers. One interesting result of this synthesis also addresses the effect on physiological measures.

Although there are four articles reporting on these variables, the research does not provide evidence to conclusively state the effect of ADS and secondary task engagement on such measures. Future research may be required on this particular topic to further understand the significance of the effect on physiological measures.

The results from this review cover an essential point as with advancing technology, it is obvious that higher levels of automation will soon become available to use on roads. Unless the limits are realized and necessary policies are enacted, usage of ADS may end up impacting drivers negatively.



## **CHAPTER IV**

### **CONCLUSION**

This thesis aims to understand the impact of using automation on driving behaviors, specifically when drivers engage in secondary tasks. To this end, I have conducted two systematic literature reviews, one focusing on Advanced Driver Assistance Systems (ADAS) and secondary task engagement (Phase I) and the second on Automated Driving Systems (ADS) and secondary task engagement (Phase II). The approach to identifying relevant literature is the same, by using a specific set of keywords on five databases – Academic Search Premier, CINAHL, PubMed, PsychINFO, and TRID. For Phase I review, I used research questions relevant to the use of ADAS features available today and synthesized literature with respect to these questions. With Phase II, I synthesized the literature based on relevant categories to driving behaviors while driving with ADS. This is because ADS technologies are still in development and are not adopted on a mass scale. Focusing on specific research questions could lead to losing vital information about driving behavior.

With both reviews, I focused on understanding the secondary task engagement while driving with automation and the change that may be reflected in other driving behaviors because of this engagement. The changes in these driving behaviors are vital in understanding how the advancements in automation technologies affect the relationship between driver and vehicle and how to prevent any adverse effects. In Sections 2.5 and 3.5, we discuss these changes in driving behaviors based on previously conducted studies and there are a few critical takeaways.

Both Phase I and Phase II reviews show an increase in secondary task engagement and performance. Visual-Manual tasks or secondary tasks that require visual and manual engagement (naturalistic tasks, such as texting, using IVIS or experimental tasks such as SURT) have higher engagement than tasks that require only one mode of engagement. This can also be discussed in terms of cognitive workload, with more engagement in secondary tasks that require higher cognitive abilities as compared to lower. With the increase in secondary task engagements, drivers' attention towards the forward roadway or on-road decreases, and drivers focus more on secondary tasks. This observed change has been noted in simulators and on-roads with measures such as Percent Road Centre (Victor et al., 2005), by the number of eye glances, gaze dispersion levels, etc. Using survey measures, specifically the NASA-TLX survey (Hart & Staveland, 1988), differences have also been observed in workload, with drivers using both ADAS and ADS reporting decreased workload unless engaging in secondary tasks. However, with drivers using ADS, some studies report that a low-effort secondary task may help drivers with drowsiness and fatigue. This difference can be explained in part by the level of involvement of the driver, which is lower for L3 as compared to L2. A single mode task such as verbal only (e.g., n-back task), manual only (e.g., pushing a button on the steering wheel) or any low cognitive effort task can be used to prevent fatigue in operators if L3 and above. In the case of trust in automation, drivers using ADAS, or ADS end up trusting the systems more as they use it and experience it. Trust also differs based on the method of introduction or the level of capability of the system and failures in the system decreasing trust in users of automation. Studies also reported that drivers trusting the systems more were willing to engage in secondary tasks.

There is also a very notable change in takeover behaviors with respect to the use of ADS. Drivers using ADS or ADAS and engaging in secondary tasks show a considerable increase in take-over times and a decrease in take-over quality. Although only a few studies on this have been conducted with ADAS, this behavior is concerning for all users. Studies discussed in Section 3.5.3 help us understand that driving with L3 systems while engaging in secondary tasks does lead to a significant increase in take-over times and responses to first action, which has worrying consequences on hazard anticipation and mitigation. Since only Level 4 and Level 5 users can entirely depend on the system to control the vehicle safely, drivers using L3 and below cannot be lax in terms of attention and being aware to take back control. It is important to design interventions or building educational programs to help drivers understand how to operate ADS safely. The age of the drivers may also be an important consideration while considering the training programs. As discussed in Section 3.5.9, younger drivers tend to engage more in risky driving behaviors, whereas older drivers may have slower response times to identifying and reacting to hazards. In terms of take-over behaviors, this is a troublesome group behavior as what may prove effective for one may not be effective for the other. An important consideration is also the time budget and process of take-over requests (Section 3.5.10) given to participants. A multi-step take-over request or a request with a window large enough for the driver to acclimatize themselves to the situation.

The two reviews provide a synthesis of literature available on the use of ADS and ADAS while engaging in secondary tasks. Given that these features will be used or are already in use widespread, we must understand the behaviors affected and how they are affected. The reviews reveal a series of concerning key points. The increase in vehicle

automation does lead to an increase in secondary tasks that may have adverse effects in the form of decreased visual attention, higher workload, and decreased takeover abilities. The observed changes indicate that unless drivers do not adequately understand the limitations of the systems they use, they may not reap all the benefits of these safety systems. Like mentioned previously, training/ education may be an effective method. Research has already demonstrated that providing drivers with any level of information may help them manage and use automation better. The literature describes that the preferred method of learning is owner's manual (Beggiato & Kerms., 2013; McDonald et al., 2018), however as it is complicated and too long (Mehlenbacher et al., 2002), drivers also tend to prefer Trial and Error – mostly younger drivers (Abraham et al., 2017). It is also important to understand the overall implications of using automation while driving. Drivers today are used to multitasking while driving and handling potential crash scenarios. However, giving partial control over to an automated system for longer periods of time may lead to deskilling. Training specifically monitored towards the use of automated vehicle systems could prove effective in calibrating skills required to drive with new and complex technologies.

In Section 3.10, we discuss the role of feedback or intervention systems to keep drivers alert and prevent delays in taking back control of the car. Drivers that are provided support by such systems show a quicker reaction time in takeover situations and better takeover abilities. One notable method of monitoring driving performance or driver state is Driver State Monitoring (DSM). DSM are systems that “collect observable information about the human driver in order to assess the driver's capability to perform the driving task in a safe manner” (Concalves and Bengler, 2015). Given that vehicle

control transition plays an important and critical role in driving safely with ADS and higher levels of automation, DSM will play an important role in helping drivers remain alert and navigate takeover situations correctly and safely. DSM systems can also be tailored to a specific driver and can provide aid based on the driver's attention needs.

Automation in automobiles is not a new concept however, its implementation and practical use have become more prolific recently (Mallozzi et al., 2019; Othman, 2021). Some of the studies from the reviews have been conducted almost two decades ago, with the oldest conducted in 2004. Since then, automated vehicle systems have evolved, as have drivers' understanding and usage of these systems. It is only reasonable to expect drivers' knowledge of automated vehicle systems today to be more than what it was two decades ago. Overall, despite the change in understanding, the outcomes of older papers and newer studies in both reviews are similar, suggesting that although drivers may now have better knowledge of automated vehicle systems, the interactions have not significantly changed.

There are some limitations associated with this literature review. The literature review was an effort to gather and conduct a synthesis of published relevant studies. However, this search was concentrated on literature available in the public domain, limited to keyword searches made through five databases only. The initial literature search for Phase II was conducted in March 2021. This creates a significant time period from the time of data identification to reporting the outcomes of literature synthesis. It is evident that relevant literature would have been published during this process. Consequently, a second search of the databases was conducted using the same keywords from March 2021 to August 2022 to identify the number of relevant research published.

The second search reveals a total of 59 papers relevant to the topic of Automated Driving Systems (ADS) and the use of secondary tasks. The second search was conducted only to identify the number of relevant literature published during the synthesizing and reporting of Phase II. The synthesis and outcome reporting is beyond the scope of this review, and as such, they have not been included. Lastly, a potential limitation is the file drawer problem (Rosenthal, 1979; Scargle 1999). The file drawer problem occurs when journals tend to publish results agreeing with the hypotheses or reject studies that have no significant or negative results. For the process of systematic reviews, only articles that have been published in peer-reviewed journals are included. For these reviews as well, literature not published in journals has not been included in the reviews.

There are multiple considerations that can be made for future research. One, the use of automated driving systems is steadily increasing. Two, drivers will increase engagement in secondary tasks while driving with automation of any level. This increase may lead to increases in takeover times and decreases in visual attention. Three, training/education or interventions have had some success in reducing the unintended negative consequences of increased secondary tasks, but further research needs to be conducted on how to help individual drivers manage distraction activities and driving together. Further research, therefore, can be considered on how to develop accessible and easy-to-understand methods for educating drivers as well as an in-vehicle feedback system should be conducted.

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